PALEOLIMNOLOGICAL ANALYSIS OF HORSE LAKE AND LOTUS LAKE, POLK COUNTY, WISCONSIN

Joy M. Ramstack and Mark B. Edlund

St. Croix Watershed Research Station
Science Museum of Minnesota
16910 152nd Street N
Marine on St. Croix, MN 55047

Final Report submitted to:

Jeremy Williamson
Land and Water Resources Department
Polk County, WI
100 Polk County Plaza, Suite 120
Balsam Lake, WI 54810

November 2008

Recommended Citation: Ramstack, J.M. and M.B. Edlund. 2008. Paleolimnological Analysis of Horse Lake and Lotus Lake, Polk County, Wisconsin. Final Report to the Polk County, WI Land and Water Resources Department, 30pp.

TABLE OF CONTENTS

TABLES

FIGURES

EXECUTIVE SUMMARY

1. In this project, we use paleolimnological techniques to reconstruct the trophic and sedimentation history of Horse and Lotus Lakes (Polk County, WI).
2. Both lakes currently have marginal to poor water quality and are the subject of local and state concerns to develop management plans that include an understanding of presettlement conditions, management targets, and historical lake response to landuse and past management.
3. Piston and overlapping Livingston cores were collected from each lake; cores were lead-210 dated, and sediments were analyzed for changes in magnetic susceptibility, loss-on-ignition, and diatom community composition.
4. Cores from both lakes show an increase in sedimentation rate beginning in the early 1900s, with a more rapid rate of increase in the most recent 10 to 20 years.
5. In both lakes, samples that date prior to European settlement have a higher percentage of benthic diatoms, indicating higher water clarity. The more recent core sections in each lake show a shift to an increased abundance of planktonic diatoms, indicating more turbid and eutrophic conditions in modern times.
6. Both cores also show increases in diatom-inferred TP values at the time of European settlement. However, quantitative TP reconstructions in shallow lakes dominated by small *Fragilaria* species can be problematic.

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 Polk County, including shoreline development, sport fisheries, waste and stormwater discharge, water level management, logging, 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, we use paleolimnological techniques to reconstruct the trophic and sedimentation history of Horse and Lotus Lakes (Polk County, WI). Results will provide a management foundation by determining the natural or reference condition of these lakes and reconstructing a history of ecological changes that have occurred in the lakes during the last 200-300 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.

Description of Horse and Lotus Lakes – *Jeremy, could you provide a short paragraph on each lake? Just some basic information such as: size of the basin, depth, land use, damming, inflow/outflow, modern water quality, etc.*

The primary aim of this project is to quantitatively reconstruct historical environmental change in Horse and Lotus Lakes (Polk County, WI), utilizing paleolimnological analysis of dated sediment cores (Anderson and Rippey 1994, Dixit and Smol 1994). 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 and management targets, and historical lake response to landuse and past management. These goals are well-suited to a paleolimnological study. Analytical tools include radioisotopic dating of cores, geochemical analyses to determine local sediment accumulation rates, and analysis of subfossil algal communities. Multivariate analyses, diatom-based transfer functions, and comparison of diatom assemblages with an 89 Minnesota lake data set were used to relate changes in trophic conditions and diatom communities to human impacts in the local watershed. Diatoms have been widely used to interpret environmental conditions in lakes (Dixit *et al.*, 1992); many species are sensitive to specific water conditions and are useful as bioindicators. Over the past 20 years, multivariate statistical methods have been developed to estimate quantitative environmental parameters from diatom assemblages. These methods are statistically robust and environmentally sound. They have been used successfully in reconstructing a wide variety of environmental parameters including pH, total phosphorus (TP), salinity, and recently, dissolved organic carbon (DOC).

METHODS – SEDIMENT CORING

One piston core and two overlapping Livingston cores were collected from both Horse and Lotus Lakes in May of 2007. Piston cores were taken using a drive-rod piston corer equipped with a 6.5 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 in case the sedimentation rate was too high to capture sediments dating prior to European settlement within the length of the piston core.

Recovered piston cores were transported to the shore and extruded vertically in 2-cm increments to a depth with cohesive sediment texture. Core sections, material remaining in the core barrels, and Livingston cores (wrapped in aluminum foil), were returned to the laboratory and stored at 4°C. Lakes, coring locations, and core recovery are provided in Table 1.

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.

All cores (piston and Livingston) were logged for magnetic susceptibility; in addition, the piston cores and the first Livingston core from Lotus Lake, were split, imaged, and described. Appendix 1(a-c) shows the core image, magnetic susceptibility curve, and the physical description of each of the piston cores as well as the top Livingston core from Lotus. Note that these analyses were performed on the intact portion of each core; therefore these data do not exist for the portions of the core that were field-sectioned. For example, in Appendix 1a (piston core from Horse Lake), 0 cm actually corresponds to 44 cm depth, because 44 cm were sectioned off the top of the core in the field (refer to Table

1 for the length of core that was field sectioned). In the magnetic susceptibility profiles for all cores (Figures 1 and 2) the depths are actual core depths; note that there is some overlap between each of the cores.

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 – BIOGEOCHEMISTRY

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

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

Diatoms and chrysophyte cysts 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 greater than or equal to 5% relative abundance) were plotted against core date. Relationships among diatom communities within a sediment core were explored using Principal Components Analysis (PCA), which is 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 PCA 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 each lake. 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 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. Data are presented as backtransformed values, to TP in µg/l.

RESULTS AND DISCUSSION – CORING, MAGNETIC SUSCEPTIBILITY, AND CORE IMAGING

Horse Lake: A 1.68 m long piston core was recovered from Horse Lake and 44 cm were extruded from the top of the core in the field (Table 1). Two overlapping Livingston cores were also collected from the lake representing a maximum sediment depth of 3.3 m. There were no distinct color changes throughout the piston core (Appendix 1a). There are three distinct rises in magnetic susceptibility in the piston core, one beginning at approximately 46 cm depth, one beginning at 85 cm and one beginning at 150 cm; there are no notable changes in magnetic susceptibility throughout the two Livingston cores (Figure 1). Increases in magnetic susceptibility may be correlated with land use changes including land clearance, increases in terrestrial-derived sediments, and paleosols.

While sectioning and processing the Horse Lake core it was noted that macrophyte remains were absent or scarce at the top of the core, became noticeable at 24 cm, and were abundant below 38 cm.

Lotus Lake: A 1.63 m long piston core was recovered from Lotus Lake and 66 cm were extruded from the top of the core in the field (Table 1). Two overlapping Livingston cores were also recovered, representing a maximum sediment depth of 3.45 m. No distinct changes in color or sediment type were seen throughout the piston or top Livingston core (Appendices 1b and 1c). The piston core shows two distinct decreases in magnetic susceptibility, one beginning at approximately 90 cm, and another at approximately 154 cm. Decreases in magnetic susceptibility can result from increased autochthonous productivity, for example from lake eutrophication. There is a rise in magnetics at the top of the second Livingston core, beginning at approximately 264 cm; this rise in magnetics predates European settlement and initial land clearance by several decades.

RESULTS AND DISCUSSION – BIOGEOCHEMISTRY

Horse Lake: In the piston core from Horse Lake, the relative amount of carbonate remains low and fairly constant; however, there are fluctuations in the proportion of organic and inorganic matter throughout the core (Figure 3). There is a rise in inorganic material beginning at 46 cm and increasing up to 38 cm, which corresponds to the increase in magnetic susceptibility. This shift corresponds with European settlement, although the increase likely started several decades earlier.

Lotus Lake: In the cores from Lotus Lake (piston and Livingston), the relative amount of carbonate is low and remains fairly constant throughout the cores (Figure 4). There are some fluctuations in the proportion of organic and inorganic matter throughout the piston and Livingston cores. There is a rise in the relative amount of inorganic matter at approximately 80 cm, this corresponds to the early 1990s and could be the result of an increase in development in the watershed. There is a rise in organic matter at the top of the core (2000s), which could be due to increased eutrophication of the system; however, this rise could be the result of diagenetic effects.

RESULTS AND DISCUSSION – DATING AND SEDIMENTATION

Horse Lake: The unsupported lead-210 activity, the resulting lead-210 dating model, and the sediment accumulation rate for Horse Lake are shown in Figure 5. Lead-210 activity reached supported levels at 46 cm depth. The sediment accumulation rate began to increase in the early 1900s and has been increasing since that time with a more rapid rate of increase in the last decade. Changes in sedimentation rate in a single core could be due to changes in sediment focusing in the lake; however, the two changes coincide with the time of initial land clearance (early 1900s) and recent development in the watershed (last decade), suggesting that the changes seen in this core may represent increased sedimentation in the basin.

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 6. Lead-210 activity reached supported levels at 266 cm depth. The sediment accumulation rate has increased since the 1900s, with the largest increase occurring in the 1990s. The timing of increases in sediment accumulation rate is the same as what is seen in Horse Lake, suggesting that land use changes in the region (initial land clearance in the early 1900s, and increased development in the most recent decades) may have been driving these changes.

The sedimentation rate at the bottom of the core was used to extrapolate dates for the bottom core sections used for diatom analysis (1776 and 1731); these dates are only an approximation and should be interpreted as "pre-European settlement" instead of specific dates.

RESULTS AND DISCUSSION – DIATOM STRATIGRAPHY AND ORDINATIONS

Horse Lake: This core shows subtle shifts in the diatom community assemblage (Figure 7). In the core sections prior to European settlement (1795 and 1815) there is a higher percentage of the benthic diatoms *Fragilaria construens* v. *venter* and *F. pinnata* and fewer of the planktonic species, *Aulacoseira ambigua* and *Fragilaria crotonensis*. The planktonic species increase in abundance upcore, indicating more turbid and eutrophic conditions in modern times. *Fragilaria brevistriata* varieties and *F. construens* and *F. construens* v. *binodis* are present in abundance throughout the core; these are tychoplanktonic species, which can live either attached to the benthos or suspended in the plankton.

A principal components analysis (PCA) of the Horse Lake core shows that the pre-European settlement samples (1795 and 1815) cluster together (Figure 8), indicating that these samples are most similar to each other in their diatom species assemblage. The diatom community assemblage changes after settlement (1870 and 1906), and then follows a new trajectory, with the samples from 1923-1971 clustering together. The most recent samples (1980-2006) form another cluster, with a high amount of variability between samples.

The clustering on the PCA matches the changes in macrophyte remains that were found in the Horse lake core. Macrophyte remains were mostly absent in the top 24 cm of the core, which corresponds to the cluster from 1980-2006, they were noticeable from 24 to 38 cm (1923-1971), and abundant below 38 cm (1906 and earlier).

Lotus Lake: The changes in the diatom community assemblage in Lotus Lake are similar to those found in Horse Lake; however the changes in Lotus are more pronounced (Figure 9). Prior to European settlement there is a higher abundance of the benthic species *Fragilaria construens* v. *venter*, *F. pinnata* and *Martyana martyii*, which all decrease in abundance in the mid-1800s. The planktonic diatoms *Aulacoseira ambigua*, *Aulacoseira granulata*, *Fragilaria crotonensis* and *Asterionella formosa* are absent, or present in very low abundance, prior to European settlement and increase throughout the 1990s and into modern times. As in the in Horse Lake core, the tychoplanktonic species *Fragilaria brevistriata* v. *inflata* and *F. construens* are present throughout the core.

A principal components analysis (PCA) of the Lotus Lake core shows that the two pre-European settlement samples cluster together (Figure 10). There are three other clusters in the Lotus Lake samples: 1851-1891, 1908-1950 and 1960-2007. As with the Horse Lake core, there seems to be more variability between the modern samples than there is downcore.

In addition to diatoms, another biological proxy that was examined in the cores was the abundance of chrysophyte cysts. Figure 11 shows the number of cysts found in a count of 400 diatom valves for each lake. There is little change in the abundance of cysts throughout the Horse Lake core; however, in Lotus Lake the number of cysts in the two bottom (pre-European) core sections increased dramatically. This increase is indicative of a shift in the ecology of Lotus Lake, and is coincident with the shift in the diatom community assemblage in this core (Figures 9 and 10), which lends additional support to the conclusion that Lotus Lake underwent an ecological shift after European settlement.

RESULTS AND DISCUSSION – PHOSPHORUS RECONSTRUCTIONS

Horse Lake and Lotus Lake: Total phosphorus (TP) reconstructions from both Horse and Lotus Lakes show the same pattern; both show lower TP values prior to European settlement, and rising TP levels from the late 1800s into the 1900s (Figure 11). This pattern would be expected based on land clearance in the late 1800s and increasing amounts of agriculture and development throughout the 1900s and into the present. However, even though the trends in TP levels are expected, the TP reconstructions at the top of the cores are well below modern measured values in both lakes. Both lakes have recent summer average TP levels over 100 µg/l, but reconstructed values at the top of the cores are approximately 30 µg/l.

Diatom-based weighted averaging reconstructions have worked well to infer past TP concentrations in deep lakes; however, shallow lakes have posed problems with these traditional methods (Sayer 2001; SCWRS unpublished data). One of the problems is that in shallow lakes 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 makes diatom-based TP reconstructions less reliable. Recent research on shallow lakes in western Minnesota has shown fish biomass to be a better predictor of algal biomass than nutrient levels (K. Zimmer, personal communication). Therefore, the introduction of carp into these lakes may have been a significant driver of change to the diatom community. 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 species turnover in these lakes is less dependent on nutrient levels. In Horse and Lotus Lakes, small *Fragilaria* species dominate; many of these species are adapted to live on fine-grained sediments, such as those found in shallow lakes. Therefore, the presence of these species may be more dependent on habitat than nutrient levels.

CONCLUSIONS

Both lakes show increases in sedimentation rate beginning in the early 1900s, with a more rapid rate of increase in the most recent 10 to 20 years. Although changes in sedimentation rate in a single core could be due to changes in sediment focusing within the lake, the synchronous changes in both systems suggest that there may have been an increased sediment load to the lakes. These changes coincide with changes in land use in the region and may have been caused by land clearance in the early 1900s, and an increase in development in the most recent decades.

In Horse Lake there are two distinct rises in magnetic susceptibility; both predate European settlement. The second rise in magnetics corresponds to an increase in the relative amount of inorganic material which likely started several decades before settlement. The Lotus Lake cores also record a rise in magnetics that predates European settlement by several decades; the piston core from this lake shows several decreases in magnetics which likely indicate recent eutrophication of the system.

The lakes show similar shifts in their diatom community assemblages over the past few hundred years. In both lakes, samples that date prior to European settlement have a higher percentage of benthic diatoms, indicating higher water clarity. The more recent core sections in each lake show a shift to an increased abundance of planktonic diatoms, indicating more turbid and eutrophic conditions in modern times. Ordination biplots of both cores indicate that there is more variability in the diatom community assemblage in modern times.

In both cores, additional proxies corroborate the shifts seen in the diatom community assemblage. In Horse Lake, macrophyte remains increase downcore; visible changes in the amount of macrophytes correspond to shifts in the diatom community shown in the PCA, suggesting that conditions in Horse Lake was a less turbid and clear water system prior to major disturbances in the watershed. In Lotus Lake, a dramatic decrease in the abundance of chrysophyte cysts after European settlement indicates that the lake underwent a major ecological shift at this time.

Both cores also show increases in diatom-inferred TP values at the time of European settlement. However, quantitative TP reconstructions in shallow lakes dominated by small *Fragilaria* species can be problematic.

Overall, both lakes have undergone shifts in biogeochemistry and ecology over the past two hundred years that coincide with major land use changes in the region. European settlement and initial land clearance, as well as increases in development in recent decades, have affected these systems.

ACKNOWLEDGEMENTS

Erin Mortenson and Dan Engstrom (SCWRS) performed loss-on-ignition and 210-Pb analysis. LacCore (National Lacustrine Core Repository), Department of Geology and Geophysics, University of Minnesota-Twin Cities (http://lrc.geo.umn.edu/corefac.htm) and Amy Myrbo, Kristina Brady, and Anders Noren are acknowledged for coordinating

magnetics logging and core scanning.

REFERENCES

Anderson, N.J. and B. Rippey. 1994. Monitoring lake recovery from point-source eutrophication: the use of diatom-inferred epilimnetic total phosphorus and sediment chemistry. Freshwater Biol. 32: 625-639.

Appleby, P.G., and F. Oldfield. 1978. The calculation of lead-210 dates assuming a constant rate of supply of the unsupported lead-210 to the sediment. Catena 5:1-8.

Binford, M.W. 1990. Calculation and uncertainty analysis of 210-Pb dates for PIRLA project lake sediment cores. J. Paleolimnol. 3:253-267.

Camburn, K.E., and D.F. Charles. 2000. Diatoms of low-Alkalinity Lakes in the Northeastern United States. Academy of Natural Sciences of Philadelphia Special Publication 18:152pp.

Dixit, S.S., J.P. Smol, J.C. Kingston, and D.F. Charles. 1992. Diatoms: powerful indicators of environmental change. Environ. Sci. Technol. 26: 23-33.

Dixit, S. S. and J.P. Smol. 1994. Diatoms as indicators in the Environmental Monitoring and Assessment Program-Surface Waters (EMAP-SW). Environ. Monit. Assessm. 31: 275-306.

Edlund, M.B. 1994. Additions and confirmations to the algal flora of Itasca State Park. II. Diatoms of Chambers Creek. J. Minn. Acad. Sci. 59:10-21.

Edlund, M.B. and J.M. Ramstack. 2006. Diatom-Inferred TP in MCWD Lakes. Final Report to Minnehaha Creek Watershed District, Work Order #116-04, 33 pp.

Fritz, S.C., B.F. Cumming, F. Gasse, and K. Laird. 1999. Diatoms as indicators of hydrologic and climatic change in saline lakes. In Stoermer, E.F. and J.P. Smol, (eds.), The Diatoms: Applications for the Environmental and Earth Sciences. Cambridge University Press, Cambridge & New York, pp 41-72.

Heiskary, S. and M. Lindon. 2005. Interrelationships among water quality, lake morphometry, rooted plants and related factors for selected shallow lakes of West-Central Minnesota. Minnesota Pollution Control Agency, St. Paul, Minnesota, 133 pp.

Ihaka, R. and R. Gentleman. 1996. R: a language for data analysis and graphics. J. Comput. Graph. Stat. 5:299-314.

Juggins, S. 2003. C2 version 1.3, Software for ecological and palaeoecological data analysis and visualization. University of Newcastle, Newcastle upon Tyne, NE17RU, United Kingdom.

Patrick, R. and C.W. Reimer. 1966. The diatoms of the United States, exclusive of Alaska and Hawaii, Volume 1-Fragilariaceae, Eunotiaceae, Achnanthaceae, Naviculaceae. Academy of Natural Sciences of Philadelphia Monograph No. 13, 699 pp.

Patrick, R. and C.W. Reimer. 1975. The diatoms of the United States, exclusive of Alaska and Hawaii, Volume 2, Part 1-Entomoneidaceae, Cymbellaceae, Gomphonemaceae, Epithemaceae. Academy of Natural Sciences of Philadelphia Monograph No. 13, 213 pp.

Ramstack, J.M., S.C. Fritz, D.R. Engstrom, and S.A. Heiskary. 2003. The application of a diatom-based transfer function to evaluate regional water-quality trends in

Minnesota since 1970. J. Paleolimnol. 29:79-94.
Sayer, C.D. 2001. Problems with the application of diatom-total phosphorus transfer functions: examples from a shallow English lake. Freshwater Biol. 46:743-757.
Wright, H.E., Jr. 1991. Coring tips. J. Paleolimnol. 6:37-49.

Table 1. Lakes cored, length of core recovered, and results of field sectioning.

Lake Name	Coring Date	Coring Location	Type of Core	Water Depth (m)	Core length (m)	Field sectioned (cm)
Horse	5/31/2007	45°19' 13.1" N 92°34' 14.5" W	Piston	1.91	1.68	0-44
Horse	5/31/2007	45°19' 13.1" N 92°34' 14.5" W	Livingston	1.91	1.00	--
Horse	5/31/2007	45°19' 13.1" N 92°34' 14.5" W	Livingston	1.91	1.00	--
Lotus	5/31/2007	45°20' 6.7" N 92°35' 48.5" W	Piston	3.04	1.63	0-66
Lotus	5/31/2007	45°20' 6.7" N 92°35' 48.5" W	Livingston	3.04	1.00	--
Lotus	5/31/2007	45°20' 6.7" N 92°35' 48.5" W	Livingston	3.04	0.97	--

Table 2. Samples prepped for diatom analysis.

Core	Sample Depth (cm)	Lead-210 Date
Horse Lake	0-2	2006
Horse Lake	4-6	2003
Horse Lake	8-10	1999
Horse Lake	12-14	1993
Horse Lake	16-18	1987
Horse Lake	20-22	1980
Horse Lake	24-26	1971
Horse Lake	28-30	1960
Horse Lake	30-32	1954
Horse Lake	32-34	1945
Horse Lake	34-36	1935
Horse Lake	36-38	1923
Horse Lake	38-40	1906
Horse Lake	40-42	1870
Horse Lake	42-44	1815
Horse Lake	44-46	1795
Lotus Lake	0-2	2007
Lotus Lake	48-50	2001
Lotus Lake	88-90	1991
Lotus Lake	112-114	1980
Lotus Lake	134-136	1970
Lotus Lake	152-154	1960
Lotus Lake	166-168	1950
Lotus Lake	178-180	1941
Lotus Lake	192-194	1929
Lotus Lake	202-204	1919
Lotus Lake	210-212	1908
Lotus Lake	220-222	1891
Lotus Lake	230-232	1872
Lotus Lake	240-242	1851
Lotus Lake	264-266	Pre-European settlement (approx. 1776)
Lotus Lake	274-276	Pre-European settlement (approx. 1731)

Figure 1. Magnetic susceptibility (SI) profiles from the overlapping piston and Livingston cores from Horse Lake.

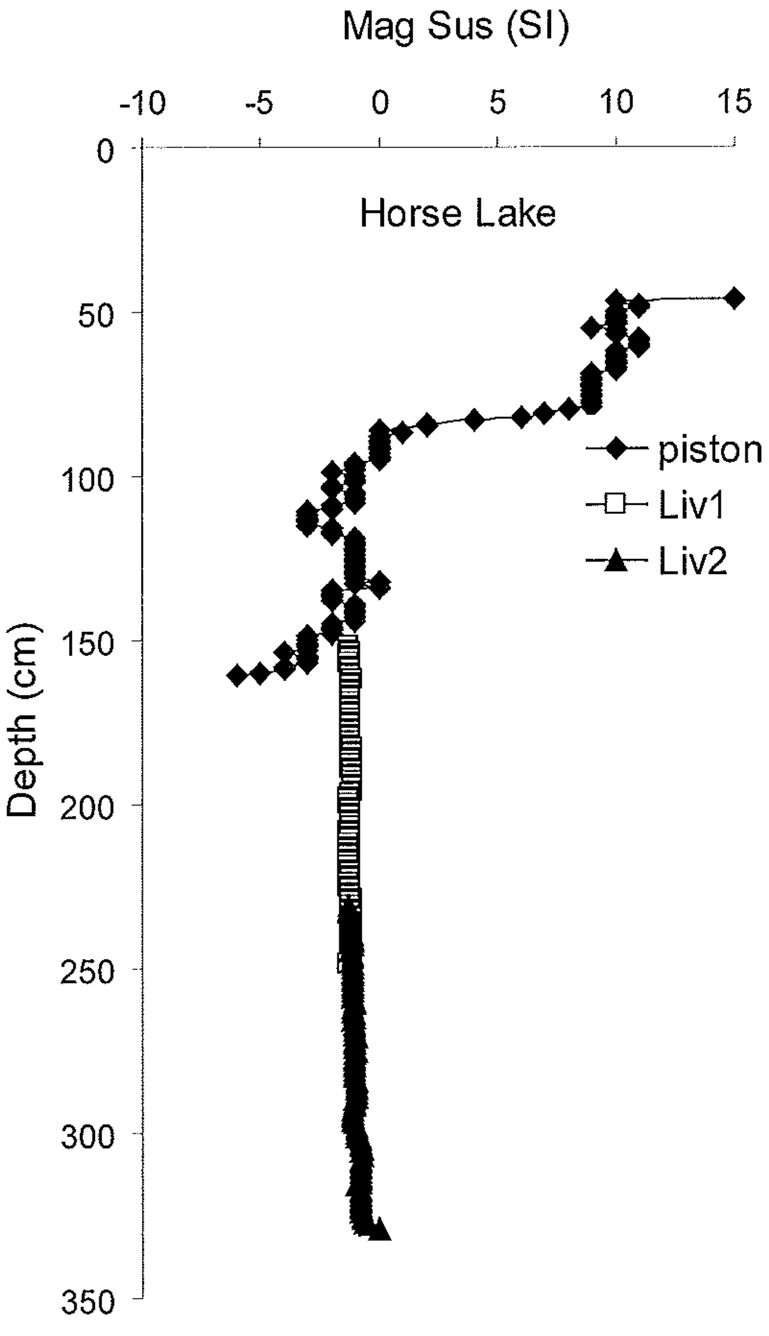


Figure 2. Magnetic susceptibility (SI) profiles from the overlapping piston and Livingston cores from Lotus Lake.

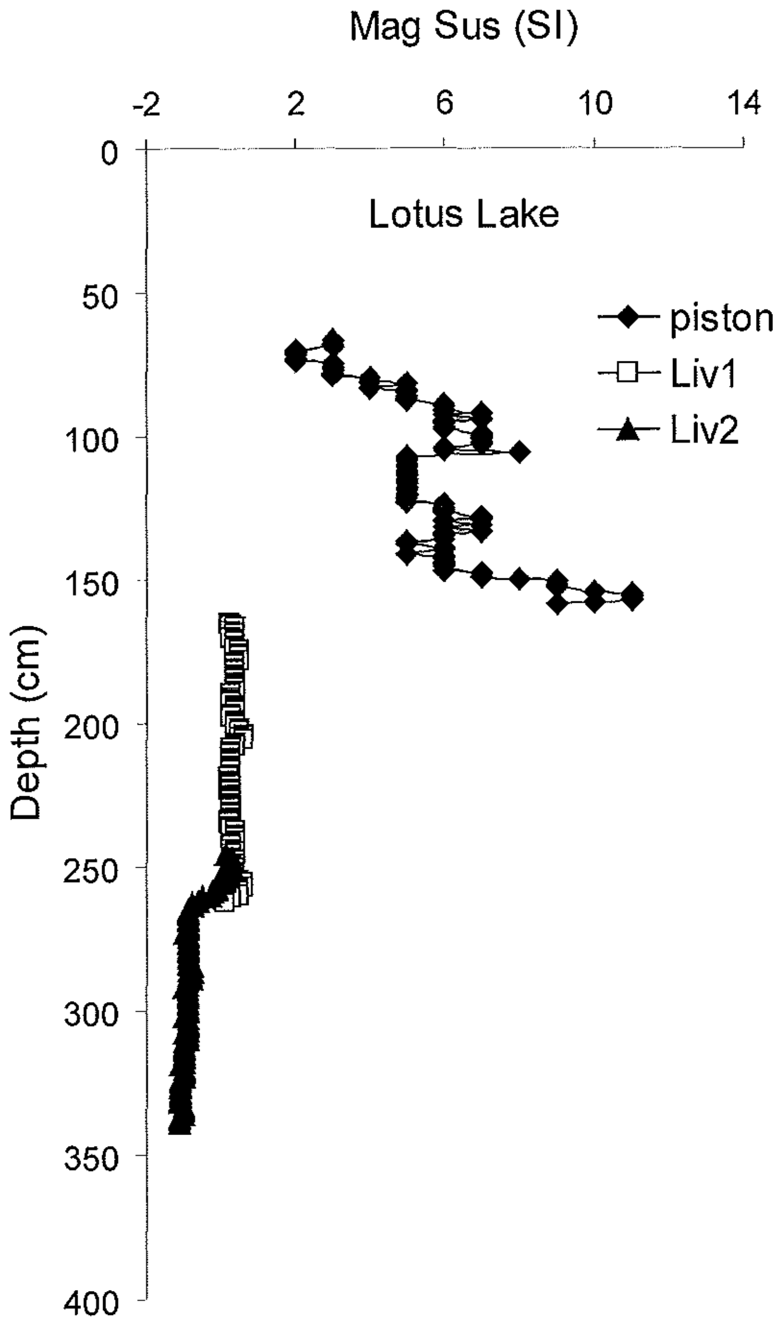


Figure 3. Percent concentration of organic, CaCO3, and inorganic matter in the Horse Lake piston core.

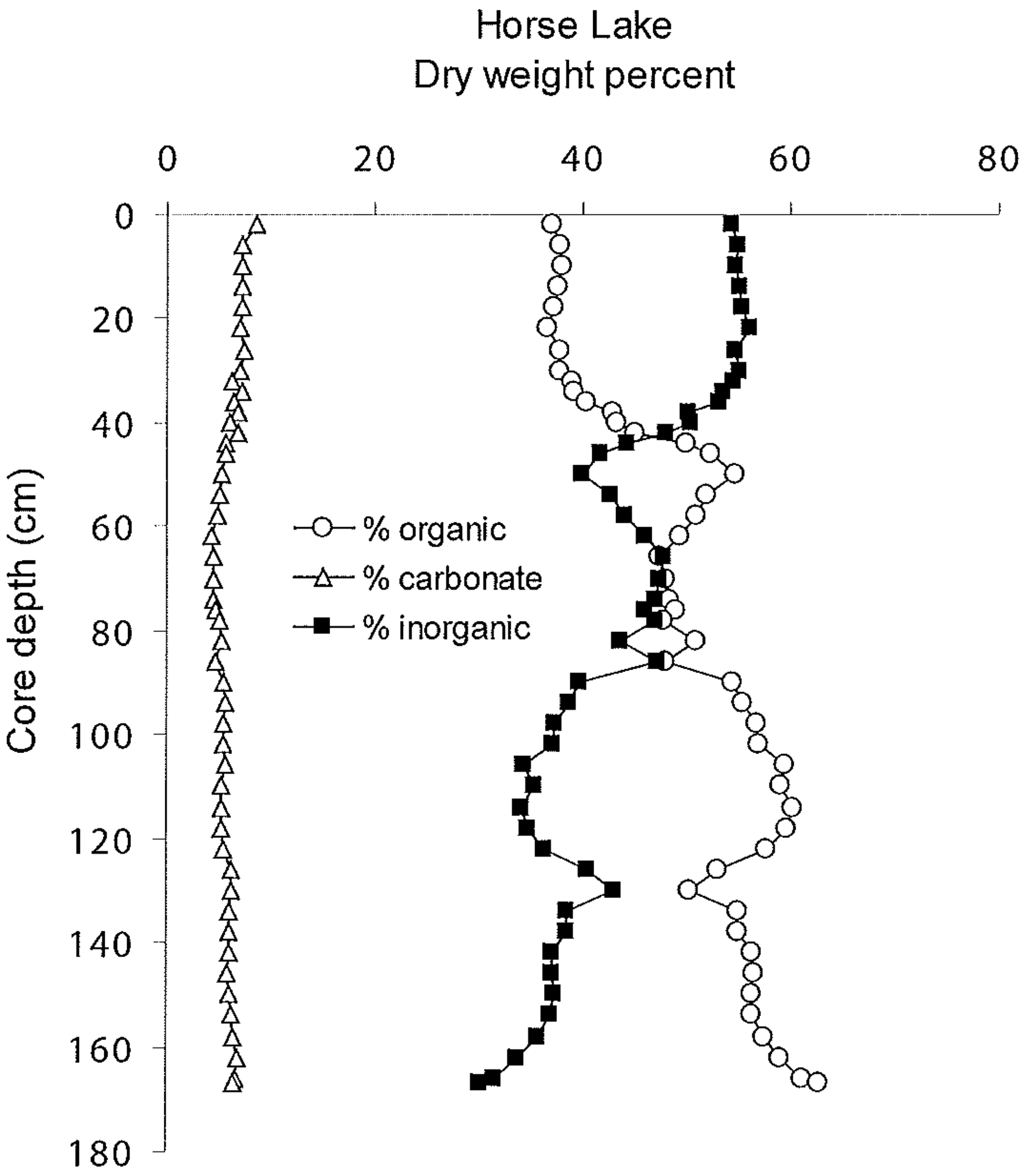


Figure 4. Percent concentration of organic, CaCO3, and inorganic matter in the piston and Livingston cores from Lotus Lake.

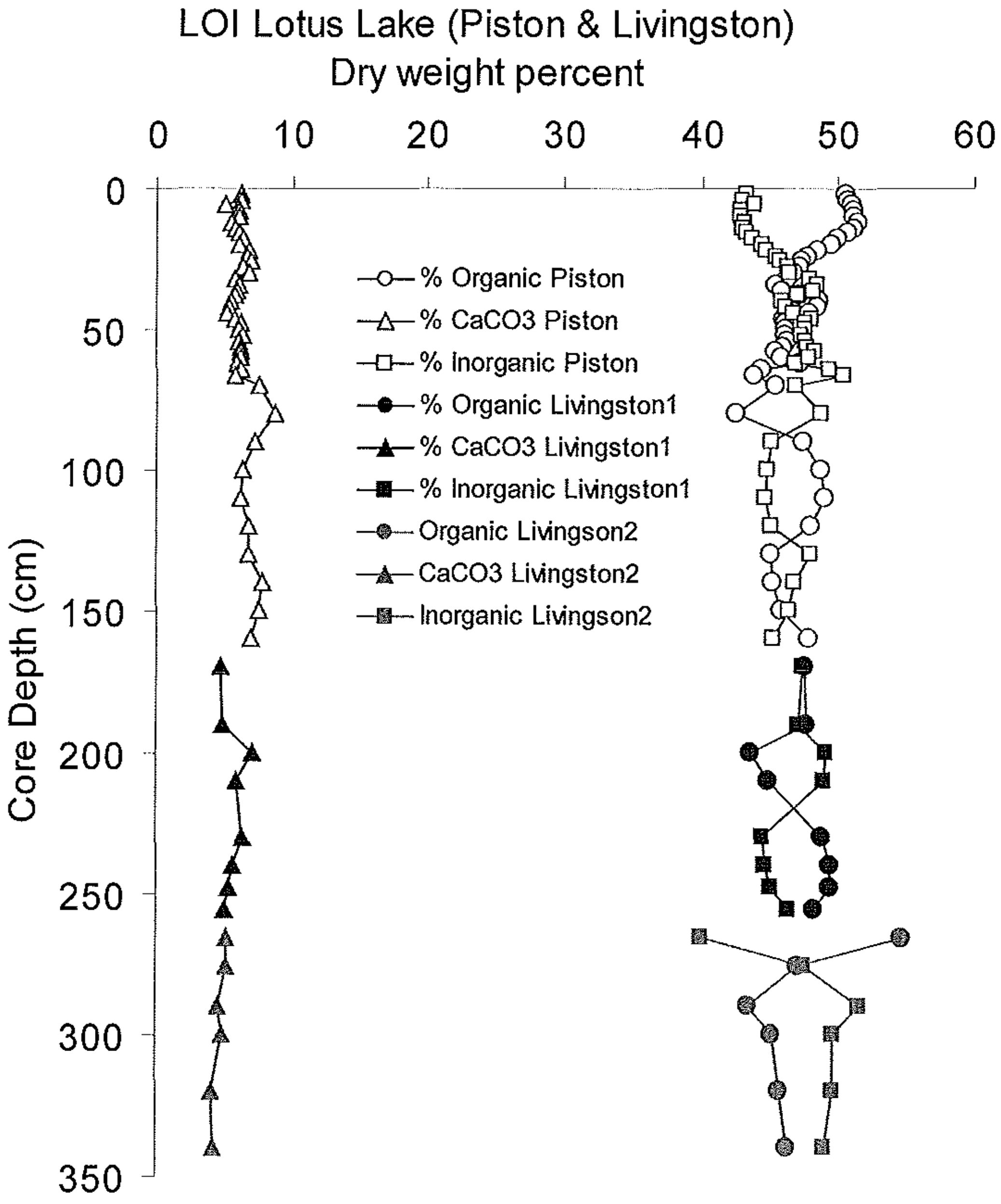


Figure 5. Lead-210 dating model and sediment accumulation rate for Horse Lake.

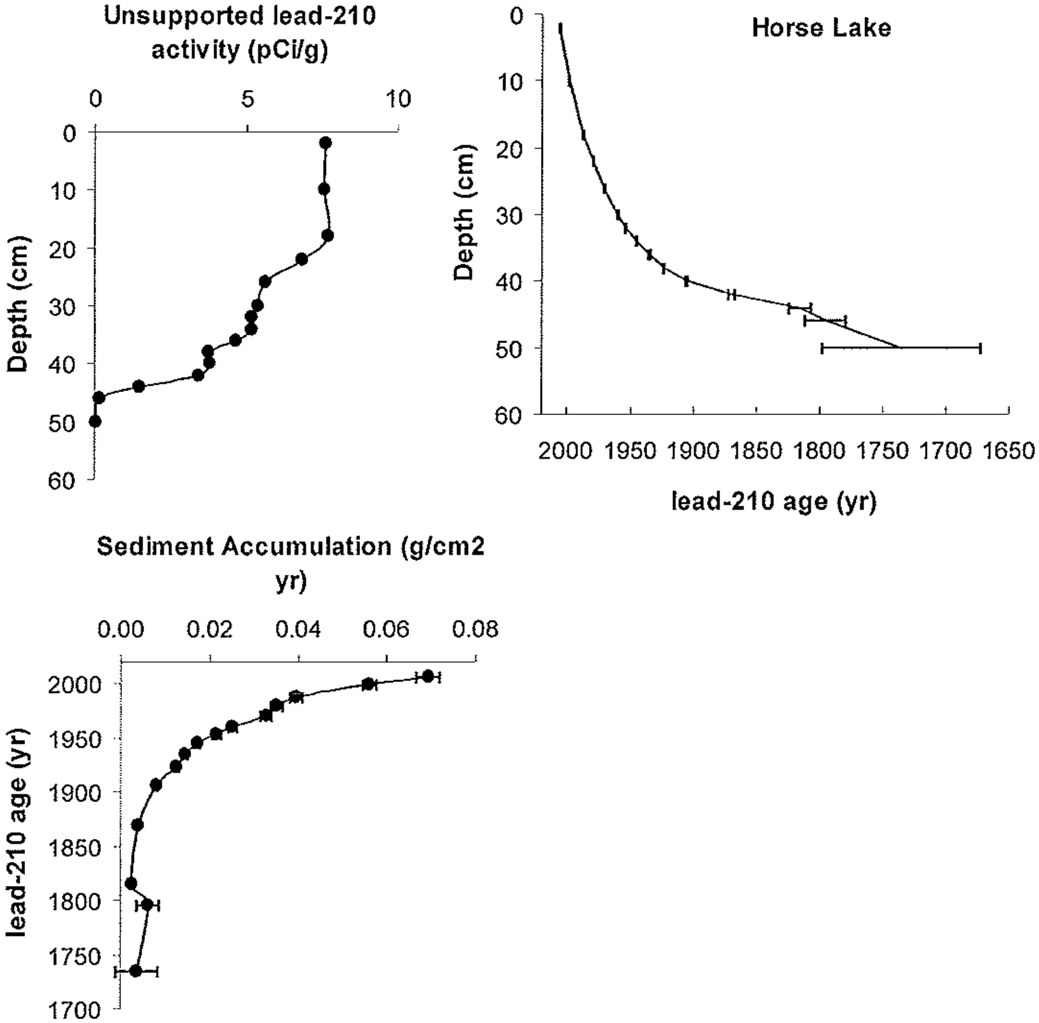


Figure 6. Lead-210 dating model and sediment accumulation rate for Lotus Lake.

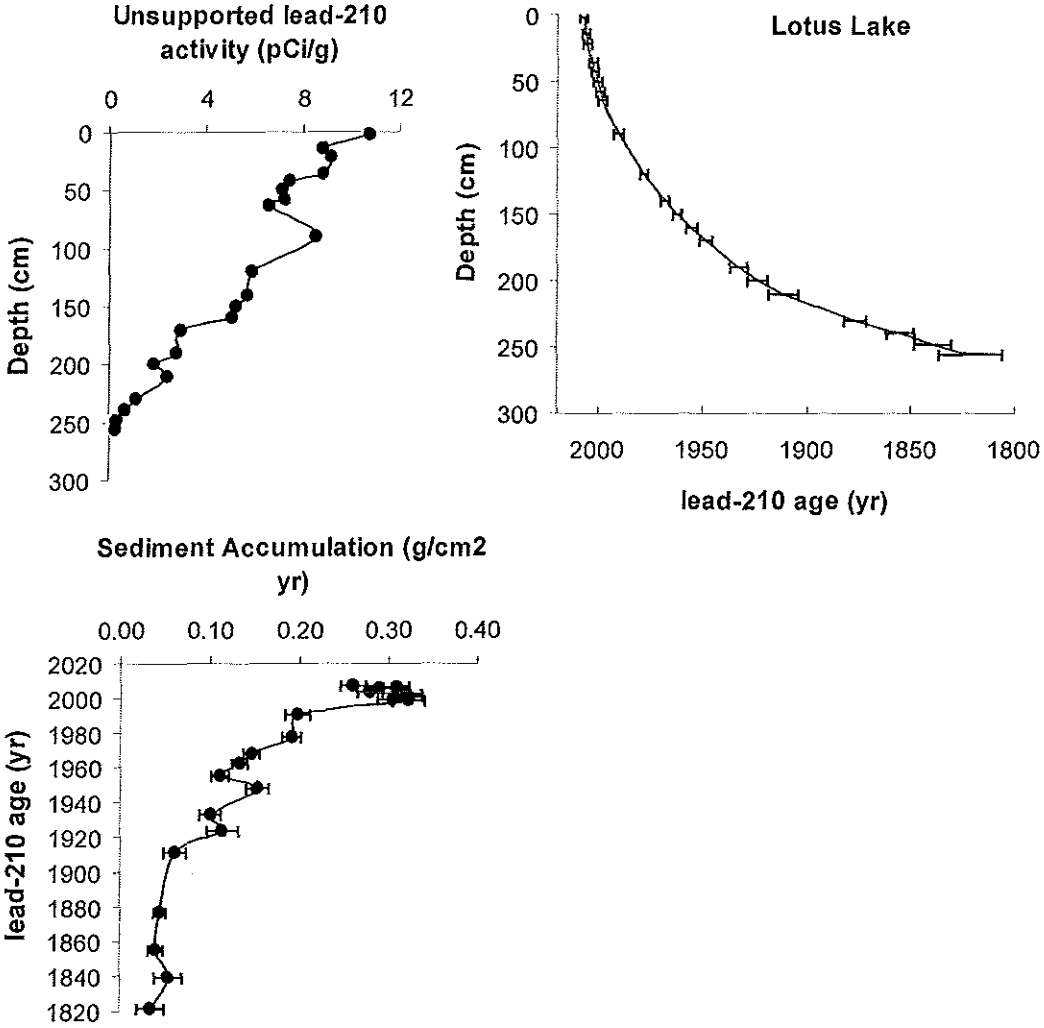


Figure 7. Downcore stratigraphy for predominant diatom taxa (greater than or equal to 5% relative abundance) in Horse Lake (1795-2006). Lines were drawn to indicate changes in the diatom community observed on the PCA plot. The corresponding observations of plant fragments in the core are noted.

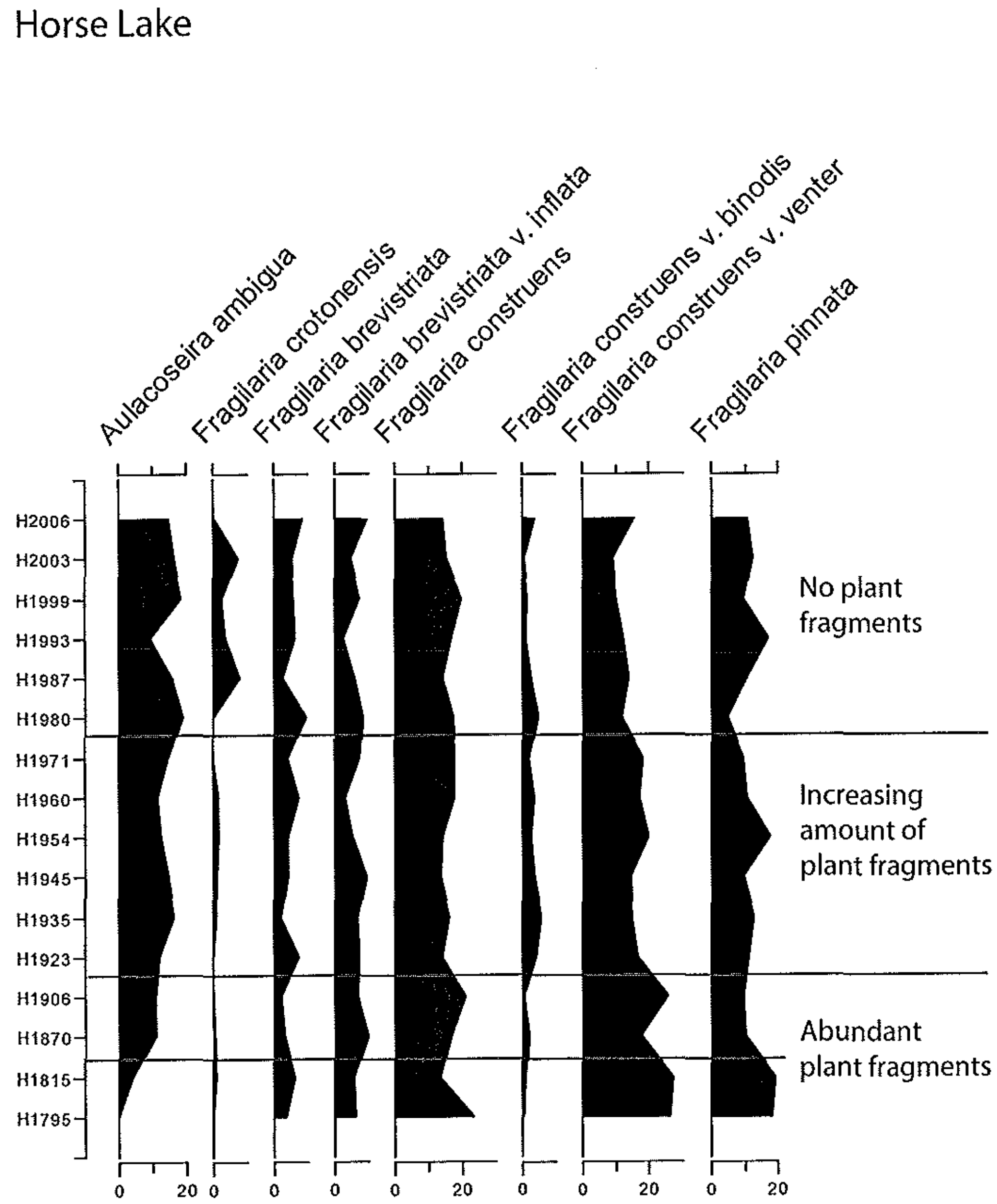


Figure 8. Principal components analysis (PCA) of diatom communities from Horse Lake. Circles and arrows were drawn to illustrate the trajectory through time.

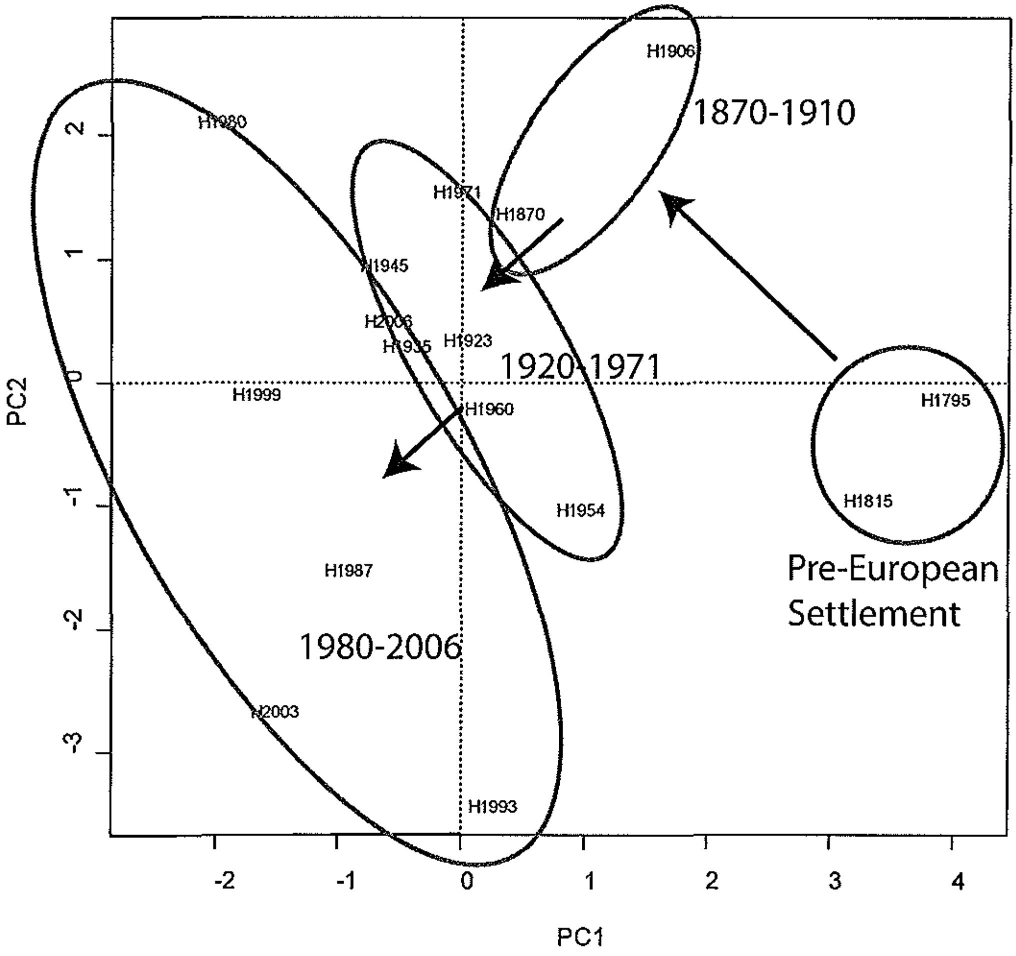


Figure 9. Downcore stratigraphy for predominant diatom taxa (greater than or equal to 5% relative abundance) in Lotus Lake (pre-European settlement-2007). Lines were drawn to indicate changes in the diatom community observed on the PCA plot.

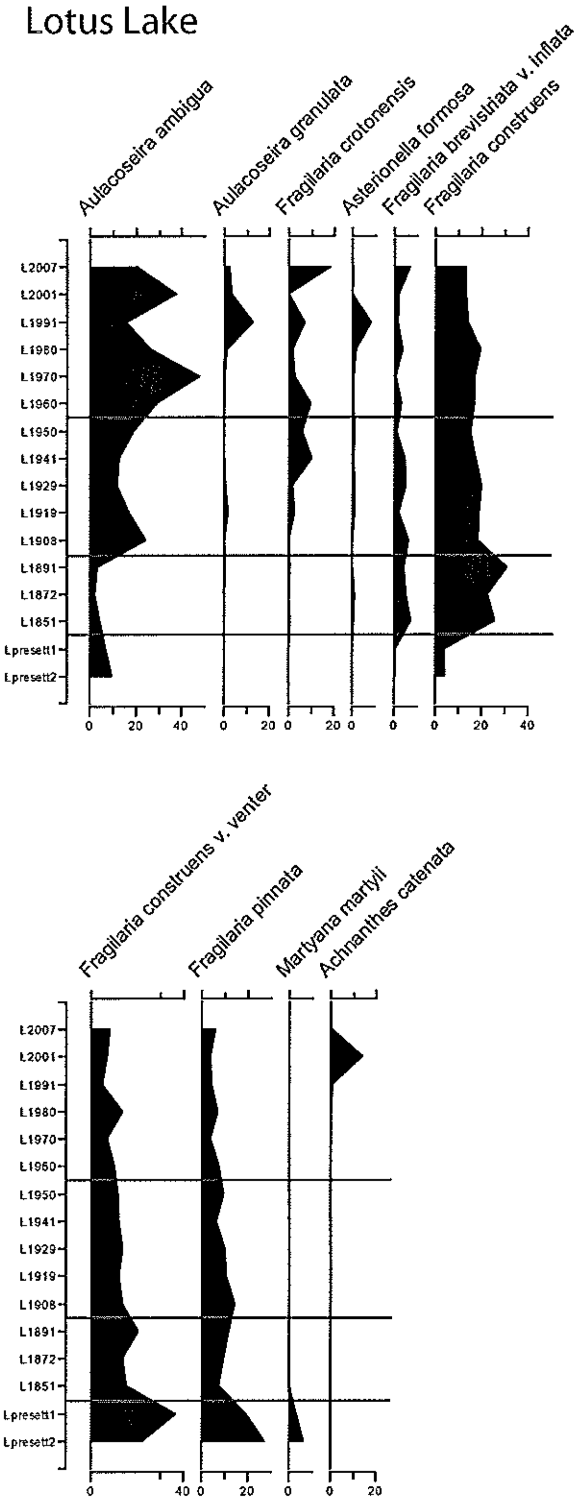


Figure 10. Principal components analysis (PCA) of diatom communities from Lotus Lake. Circles and arrows were drawn to illustrate the trajectory through time.

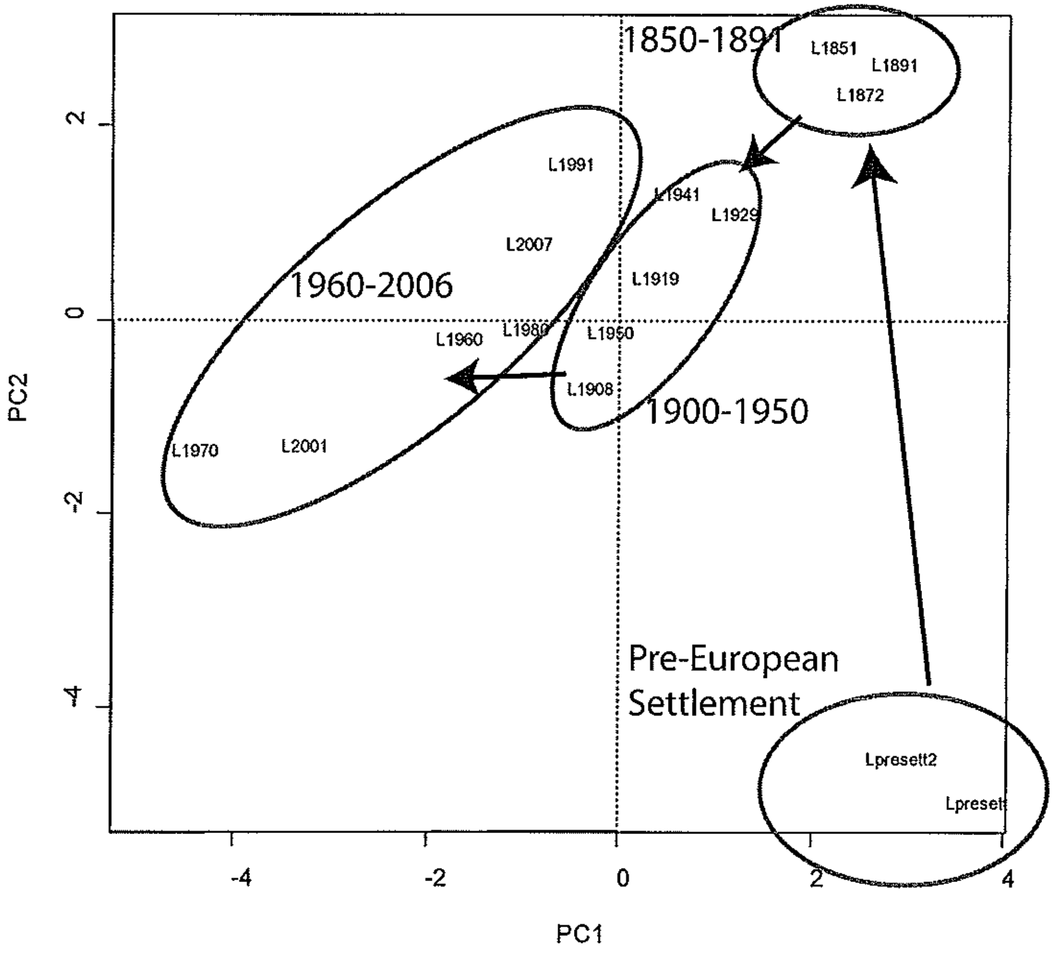


Figure 11. The number of chrysophyte cysts found in the count of 400 diatom valves from Horse and Lotus Lakes.

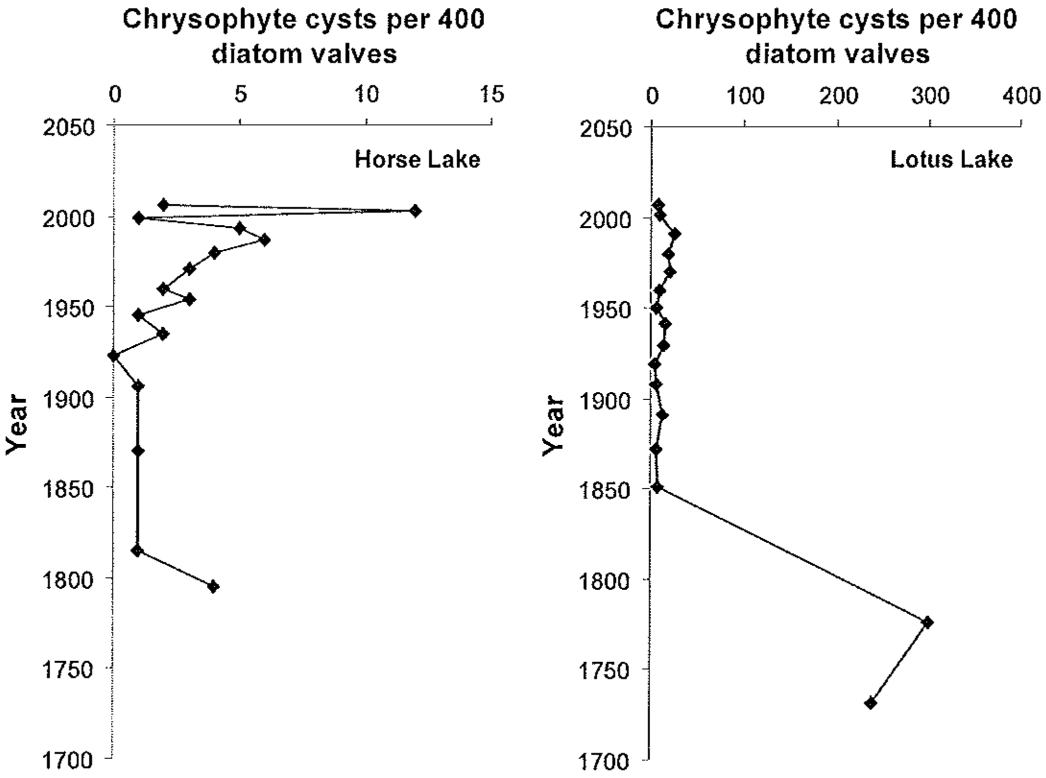
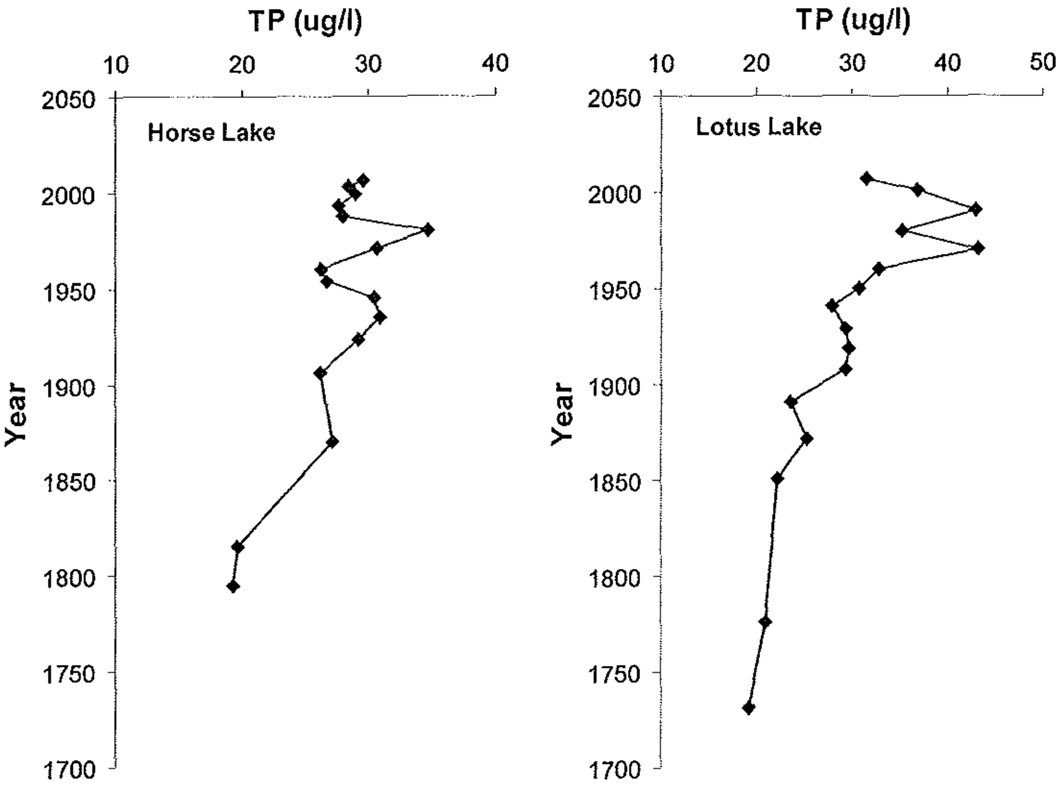
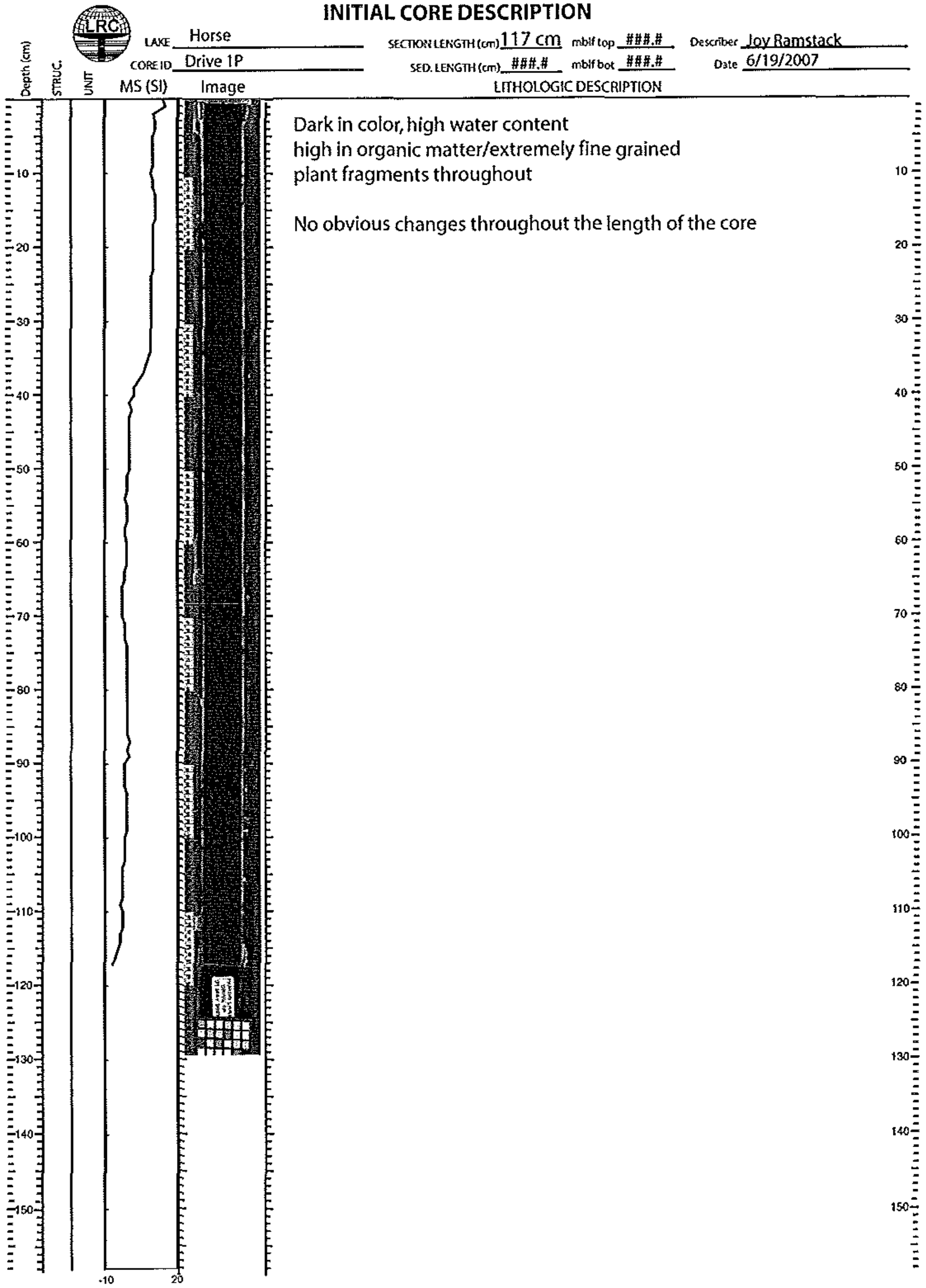


Figure 12. Diatom-inferred total phosphorus (TP) reconstructions for Horse and Lotus Lakes.



Appendix 1a. Core image, magnetic susceptibility, and physical description of the piston core from Horse Lake. Note that 44 cm have been extruded from the top of the core.



INITIAL CORE DESCRIPTION

LAKE Horse

CORE ID Drive 1P

SECTION LENGTH (cm) 117 cm mblf top ###.# Describer Joy Ramstack

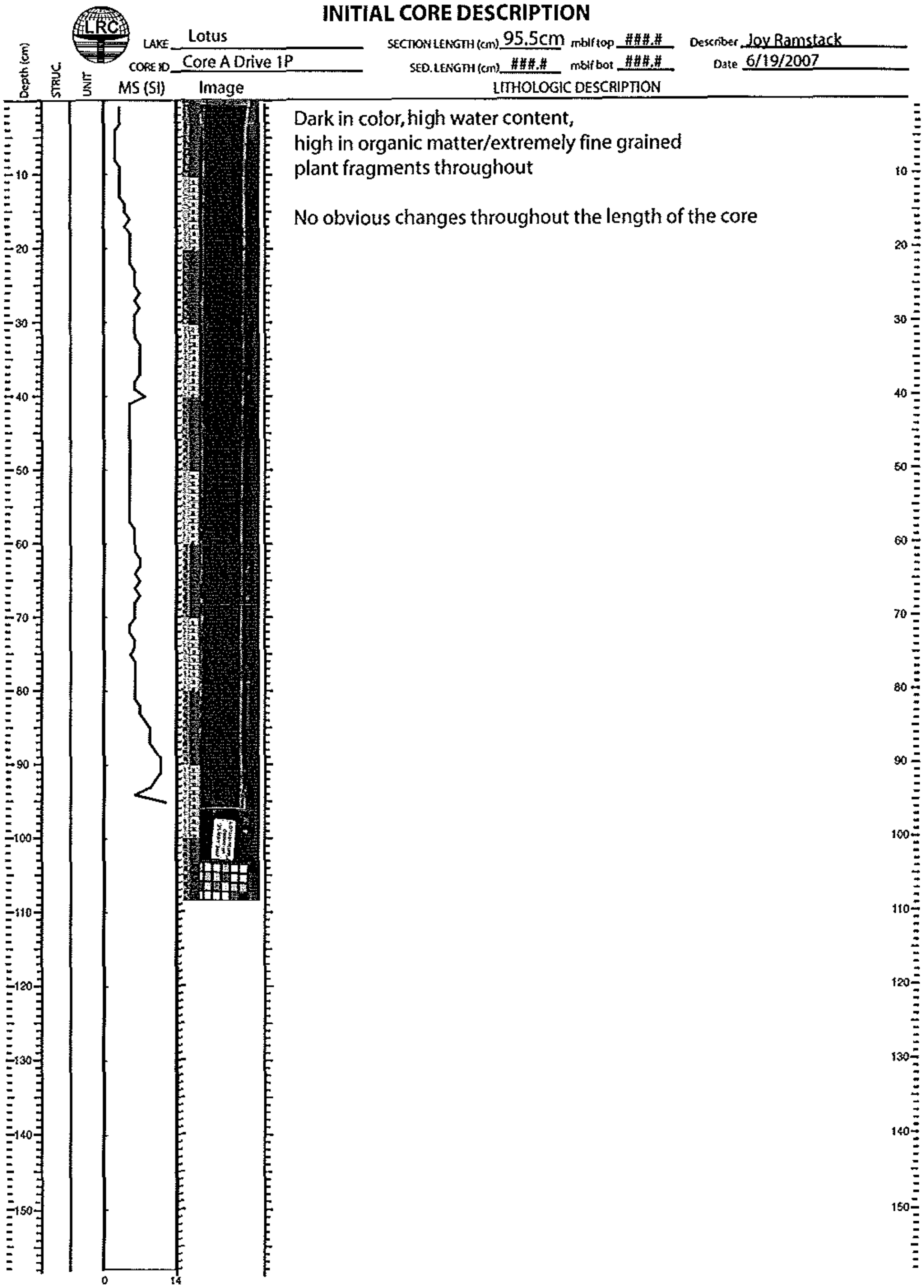
SED. LENGTH (cm) ###.# mblf bot ###.# Date 6/19/2007

LITHOLOGIC DESCRIPTION

Dark in color, high water content
high in organic matter/extremely fine grained
plant fragments throughout

No obvious changes throughout the length of the core

Appendix 1b. Core image, magnetic susceptibility, and physical description of the piston core from Lotus Lake. Note that 66 cm have been extruded from the top of the core.



INITIAL CORE DESCRIPTION

LAKE Lotus
CORE ID Core A Drive 1P
SECTION LENGTH (cm) 95.5cm mblf top ###.#
SED. LENGTH (cm) ###.# mblf bot ###.#
Describer Joy Ramstack
Date 6/19/2007

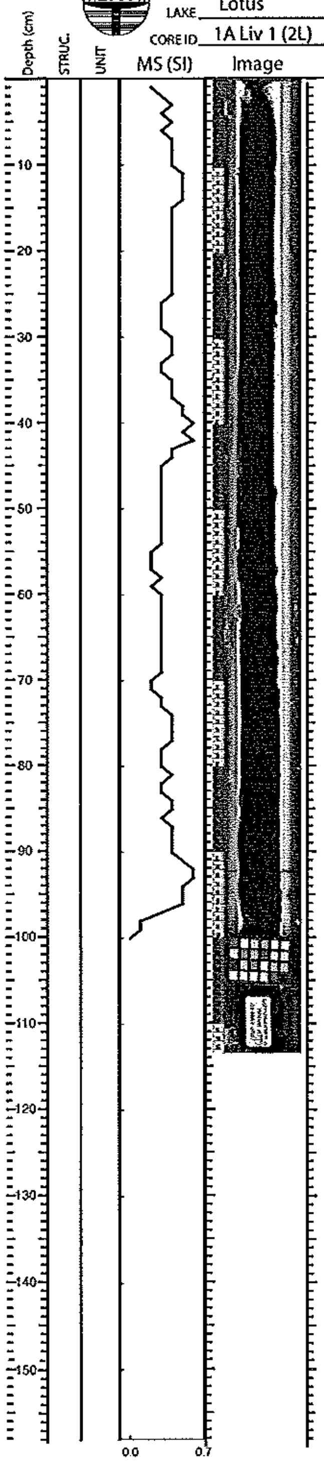
Dark in color, high water content,
high in organic matter/extremely fine grained
plant fragments throughout

No obvious changes throughout the length of the core

Appendix 1c. Core image, magnetic susceptibility, and physical description of the top Livingston core from Lotus Lake.

INITIAL CORE DESCRIPTION

LAKE Lotus
CORE ID 1A Liv 1 (2L)
SECTION LENGTH (cm) 97.5cm mblf top ###.#
SED. LENGTH (cm) ###.# mblf bot ###.#
Describer Joy Ramstack
Date 6/22/2007



LITHOLOGIC DESCRIPTION

dark in color, high water content,
sediments somewhat unconsolidated,
bits of plant material throughout
no visible changes throughout length of core