Historical Water Quality and Biological Change in Peltier Lake, Anoka Co., MN

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REPORT CONTENTS

EXECUTIVE SUMMARY

1. In this project, we use paleolimnological techniques to reconstruct the trophic and sedimentation history of Peltier Lake, Anoka County, Minnesota.

2. The ~2.6 m core sequence recovered from Peltier Lake captured sediments from ca 1840-present including pre-Euroamerican settlement, post-settlement and pre-damming, and post-damming.

3. Peltier Lake has a very fast sedimentation rate. This produces somewhat greater uncertainty in dating and sedimentation rates, especially in early 210-Pb dates, than we expect from other central MN lakes.

4. The major event recorded in the Peltier core is dated at 1885 AD and located 200 cm downcore. It is recorded as a major increase in magnetics and an increase in inorganic sedimentation. We believe this shift marks settlement and land clearance in the Peltier watershed, which would have been characterized by erosional events and a shift in sediment sources to the basin.

5. Damming is recorded as a slight decrease in magnetics and is located approximately 150 cm downcore.

6. The diatom communities can be separated into 3 zones in the core: 1. bottom-1915, 2. 1939-1985, 3. 1985-2006. The lake has been continuously dominated by three species: *Aulacoseira granulata*, *A. ambigua*, and *Stephanodiscus niagarae* with several small *Stephanodiscus* species. Zone 1 has high abundance of *Aulacoseira* species, a higher proportion of benthic/attached species, and many chrysophyte cysts. Zone 2 has lower abundance of *Aulacoseira* species and higher abundance of *Stephanodiscus niagarae*, *S. hantzschii*, and *S. parvus*. Zone 3 again has higher abundance of the *Aulacoseira* species, decreased abundance of several small *Stephanodiscus* spp., and increased abundance of several eutrophication indicators including *Fragilaria capucina* v. *mesolepta* and *S. hantzschii* f. *tenuis*.

7. The major biological change in the core occurs around WWII. There was a large community shift in the diatoms from Zone 1 to Zone 2. Several indices of eutrophication record this even including a sharp increase in the plankton to benthic diatom ratio and the diatom to chrysophyte cyst ratio (Table 1).

8. Phosphorus reconstructions (Fig. 6) show that Peltier Lake is currently hypereutrophic (>100 ppb TP). This increase in TP is coincident with the WWII-era biological change. Samples deposited previous to WWII, including presettlement, pre-damming, and immediate post damming samples, have diatom-inferred TP levels that are estimated from 60-80 ppb TP, i.e. Peltier Lake has long been a productive and eutrophic system, but was not historically hypereutrophic. Our two lowest samples (1840s) show spurious high TP reconstructions that are difficult to interpret. The diatom communities are clearly different than modern samples (higher benthics, higher c-cysts) but are made up of the same three species that dominate the rest of the

core. Given the shifts in magnetics and LOI during this time, it may be that Peltier Lake was a more hydrologically dynamic system (lake level changes) than we see in the dammed lake today.

9. Other work to be considered on the Peltier core would include confirmation of dating model using pollen and 137-Cs. We could analyze diatoms in a sample from the 1920s. Pigment analysis may help clarify the onset of blue-green algal blooms and algal productivity. Biogenic silica analysis would also help us understand changes in historical algal productivity.

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 Anoka County, including shoreline development, sport fisheries, waste and stormwater discharge, water level management, 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, we use paleolimnological techniques to reconstruct the trophic and sedimentation history of Peltier Lake, Anoka County, Minnesota. Results will provide a management foundation for TMDL development by determining the natural or reference condition of these lakes and reconstructing a history of water quality and ecological changes that have occurred in the lake during the last 150 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 determine response to and recovery from short-term disturbances.

Peltier Lake is located in southwest Anoka County and is part of the Rice Creek drainage. The lake is approximately two miles long (N-S) and one mile wide (E-W). The lake is largely a single shallow basin with a max depth of 16 ft recorded forty years ago. A large wooded island separates the larger and deeper southern basin from the smaller and shallower northern basin. Two streams, Rice Creek and Hardwood Creek feed the northern basin, whereas Clearwater Creek enters along the SE shore of the southern basin. A single outlet, Rice Creek, drains Peltier Lake to George Watch Lake along its SW shoreline, although some southern drainage may enter Centerville Lake during high water. The outlet to George Watch Lake has been controlled by a dam since 1905, although details of the water management of Peltier Lake have not been located.

The primary aim of this project is to quantitatively reconstruct historical environmental change in Peltier Lake utilizing paleolimnological analysis of a dated sediment core (Anderson and Rippey 1994, Dixit and Smol 1994). The lake currently has marginal to poor water quality and is the subject of local and state concern. This project will provide data necessary to develop management plans that include an understanding of presettlement conditions, pre- and post-damming conditions, historical lake response to landuse and past management, and development of management targets through TMDL planning. Analytical tools used include radioisotopic dating of the core, geochemical analyses to determine local sediment accumulation rates, and analysis of subfossil algal (diatom) communities. Multivariate analyses, diatom-based transfer functions, and comparison of algal assemblages with an 89 Minnesota lake data set are used to relate changes in trophic conditions and algal communities to human impacts in the local watershed.

METHODS-SEDIMENT CORING

One piston core and one Livingston core were collected in October of 2006 (Table 1). The piston core was taken using a drive-rod piston corer equipped with a 7 cm diameter polycarbonate barrel (Wright 1991). A Livingston corer was used to collect a secondary core from sediment depths below that of the piston core. The piston core was transported to the shore and extruded vertically in 2-cm increments to a depth with cohesive sediment texture (50 cm). Core sections, material remaining in the core barrel, and the Livingston core (wrapped in aluminum foil), were returned to the laboratory and stored at 4°C.

METHODS-MAGNETIC SUSCEPTIBILITY LOGGING AND CORE IMAGING

Magnetic susceptibility provides a non-destructive measure of relative quantity and size of ferro-magnetic minerals. Increases in magnetic susceptibility signatures may be correlated with land use changes including land clearance, increased terrestrial-derived sediments, and paleosols. Decreases in magnetic susceptibility often accompany increased carbonate and organic fluxes to the sediments from increased productivity.

A Geotek Standard MSCL with an automated trackfeed was used for magnetic susceptibility logging. Susceptibility measures were taken at 1-cm intervals, which integrated a signal over a 5-10-cm length of core. Following susceptibility logging, cores were split lengthwise, physically described, and digital images taken of each core section using a Geoscan Corescan-V. Following scanning, cores were returned to storage at 4°C. Magnetic susceptibility logging and core imaging were performed at the Limnological Research Center's core lab facility at the University of Minnesota.

METHODS-LEAD-210 DATING

Sediments have been 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-BIOGEOCHEMISTRY

Weighed subsamples were taken from regular intervals throughout the piston and Livingston cores for loss-on-ignition (LOI) analysis to determine dry density and weight percent organic, carbonate, and inorganic matter. Sediment subsamples were heated at 105ºC for 24 hr 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.

METHODS-DIATOM AND NUMERICAL ANALYSES

Fifteen core sections were prepared for diatom analysis (Table 2). Samples listed as pre-settlement have approximate dates based on extrapolation of the Pb-210 model below1886 by assuming a constant sediment accumulation rate prior to settlement.

Diatoms and chrysophyte cysts were prepared by placing approximately 0.25 cm^3 of homogenized sediment in a 50 cm^3 polycarbonate centrifuge tube, 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 a 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.

Species present at greater than 1% relative abundance in two or more samples or at greater than 5% relative abundance in one sample were included in further analyses; the same selection criteria were used by Ramstack et al. (2003). Stratigraphies of subdominant diatoms were plotted again core date. Relationships among diatom communities within a sediment core were explored using Correspondence Analysis (CA), which available in the 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 interpretting a CA is that samples that plot closer to one another have more similar assemblages.

Downcore diatom communties were also used to reconstruct historical epilimnetic phosphorus levels in Peltier Lake. A transfer function for reconstructing historical logTP was earlier developed based on the relationship between modern diatom communities and modern environmental variable in 89 Minnesota lakes (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 is 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. Reconstucted logTP values are plotted downcore and also backtransformed to TP in ppb. The error bars represent the root mean squared error of prediction (RMSEP, bootstrapped), i.e. the error of the model. In interpreting change in a reconstruction, we assign significance to changes that are greater than the RMSEP (Ramstack et al. 2003).

RESULTS & DISCUSSION-CORING, MAGNETIC SUSCEPTIBILITY AND CORE IMAGING

A 2.02 m long piston core and a 1.03 m long Livingston core were recovered from the south basin of Peltier Lake on October 30, 2006. Coring location and recovery details are provided in Table 1. Both the piston and Livingston cores were logged for magnetic susceptibility (Fig. 2), split, imaged, and described (Figs 1, 2). There was minimal color change or obvious stratigraphy in the core. The magnetic susceptibility analysis and imaging are performed on the intact portion of the core; therefore these data do not exist for the portions of the core that were field sectioned (top 50 cm of the piston core). There is a rise in magnetic susceptibility at the top of the Livingston core and in the corresponding bottom portion of the piston core, at approximately 190-200cm depth in the core (Fig. 2). An increase in magnetic susceptibility is often seen at the time of European settlement, when initial land clearance increased the amount of terrestrial-derived sediments to the lake.

RESULTS & DISCUSSION-BIOGEOCHEMISTRY

Sediments from Peltier Lake have historically been dominated by inorganics (Fig. 4). There is a distinct shift in the relative amounts of organic and inorganic material at about 190 cm in the core, which coincides with the rise in magnetic susceptibility. Based on the 210-Pb dating model, this change occurred at approximately 1890, which again suggests that this shift pre-dates damming of the system and more closely corresponds with initial settlement, land clearance, and the onset of agriculture.

RESULTS & DISCUSSION-DATING AND SEDIMENTATION

Peltier Lake showed a monotonic decrease in ^{210}Pb activity and reached supported levels below 160 cm core depth. Figure 3 show the unsupported lead-210 activity, the resulting lead-210 dating model, and the sediment accumulation rate for Peltier Lake. The lead-210 model dates the rise in magnetic susceptibility (approx. 190-200 cm) at about 1880-1890, which suggests that the rise in magnetics pre-dates damming of the system and is a result of initial land clearance in the area. Because of the very high sedimentation rates in Peltier Lake, levels of unsupported Pb-210 are diluted compared to lakes with more modest sedimentation rates, which leads to somewhat greater uncertainty in the dating models.

Sedimentation rates have not varied considerably in the recent history of Peltier Lake (Fig. 3). There is a period from 1900 through the 1940s that has slightly higher sedimentation rates in comparison to pre-damming and post-1940s levels. An initial peak in sedimentation (ca. 1910) may correspond to construction of the dam at Peltier's outlet. Increased water depth and inundation can both increase and shift depositional patterns in a reservoir.

RESULTS & DISCUSSION-DIATOM STRATIGRAPHY

The diatom communities can be separated into three zones in the core: 1. core bottom-1915, 2. 1939-1985, 3. 1985-2006 (Fig. 1). The diatom community has been continuously dominated by three species: *Aulacoseira granulata*, *A. ambigua*, and *Stephanodiscus niagarae* with several small *Stephanodiscus* species (Fig. 5). Zone 1 has high abundance of *Aulacoseira* species, a higher proportion of benthic/attached species, and many chrysophyte cysts. Zone 2 has lower abundance of *Aulacoseira* species and higher abundance of *Stephanodiscus niagarae, S. hantzschii*, and *S. parvus*. Zone 3 again has higher abundance of the *Aulacoseira* species, decreased abundance of several small *Stephanodiscus* spp., and increased abundance of several eutrophication indicators including *Fragilaria capucina* v. *mesolepta* and *S. hantzschii* f. *tenuis*. Overall, the species in the diatom community of Peltier Lake are indicative of eutrophy although some can also be found in mesotrophic systems (e.g. *Aulacoseira ambigua*, *Stephanodiscus niagarae*).

RESULTS & DISCUSSION-PHOSPHORUS RECONSTRUCTION

Downcore total phosphorus reconstructions (Fig. 6) show that Peltier Lake is currently hypereutrophic (>100 ppb TP). This increase in TP is coincident with the WWII-era biological change in Peltier Lake. Modern TP levels in Peltier Lake are often even higher than our reconstructed values (>150 ppb; Westrick pers. comm.). It is not possible to reconstruct TP values >200 ppb TP using our current calibration models and, at these extreme phosphorus levels, other abiotic gradients are controlling diatom abundances. Samples deposited previous to WWII, including presettlement, pre-damming, and immediate post damming samples, have diatom-inferred TP levels that are estimated from 60-80 ppb TP, i.e. Peltier Lake has long been a productive and eutrophic system, but was not historically hypereutrophic. Our two lowest samples (1840s) show spurious high TP reconstructions that are difficult to interpret. The diatom communities are clearly different than modern samples (higher benthics, higher c-cysts, Table 3), but are made up of the same three species that dominate the rest of the core. Given the shifts in magnetics and LOI during this time, it may be that Peltier Lake was a more hydrologically dynamic system (lake level changes) than we see in the dammed lake today. In interpreting change in a reconstruction, we assign significance to changes that are greater than the RMSEP (Ramstack et al. 2003). In the case of Peltier this condition is met when comparing the post settlement/immediate post damming nutrient levels with modern diatom-inferred levels in the lake.

CONCLUSION AND RECOMMENDATIONS

Based on diatom analysis, Peltier Lake has been a eutrophic system during pre-European settlement, post-Eurosettlement, pre-damming, and immediate post-damming with diatom-inferred TP levels of 60-80 ppb. A major ecological shift toward more eutrophic to hypertrophic conditions occurred in the 1940s as indicated by biological shifts and increased diatom-inferred TP levels (90-125 ppb TP). Other work to be considered on the Peltier core would include further confirmation of the dating model using pollen and/or 137-Cs. We could analyze diatoms in a sample from the 1920s to fill the gap where some of the major changes occurred. Pigment analysis may help clarify the onset of blue-green algal blooms and algal productivity. Biogenic silica analysis would also help us understand changes in historical algal productivity.

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TABLES

Table 1. Core type, date of collection, location, depth of sampling site, length of core recovered, and results of field sectioning.

Type of Core	Coring Date	Coring Location	Water Depth (m)	Core length (m)	Sediment depth (m)	Field sectioned (cm)
Piston	30X2006	45°10'37.1" N 93°03'31.3" W	4.73	2.02	0-2.02	50
Livingston	30X2006	45°10'37.1" N 93°03'31.3" W	4.73	1.03	1.82-2.85	--

Table 2. Samples prepped for diatom analysis.

Sample Depth (cm)	Lead-210 Date
2	2006
24	1996
38	1985
50	1976
60	1968
72	1957
84	1947
96	1939
120	1923
132	1915
144	1908
168	1896
184	1886
220	Pre-settlement (approx. 1862)
244	Pre-settlement (approx. 1847)
264	Pre-settlement (approx. 1834)

Table 3. Two indicators of eutrophication, planktonic to benthic diatom ratio (P:B) and the diatom to chrysophyte cyst ratio (diatom:cyst), suggest dramatic ecological changes occurred in Peltier Lake at about the time of WWII. These indicators suggest a response to changes in nutrient loading and a shift to more water column algal productivity.

Date	Depth (cm)	P:B	Diatom:cyst ratio
2006	0-2	10.3	35.7
1996	22-24	9.9	82.6
1985	36-38	10.2	46.0
1976	48-50	14.1	45.3
1968	58-60	12.4	59.3
1957	70-72	11.8	34.1
1947	82-84	17.7	31.7
1939	94-96	10.7	20.6
1915	130-132	4.0	13.8
1908	142-144	4.3	9.9
1896	166-168	5.4	4.1
1886	182-184	5.4	7.8
1862	218-220	2.5	2.3
1847	242-244	5.5	3.6
1840	250-252	10.3	9.3

FIGURES

Figure 1. Images of the piston and Livingston cores. The piston core image begins at 50cm because the top of the core was sectioned in the field.

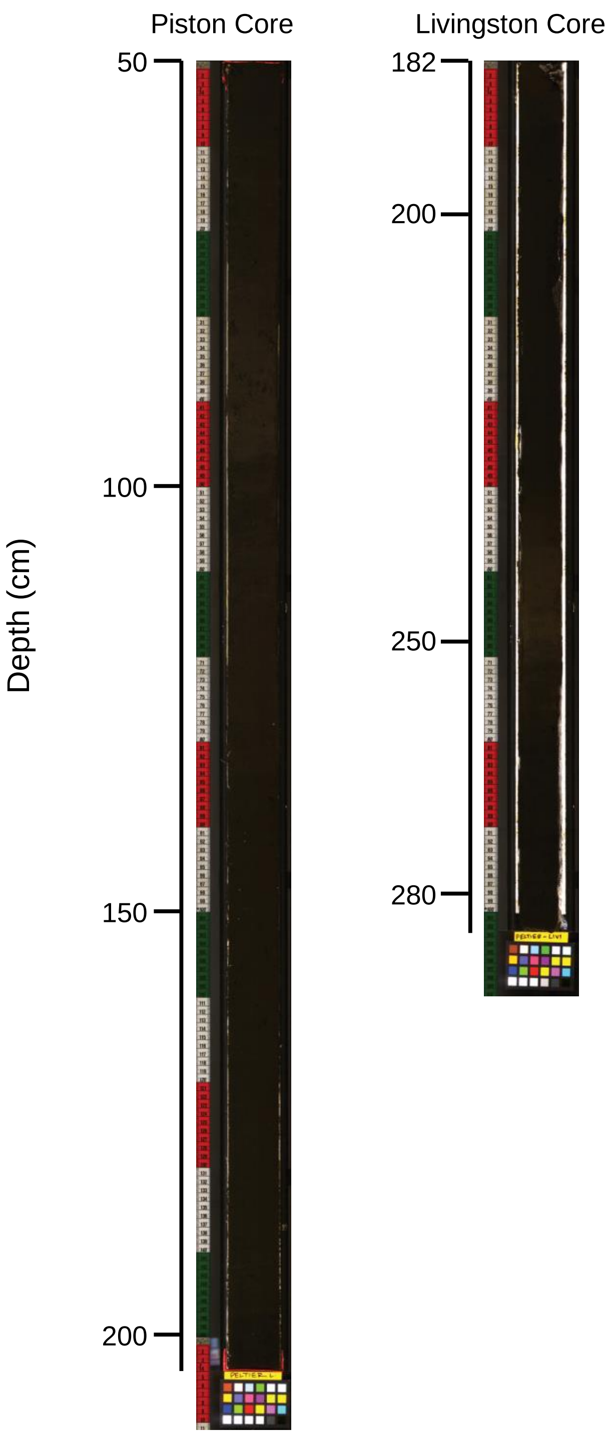


Figure 2. Magnetic susceptibility profiles from the piston and Livingston cores. Cores are overlapped during the coring process to insure a continuous sediment record is recovered.

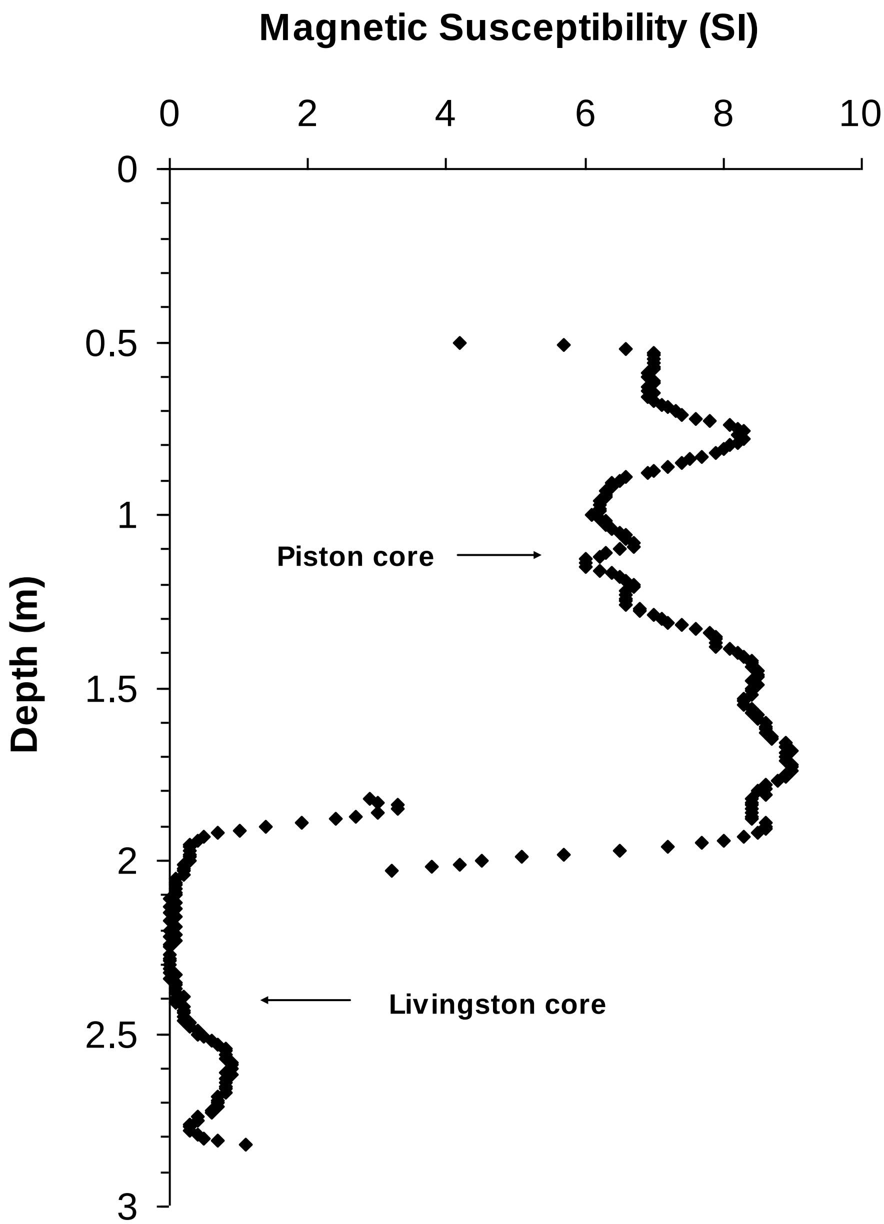


Figure 3. Unsupported lead-210 activity, resulting dating model, and sediment accumulation rate.

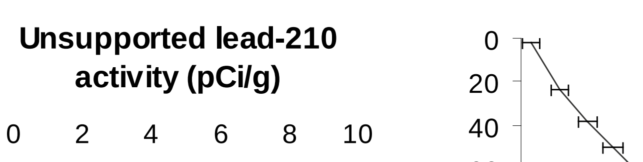
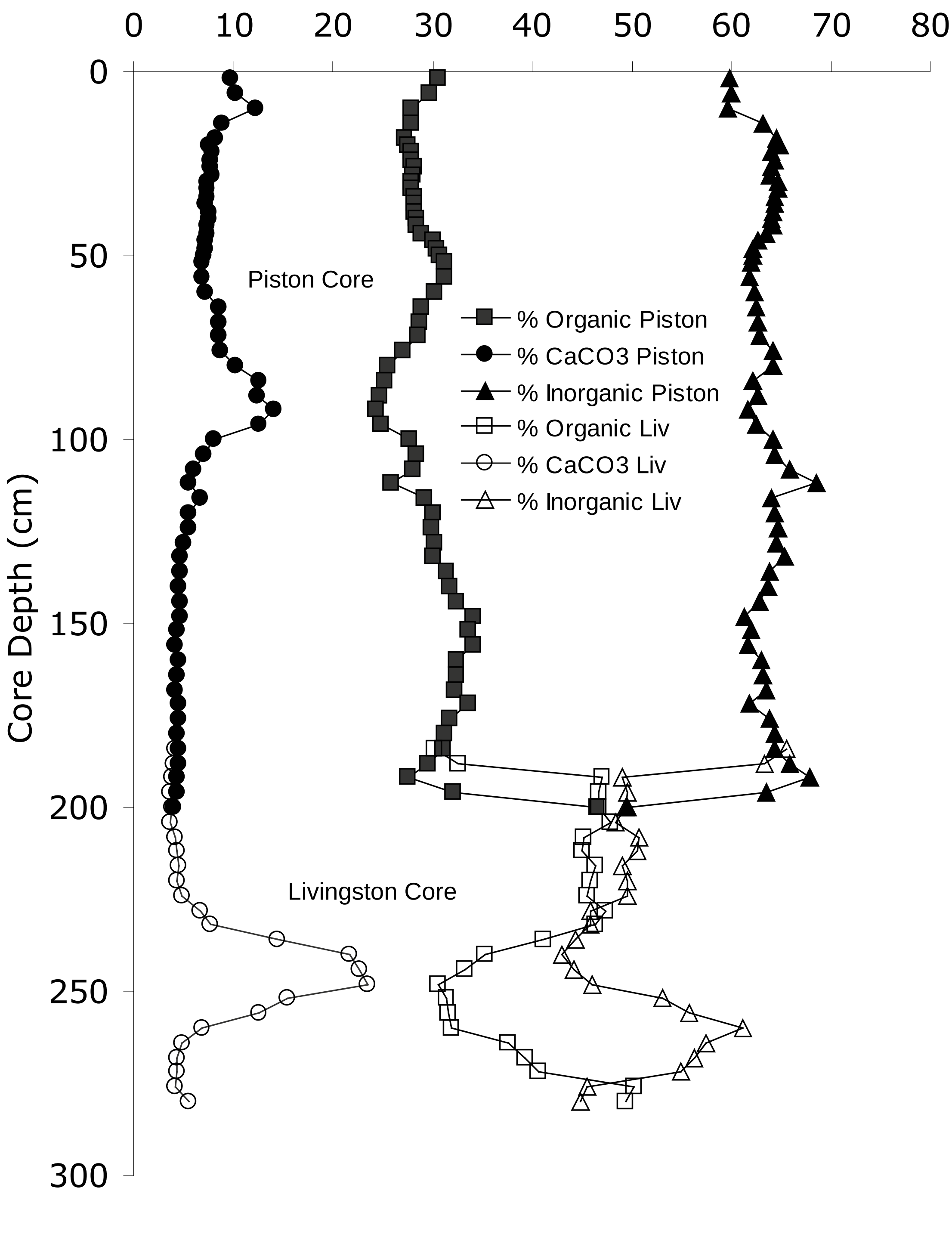


Figure 4. Percent concentration of organic, $CaCO_3$, and inorganic matter in the piston and Livingston cores.



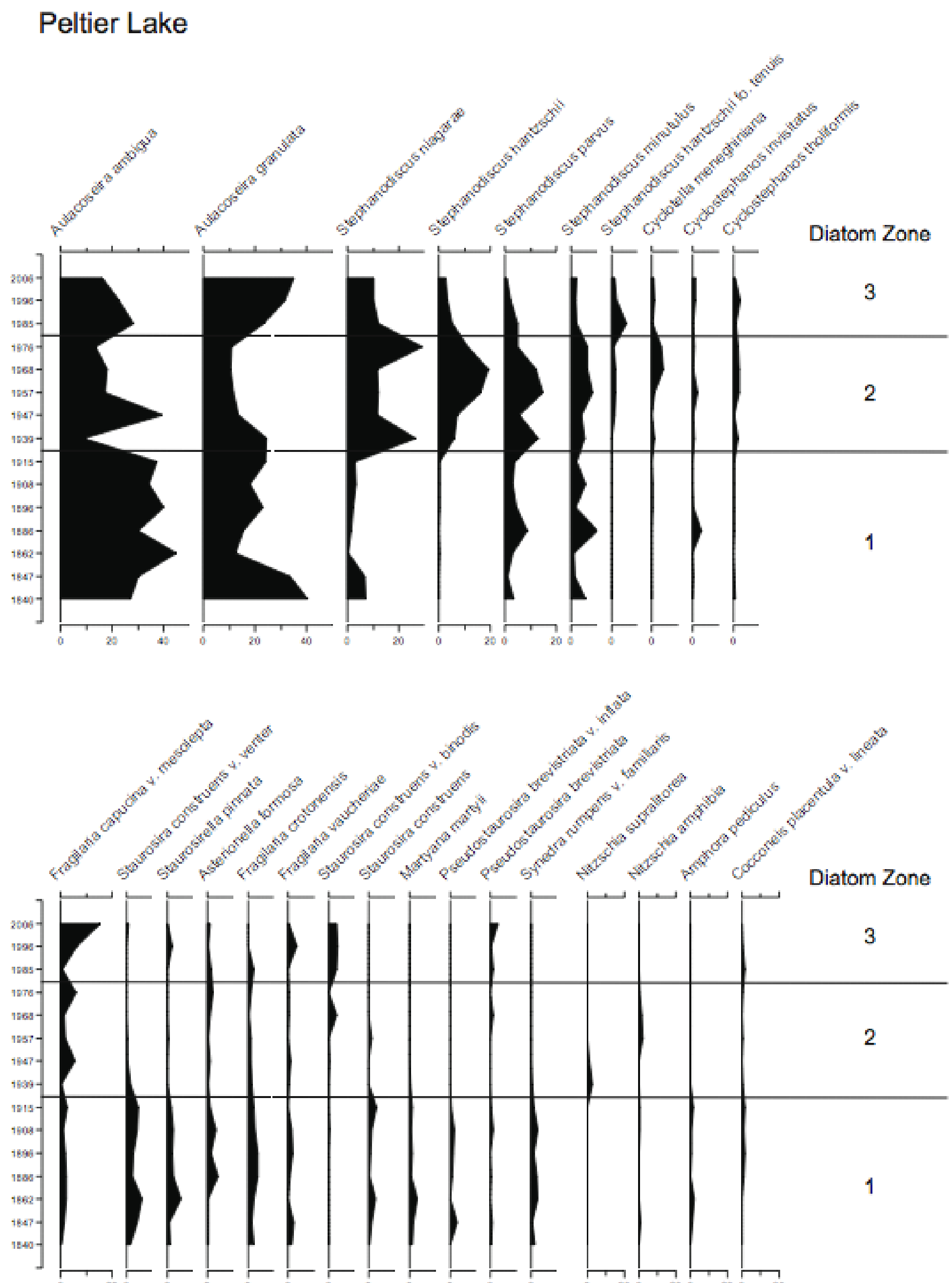


Fig. 5. Downcore stratigraphies for subdominant diatom taxa in Peltier Lake 1840-2006. Three stratigraphic zones identified using correspondence analysis are indicated with horizontal lines.

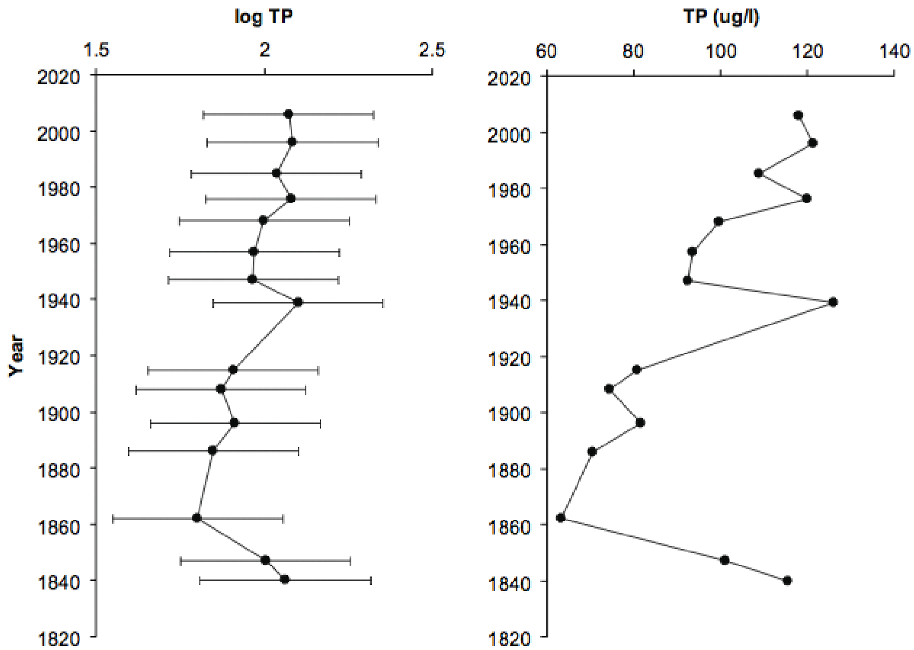


Fig. 6. Diatom-inferred total phosphorus reconstructions for Peltier Lake 1840-2006. Total phosphorus is reconstructed as log TP; error bars represent the bootstrapped root mean square error of prediction for the Minnesota lakes diatom calibration model. Peltier Lake is currently hypereutrophic (>100ppb TP). This increase in TP is coincident with the WWII-era biological change. Samples deposited previous to WWII, including presettlement, pre-damming, and immediate post damming samples, have diatom-inferred TP levels that are estimated from 60-80 ppb TP, i.e. Peltier Lake has long been a productive and eutrophic system, but was not historically hypereutrophic. Our two lowest samples (1840s) show spurious high TP reconstructions that are difficult to interpret (see text).