

# Using Wetland Environmental Histories to Develop Management Strategies for the St. Croix National Scenic Riverway

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## PROJECT OVERVIEW

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Floodplains are a dominant feature in the Lower St. Croix National Scenic Riverway. Braided channels and wetlands along the St. Croix harbor high diversity of plants and wildlife, and are crucial nesting and nursery areas. Recreational uses include wildlife watching, fishing, and hunting. NPS management objectives for the St. Croix center on protection of natural ecological processes. Floodplains are a crucial component in preventing unnatural water quality degradation, maintaining natural patterns and amounts of flow, and maintaining native organisms and their habitats. However, historical data indicate that floodplain wetlands have undergone significant changes possibly from exotic species introductions, land use changes in the watershed, and river management.

For guiding management decisions on the river, an understanding of the timing and magnitude of change in river conditions before and since European settlement is crucial and well suited to paleolimnological investigation. However, paleolimnology of rivers provides unique challenges. Sediment transport is often too episodic and complex to allow accumulation of continuous sedimentary sequences. Therefore, previous paleolimnological studies on the river have targeted Lake St. Croix (a natural impoundment of the river) and demonstrated that, despite its perception of being a pristine river, significant increases in nutrients, sedimentation rate, and algal productivity have occurred since European settlement (Edlund and Engstrom 2001, Triplett et al. 2003).

Environmental impacts on the river are not limited to Lake St. Croix; for that reason, we have analyzed sediment cores from three floodplain wetlands on the lower reaches of the St. Croix River. Dating of sediment cores from riverine systems is extremely challenging. To provide reliable dating models for these cores, careful site selection was coupled with a combination of lead-210, cesium-137, magnetics, and pollen analyses. Once dating models were established for these floodplain wetland cores, sediment diatom communities were analyzed with decadal scale resolution for the past 200-270 years. Shifts in the diatom community structure were then correlated with the land use history of the St. Croix watershed.

Two of the three floodplain wetland cores that were analyzed for diatoms showed distinct shifts in the diatom communities that began at the time of European settlement and initial land clearance. These two cores continued to show changes in the diatom communities throughout the 1900s and into recent times. One of the floodplain wetland cores, which was from the site that is in closest communication with the river, did not show significant changes in the diatom community since 1730.

## INTRODUCTION

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The St. Croix River has been variously declared by the states of Wisconsin and Minnesota to have "outstanding" or "exceptional resource value," and hence, has been the focus of state and federal protection and remediation concerns. Although much of the river has been protected as a National Scenic Riverway under the Wild and Scenic Rivers Act since 1968, major threats to its future and natural resource challenges include increased recreational use and heightened land development, particularly in the Lower St. Croix Valley. The St. Croix River basin has undergone significant land-use changes since European settlers arrived in the 1840s.

The impacts and implications of land use change on the Riverway are finally being realized. Three paleolimnological efforts have targeted the St. Croix River to address historical environmental change, primarily within the natural impoundment at the terminus of the St. Croix River, Lake St. Croix. Sedimentation rates began increasing between 85 and 120 years ago. Increases in organic content accompanied initial logging activity on the river, and subsequently organic, carbonate, and chlorophyll concentrations increased between 1940 and 1990. These latter increases were considered indicators of cultural eutrophication in Lake St. Croix associated with urbanization in the lower basin (Triplett et al. 2003).

Environmental impacts identified in the previous paleolimnology studies are not limited to Lake St. Croix. Sediment and nutrient loadings are a priority concern along the length of the St. Croix River for the Riverway and understanding the impacts of historical land use on sedimentation and nutrient dynamics in the floodplain wetlands of the St. Croix River is the focus of this project. Floodplain wetlands are extensively developed between Osceola, Wisconsin, and Stillwater, Minnesota, along approximately twenty-five river miles (Hindall and Zuehls 1979). The wetlands serve as critical nesting, nursery and diversity hotspots for plants and animals such as great blue herons, bald eagles, and Blandings (proposed for federal listing) and wood turtles, which utilize floodplain forests and shallow sloughs. Riparian wetlands are both imperiled and critical ecosystems worldwide. More than 70% of US riparian ecosystems have been altered and natural riparian communities make up less than 2% of the US land area (Mitsch and Gosselink 1986). Riparian wetlands critically function as the interface between the upland terrestrial ecosystems and the river channel to store and process carbon, nutrients and sediments (Bayley 1995, Sparks 1995). Riparian ecosystems can be characterized by a combination of high species diversity, high habitat diversity, high species densities, and high productivity (Mitsch and Gosselink 1986).

The St. Croix wetlands have had a long history of both cultural and natural resource significance. Wetlands have historically been the site of Native American wild rice processing encampments, but wetlands along the Riverway were subject to alteration during the era of log drives and from changes to water levels caused by dam construction (National Park Service 2000). Other significant changes have included the loss of wild rice in many wetlands, the establishment of exotic animals (carp) and plants (purple loosestrife), and fill-in. Wetlands on the Riverway are presently used for wildlife watching, waterfowl hunting, wild rice harvesting, and bank and small boat fishing. Some wetlands are currently being artificially created, while others have been lost through fill-in and other activities. Threats to wetlands exist along the Riverway including: drainage and filling, private and park development, and artificial changes in stream flow.

However, there is currently no overall management program for the protection and investigation of these wetlands in place.

Management policy in the St. Croix National Scenic Riverway has clearly identified wetland ecosystems as priority concerns (Holmberg et al. 1997). The overall management objective for the Riverway's natural resources program involves the identification, maintenance and protection of the natural ecological processes occurring in the river and immediate environs. Goals for the park's water resources are broadly identified to (1) prevent any unnatural degradation of water quality away from natural conditions; (2) maintain near natural patterns and amounts of stream flow in order to protect river and floodplain morphology and the ecosystems they support; and (3) maintain native aquatic organisms and the hydrologic and biotic systems that support them (National Park Service 2000).

This study builds on these management priorities and earlier paleolimnology efforts by analyzing diatom remains and geochemistry in three dated cores from wetlands within the Lower St. Croix River floodplain for post-settlement signals of trophic change and sedimentation. For inferring historical trophic change, diatom-based reconstructions have been adopted as the most powerful tool at hand (Fritz et al. 1991, 1993, Anderson and Rippey 1994, Reavie et al. 1995, Rippey and Anderson 1996). Analysis of the sediment cores will provide historical background on pre-European settlement wetland conditions and variability, and also provide a temporal record of changes that have occurred in the wetland lakes as a result of natural and anthropogenic perturbations resulting from logging, damming, management, and land use changes in the St. Croix watershed (Charles et al. 1994). These data will be crucial in developing sound policy for wetland use, restoration, and management.

## SEDIMENT CORING

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Six piston cores were collected from five wetland lakes along the St. Croix River between July 2005 and January 2006. Cores were taken using a drive-rod piston corer equipped with a 7 cm diameter polycarbonate barrel (Wright 1991). Recovered cores were transported to shore and extruded vertically in 1-cm increments to a depth with cohesive sediment texture. Core sections and material remaining in the core barrels were returned to the laboratory and stored at 4°C. Target wetlands, coring locations, and core recovery are provided in Table 1.

One of our originally proposed sites, Peasley Lake, was visited on August 16, 2005 and found to be dry, except for a small, spring fed stream that was running along the western edge of the site. Since we could not find a reasonable coring location at Peasley Lake we decided to instead collect a core from the backwater area adjacent to the St. Croix Watershed Research Station. We then added two additional sites to the project, in November 2005 we collected a core from a backwater area on the Wisconsin side of the river, north of Marine on St. Croix, near the town of Otisville, MN. In January 2006 we collected an additional core from the WI side of the river at Cedar Bend, which is located between the towns of Osceola, WI and Marine on St. Croix, MN. Another lake known as Rice Lake, which is adjacent to Peasley Lake, was being considered until we found the site to be dry when we visited it in the summer of 2005.

Table 1. Wetland lakes cored July 2005 – January 2006, length of core recovered, and results of field sectioning.

Wetland Lake Name	Coring Date	Coring Location	County	Z (m)	Core length (cm)	Field and lab sectioned (cm)
Rice Lake (Osceola)	7/20/05	45°19.768' N 92°42.543' W	Chisago (MN)	1.85	120	0-20
St. Croix Islands State Wildlife Area (Core 1)	9/16/05	45°9.362' N 92°44.799' W	St. Croix (WI)	3.92	149	0-31
St. Croix Islands State Wildlife Area (Core 2)	9/16/05	45°10.149' N 92°44.875' W	St. Croix (WI)	0.74	79	0-9
Backwater Adjacent to SCWRS	9/20/05	45°10.431' N 92°45.510' W	Washington (MN)	0.70	90	0-18
Otisville	11/15/05	45°14.952' N 92°45.452' W	Polk (WI)	0.89	88	0-5*
Cedar Bend	1/25/06	45°17.033' N 92°45.570' W	Polk (WI)	0.69	100	0-20

\*17 cm of sand were also sectioned off the bottom of this core to allow the piston to move in the core barrel.

## 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 in-lake 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. Split cores were secondarily scanned for magnetic susceptibility using a Geotek XYZ MSCL split-core logger. 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 six cores were logged for magnetic susceptibility, imaged, split, and described (Figures 1 and 2). Features in the magnetics profile were correlated with core description and core image. From the magnetics and physical features, samples were selected for cesium-137 and lead-210 analysis.

## CESIUM-137 AND LEAD-210 DATING, AND POLLEN ANALYSIS

Sediments from each core were analyzed for cesium-137 to identify the depositional peak associated with the 1963-64 peak in atmospheric nuclear testing, and the first appearance of cesium-137, which corresponds to 1950. In the Rice Lake-Osceola core the cesium-137 peak

was found to be at 22-24 cm (representing 1964), and the first appearance of cesium-137 was at 36-38 cm (representing 1950) (Figure 3). The other cores do not have distinct peaks in cesium-137; therefore, in the remaining cores it was possible to use the first appearance of cesium-137 as a marker for 1950, but we could not determine the 1964 peak (Figure 3).

Sediments 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). Samples from all six cores were analyzed for lead-210 and the results are summarized in Figures 4 and 5.

Pollen was analyzed from sub-samples of selected cores to identify the *Ambrosia* (ragweed) horizon that signals the onset of land clearance. Fourteen samples from the Rice Lake – Osceola core were analyzed for pollen; we found that a significant increase in *Ambrosia* pollen occurred at 74 cm downcore. Twelve samples from the St. Croix Islands 2 core were analyzed for pollen; however, in this core we did not see a distinct decrease in pine pollen or a decrease in *Ambrosia* pollen. Therefore, the results of the St. Croix Islands 2 pollen analysis were not used in determining a dating model for this core.

## BIOGEOCHEMISTRY

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Weighed subsamples were taken from each homogenized 1-cm field-sectioned sediment interval, as well as additional downcore sections, 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.

Loss-on-ignition analysis was completed on field-sectioned samples, as well as additional downcore samples, for all six cores (Figure 6).

## AERIAL PHOTOS AND HISTORIC INFORMATION

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Aerial photos from the 1930s, through the 1990s were obtained for each of the study sites. Analysis of the aerial photos gives us confidence that our chosen study sites have existed as wetlands throughout the last century, even as flow patterns in the river have shifted. The SCWRS site shows that it may have dried up in 1938, which means that it may not be possible to get a continuous sedimentary sequence from this site. These photos also allowed us to correlate changes in our cores with changes that we see in the watershed; for example, at the Rice Lake–Osceola site we were able to examine how the construction of a new bridge in 1953/54 may have impacted the study site.

## SELECTED CORES AND DATING MODELS

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Of the six cores that were collected, three were selected for diatom analysis based on aerial photos, magnetic susceptibility profiles, and level of success with lead-210, cesium-137, and pollen dating.

The Rice Lake-Osceola core was used for diatom analysis. There was a strong cesium-137 peak in this core, which gave the dating markers of 1964 for the peak, and 1950 for the first appearance of cesium-137 (Figure 3). It was found that there was a shift in pollen assemblage from *Ambrosia* pollen to pine pollen at 74-80 cm, which signals the onset of land clearance in the watershed. There was also a sharp rise in magnetic susceptibility in this core between 70 and 72 cm, which we believe corresponds with land clearance (cores from Lake St. Croix also showed a marked increase in magnetic susceptibility at the time of European settlement in the watershed (Triplett et al. 2003)). Since the pollen and magnetic susceptibility data match up well, we believe that approximately 80 cm corresponds to the onset of land clearance at this site and have used 80 cm downcore to represent 1860. The lead-210 dating model does not match up well with our other dating markers for this core; lead-210 dating of floodplain/wetland sediments can be problematic because lead-210 is often not supplied to the system at a constant rate. Therefore, at this site we combined the information from the cesium-137, pollen, and magnetic susceptibility data to develop a dating model and section the core for diatom analysis (with approximately decadal scale resolution).

The core from Cedar Bend was also used for diatom analysis. In this core, the lead-210 dating model matches up well with both the cesium-137 dates and with the increase in magnetic susceptibility. Therefore, the lead-210 dating model from this core has been used to section the core with approximately decadal scale resolution for diatom analysis.

The St. Croix Islands 2 core was the third core used for diatom analysis. The first appearance of cesium-137 in this core corresponds well with our lead-210 dating model. In this core we do not see the same strong rise in magnetic susceptibility that we did in the Rice Lake and Cedar Bend cores; also, the results of the pollen analysis did not show a distinct decrease in pine pollen and/or a decrease in *Ambrosia* pollen. Therefore, we used the lead-210 dating model (which corresponds well with our cesium-137 data) to section the core in decadal increments for diatom analysis.

## DIATOM ANALYSES

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To prepare samples for diatom analysis, between 25 and 60 mg of freeze-dried material was heated in 10 ml of 30% hydrogen peroxide in an 85°C water bath for 3 hours. Cleaned sediment was cooled and rinsed six times with distilled water, allowing twelve hours of settling between rinses. All cleaned material was dried onto coverslips and mounted onto microscope slides with Naphrax.

Diatom valves were identified and counted along one or more random microslide transects on an Olympus BX50 microscope using full oil immersion optics capable of N.A. 1.4 and 1250x until a total of 400 diatom microfossils was reached. Diatoms were identified using floras and monographs by Patrick and Reimer 1966, Krammer and Lange-Bertalot 1986, 1988, 1991a, b,

Edlund 1994, Camburn and Charles 2000, Reavie and Smol 1998, as well as all other pertinent literature.

In the Cedar Bend core, diatom samples were analyzed in decadal intervals from 1740 to the present. Figure 7 shows a correspondence analysis (CA) of the diatom communities from 1740 to the present; this indirect analysis shows how the samples change over time based entirely on changes in the diatom community composition. The diatom community structure remains relatively stable from 1740 to 1880, and then begins to show major fluctuations. From 1890 to about 1960 there are major changes in the diatom community structure along CA axis 1, then from 1970 to the present there are major changes along CA axis 2 (Figure 7). After 1890 we do not see any time interval where the diatom community returns to the assemblage seen in pre-European settlement times. Figure 8 shows the downcore changes of all diatom species which occurred at 5% or greater abundance in the Cedar Bend core; horizontal lines in Figure 8 were drawn at 1970 and 1890 to represent the major changes that were seen in the CA. The most noticeable change in the stratigraphic diagram is that small centric diatoms (*Cyclostephanos invisitatus*, *Cyclotella pseudostelligera*, *Stephanodiscus minutulus*, and *S. parvus*) were absent, or present in very low abundance, prior to 1890. These species show increased abundance from 1890 to 1970, and seem to decrease in abundance again from 1970 to the present (although they generally do not decrease to abundances as low as in pre-European settlement times). *Pseudostaurosira brevistriata*, *Staurosira construens*, *Aulacoseira ambigua*, and *A. subarctica* all show increased abundances in recent decades.

Diatom samples were analyzed at a decadal scale in the Rice Lake-Osceola core. The bottom of this core was dated at 1800; therefore we were able to analyze samples for the past 200 years at this site. Figure 9 shows a CA of the Rice Lake-Osceola diatom communities from 1800 to the present. In this core, the diatom community composition remains relatively stable from 1800 to 1860. There is a distinct change at 1870, followed by another period of relative stability in the diatom community assemblage from 1880 to 1920. Large shifts in the communities occur in the 1930s and 1940s; the period from 1950 to 1990 is relatively stable, but there is a large shift in the 2000 sample. Figure 10 shows the downcore changes of all diatom species which occurred at 5% or greater abundance in the Rice Lake-Osceola core. As in the Cedar Bend core, we see changes in the abundance of small centric diatoms (*Cyclostephanos invisitatus*, and *Cyclotella pseudostelligera*); these species were absent, or present in very low abundance, prior to 1870, then increase in abundance from 1880 to 1950, and then decrease again in post-1950. In the 1940s there is a peak in abundance of *Aulacoseira subarctica*, which makes up greater than 40% of the diatom community composition of this sample. There are two major increases in the abundance of *Fragilaria capucina* var. *mesolepta* in this core, occurring at 1870 and 2000. There is also a steady increase in *Cocconeis placentula* from 1940 to modern times.

In the St. Croix Islands 2 core, diatom samples were analyzed at a decadal scale from 1730 to 2000. Figure 11 shows the principal components analysis (PCA) of the St. Croix Islands 2 diatom data. In this case, PCA (a linear indirect analysis) was chosen instead of CA (a unimodal indirect analysis) because the gradient lengths in this dataset were too short for a unimodal method. Both the PCA of the St. Croix Islands 2 core and the stratigraphic diagram for this core (Fig 12) show that there is very little change in the diatom community composition at this site since 1730, and the small fluctuations that are seen are not directional.

To demonstrate how the diatom communities in each core change in relation to other cores, the three cores were plotted together in a CA (Figure 13). Near the center of the plot are all of the St. Croix Islands 2 samples (reinforcing the conclusion that there has been no significant change in the diatom community throughout this core), the Rice Lake-Osceola samples from 1800-1860, and the Cedar Bend samples from 1730-1900. The Rice Lake-Osceola samples from 1880-1940, and the Cedar Bend samples from 1910-1920, as well as 1950, move along a trajectory toward the lower left portion of the CA plot. Then, in more recent times (1950-2000), the Rice Lake-Osceola samples move along a different trajectory toward the upper left portion of the plot; the recent samples from Cedar Bend (1970-2000) may also be starting to follow this trajectory.

A total phosphorus (TP) reconstruction was performed for all three cores using a diatom-based calibration set of 89 MN lakes (Ramstack et. al 2003, Edlund and Kingston 2004, Edlund and Ramstack 2006). The St. Croix Islands 2 core does not show any significant changes or trends in TP. The Cedar Bend reconstruction shows an overall trend of increasing TP levels beginning in 1850 and continuing through to the present; these increases do not exceed the error of the TP model, but there seems to be an increasing trend. The Rice Lake-Osceola core shows the most variability in TP. The fluctuations in this core are significant, however the change does not seem to be directional, and the most notable changes are the increases in TP in the 1870s and in the 2000s.

## SUMMARY AND CONCLUSIONS

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### *Cedar Bend:*

The diatom community composition at the Cedar Bend site was stable from 1740-1880 (Figure 7), which is prior to European settlement and significant landscape changes in this area. Major fluctuations in the community began in the late 1800s, which corresponds to the period of intense logging and land clearance in the St. Croix watershed. There is also a slight increase in the percentage of inorganic matter in the core at this time (Figure 6), as well as a sharp increase in the magnetic susceptibility profile (Figure 2), both of which would be expected with land clearance. Significant fluctuations continue through the 1960s, which coincide with the beginning of large-scale agriculture and increased urbanization in the watershed. Small centric diatoms (*Cyclostephanos invisitatus*, *Cyclotella pseudostelligera*, *Stephanodiscus minutulus* and *S. parvus*; Figure 8) increase during the period from 1890 to 1970, suggesting that the system was more eutrophic at that time. There is a suggestion that TP levels have been increasing at this site since 1850 (Figure 14); however this trend is not significant, and TP does not seem to be the most significant driver of change in the diatom community in this system.

The most recent decades (1970-2000) show the diatom communities shifting again, this time along a different trajectory. One of the most notable results from this core is that after the changes that began in the late 1880s, the diatom community has not returned to what it was before European settlement.

### *Rice Lake-Osceola:*

In the Rice Lake-Osceola core, we again see that the diatom community was stable prior to European settlement, with changes beginning in the late 1800s and continuing until the 1950s

(Figure 9). In contrast to the Cedar Bend core, there is an intermediate period of stability in the diatom community from 1880-1920. However, this site seems to show the same overall pattern of major change first during the time of initial land clearance, and then again with the increase in agriculture and urbanization in the watershed. Again, there is a notable increase in small centric diatom species (*Cyclostephanos invisitatus*, and *Cyclotella pseudostelligera*; Figure 10) from 1870 to 1950, suggesting a more eutrophic system during those times.

The most notable change in the diatom community at the Rice Lake-Osceola site occurred in the 1940s (Figures 9 and 10). The new WI/MN interstate bridge, which is adjacent to this site, was constructed in 1953/54 (Osceola Historical Society, 1994). This is within the time frame of the error on our dating model; therefore it is likely that the extreme changes in the diatom community in this sample are due to the significant changes to the landscape that accompanied the construction of the bridge. There is also a spike in magnetic susceptibility in the late 1940s/early 1950s (Figure 2), which could be due to these changes on the landscape washing additional sediment into the site.

As with the Cedar Bend core, the most recent samples (1950-1990, and most notably 2000; Figure 9) seem to be changing along a new trajectory. This is also demonstrated in the CA of all three cores (Figure 13); the diatom communities in the Cedar Bend and Rice Lake-Osceola cores are beginning to change along a similar trajectory in recent times. In cores from other relatively pristine lakes in northern MN, WI, MI, and Ontario a change in the diatom community in the last 30-40 years has been detected (SCWRS, unpublished data). These systems may be changing due to increased atmospheric deposition of nitrogen or other pollutants, or are possibly changing due to changes in climate over the region. It's possible that these two wetland sites are responding to similar changes.

#### *St. Croix Islands 2:*

In the St. Croix Islands 2 core there is very little fluctuation in the diatom community since 1730 (Figures 11, 12, and 13). In contrast to the two other sites, the diatom community at this site has not been significantly altered by major land use changes in the St. Croix watershed. Of the three sites, this one is most closely connected to the main channel of the river, and is also closely connected to the Apple River (at its confluence with the St. Croix), which has perhaps made it a less sensitive indicator of change than the other two sites that are farther removed from the main channel.

#### *Lake St. Croix:*

A previous paleolimnological study on Lake St. Croix (Edlund and Engstrom 2001, Triplett et al. 2003) found major changes in the diatom community beginning in the 1950s, as well as a steady significant upward trend in TP levels that also began in the 1950s. The Cedar Bend and Rice Lake-Osceola sites showed changes in the diatom communities around this time, however the most drastic changes at these sites occurred much earlier (near the time of European settlement and initial land clearance), indicating that these critical wetland ecosystems are more sensitive to changes in the landscape.

## PRESENTATIONS

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Preliminary results from the project were presented in a poster format at the North American Diatom Symposium in Mobile, AL in November 2005. Oral presentations were given at the Western Great Lakes Research Conference in Ashland, WI in March 2006, the Minnesota DNR shallow lakes conference in Willmar, MN in April 2006, the International Paleolimnology Symposium in Duluth, MN in June 2006, the St. Croix Watershed Research Station annual Research Rendezvous in October 2006, and the American Society of Limnology and Oceanography national meeting in Santa Fe, New Mexico in February 2007.

Presentations of the final results are scheduled for the St. Croix Watershed Research Station annual Research Rendezvous in October 2007, and at the Geological Society of America national meeting in Denver in October 2007.

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Figure 1. Core images. The image is taken of the intact portion of each core, therefore the missing top section of each image corresponds to the portion of the core that was field-sectioned.

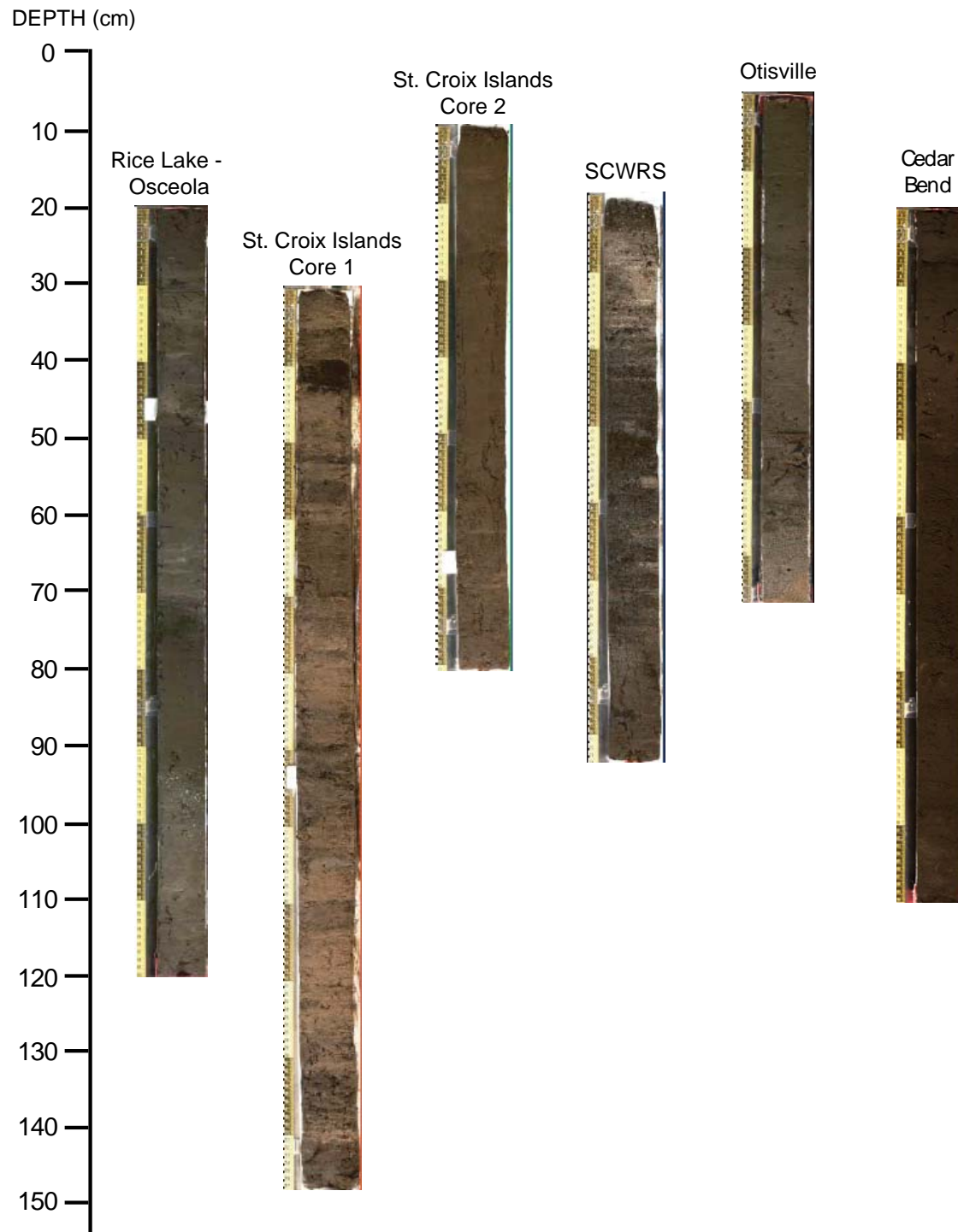


Figure 2. Magnetic susceptibility profiles from all six cores. Note that the analysis is completed on the intact portion of each core; therefore there is no data on the field-sectioned portion.

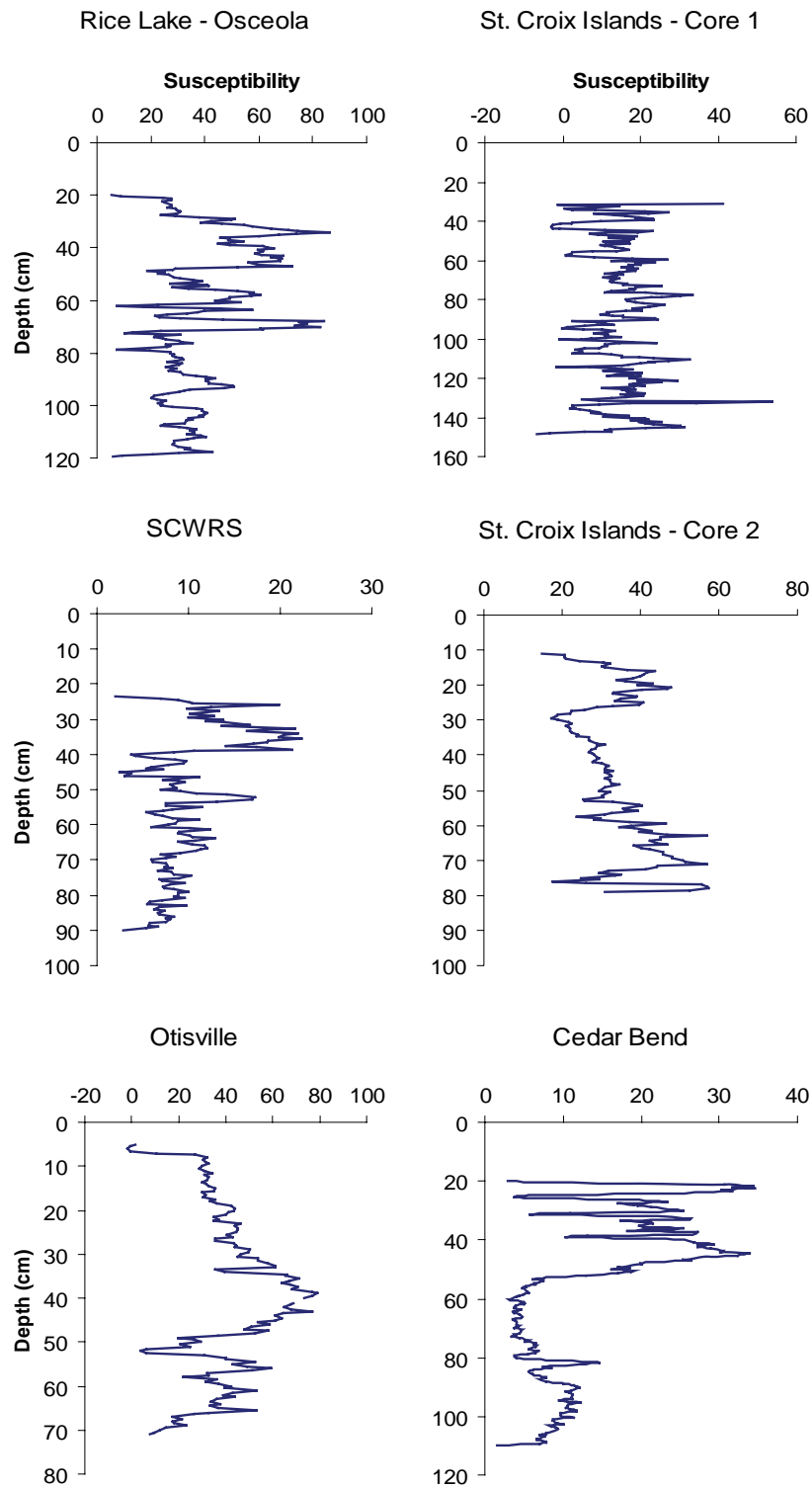


Figure 3. Cesium-137 profiles for each core.

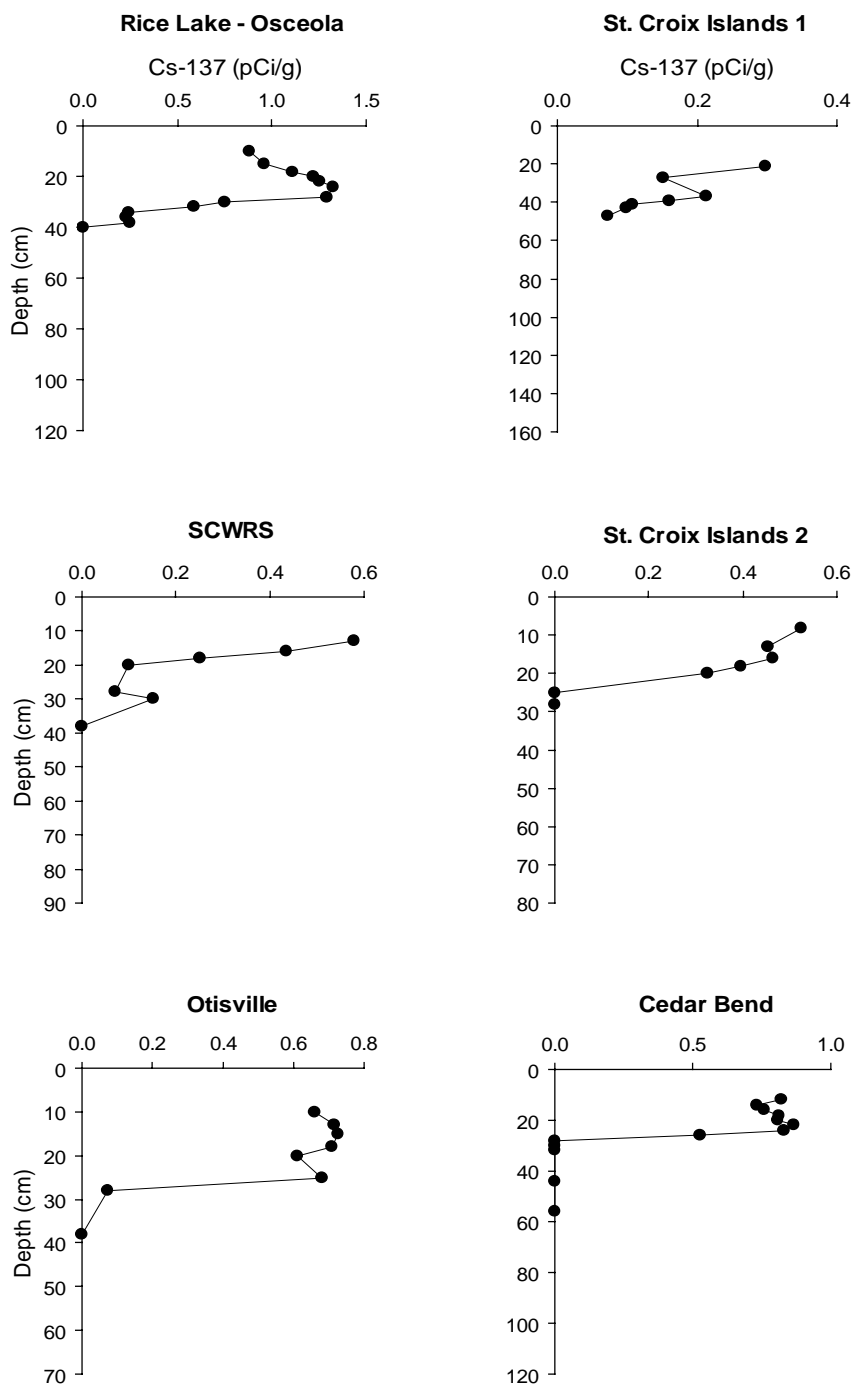


Figure 4. Lead-210 dating models for a) Rice Lake Osceola, b) St. Croix Islands 1, and c) SCWRS cores.

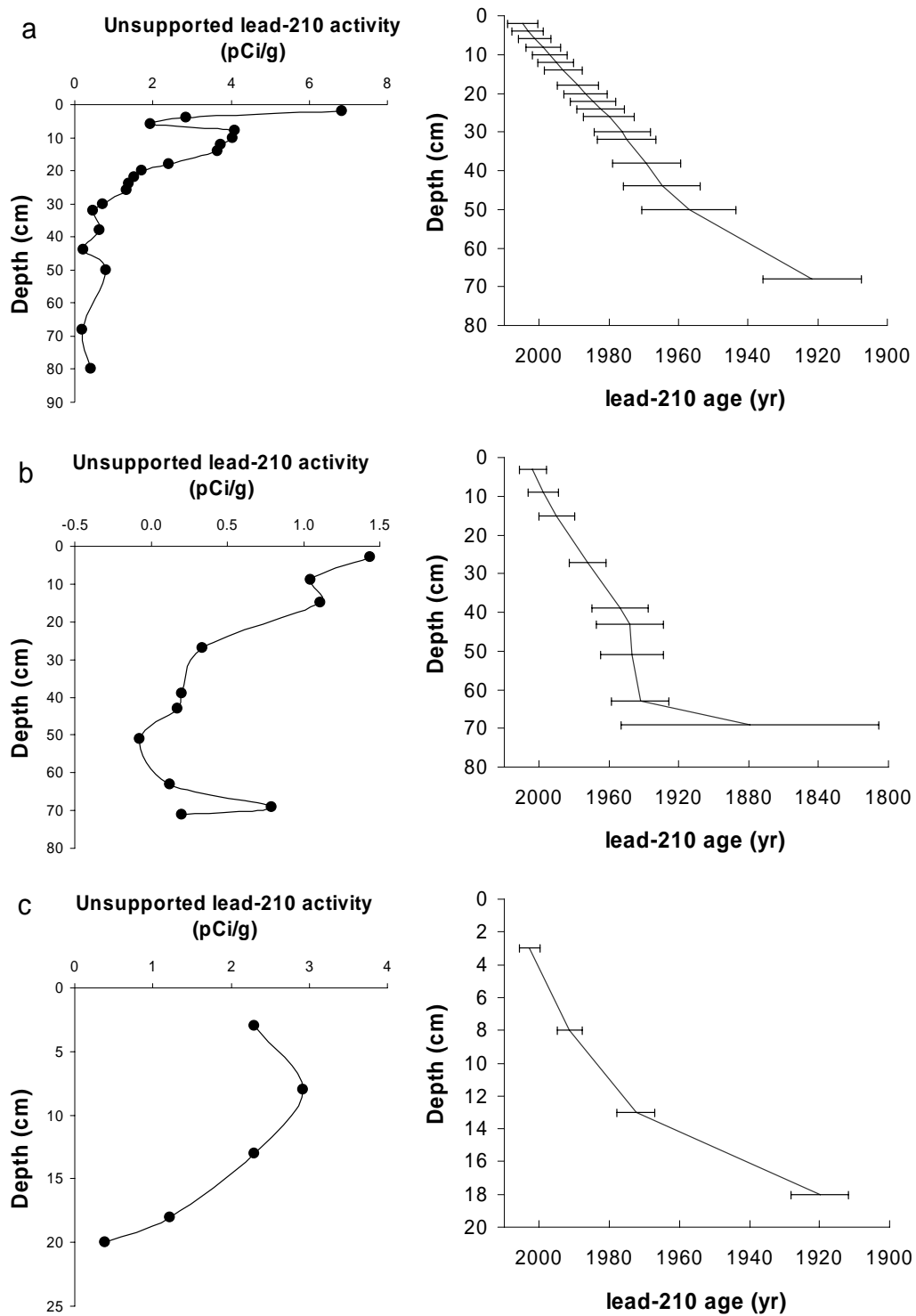


Figure 5. Lead-210 dating models for a) St. Croix Islands 2, b) Otisville, and c) Cedar Bend cores.

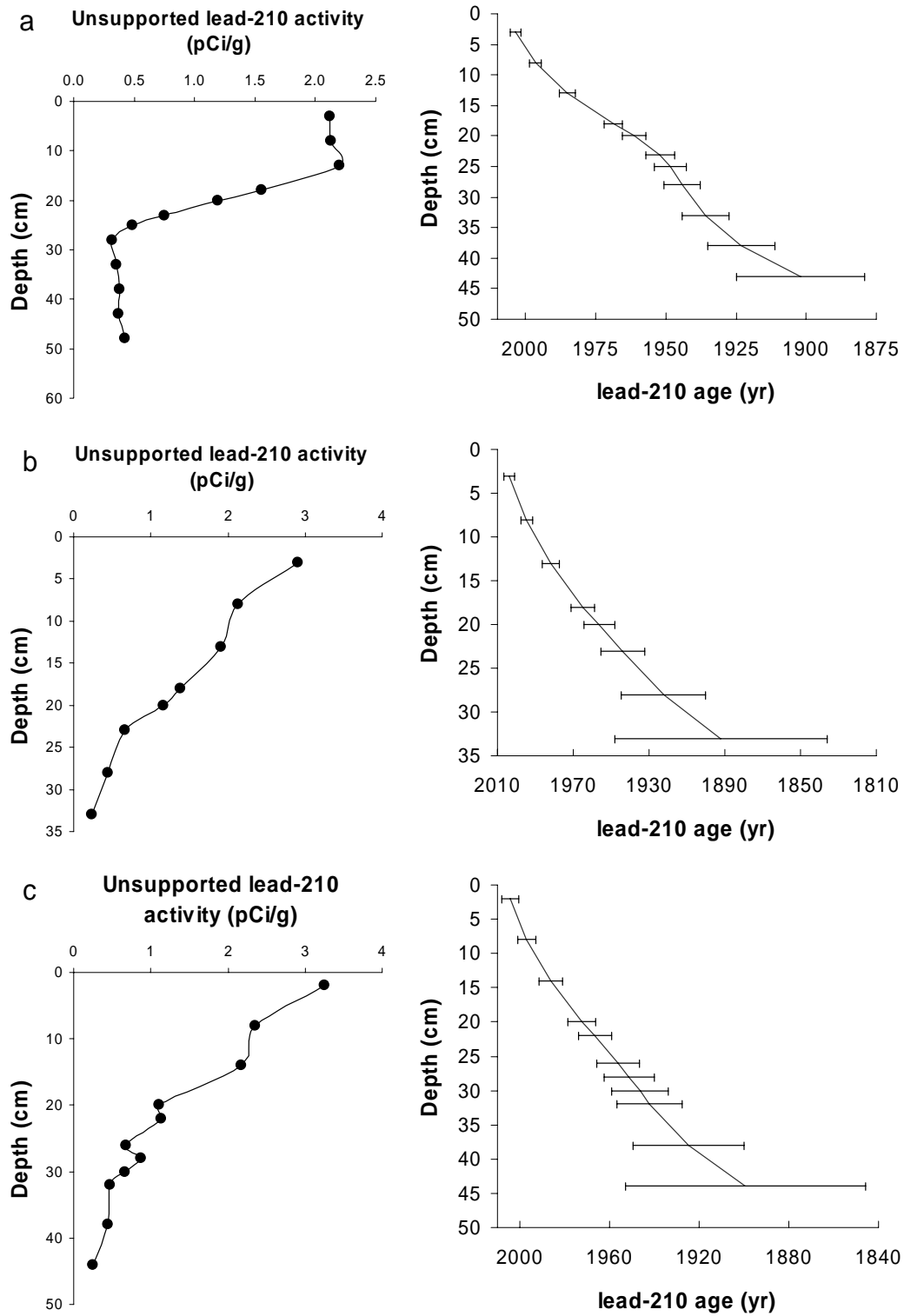


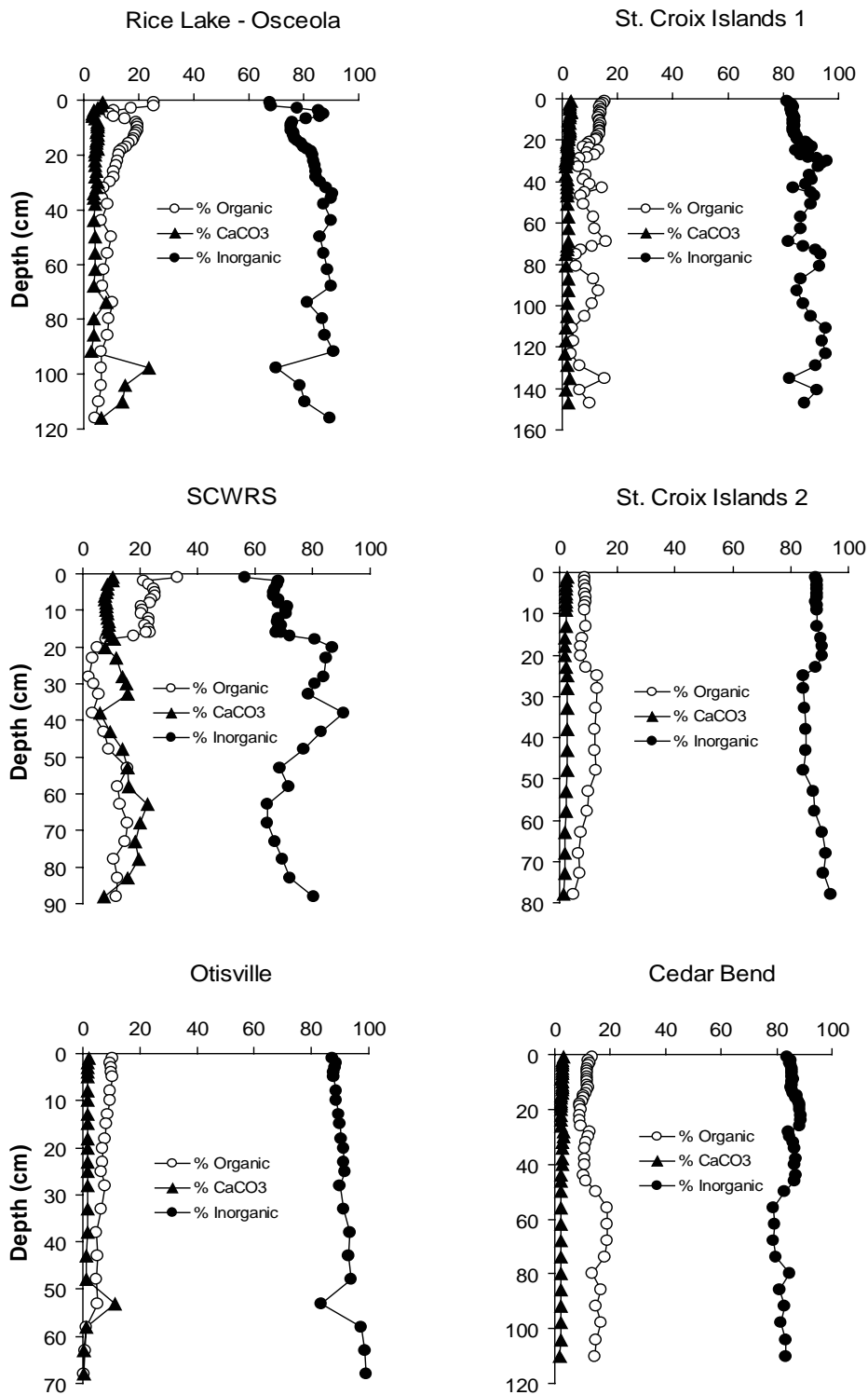
Figure 6. Percent concentration of organic,  $\text{CaCO}_3$ , and inorganic matter in each core.

Figure 7. Correspondence analysis (CA) of the diatom communities from 1740 to the present in the Cedar Bend core. Circles and lines have been drawn to illustrate the major changes through time.

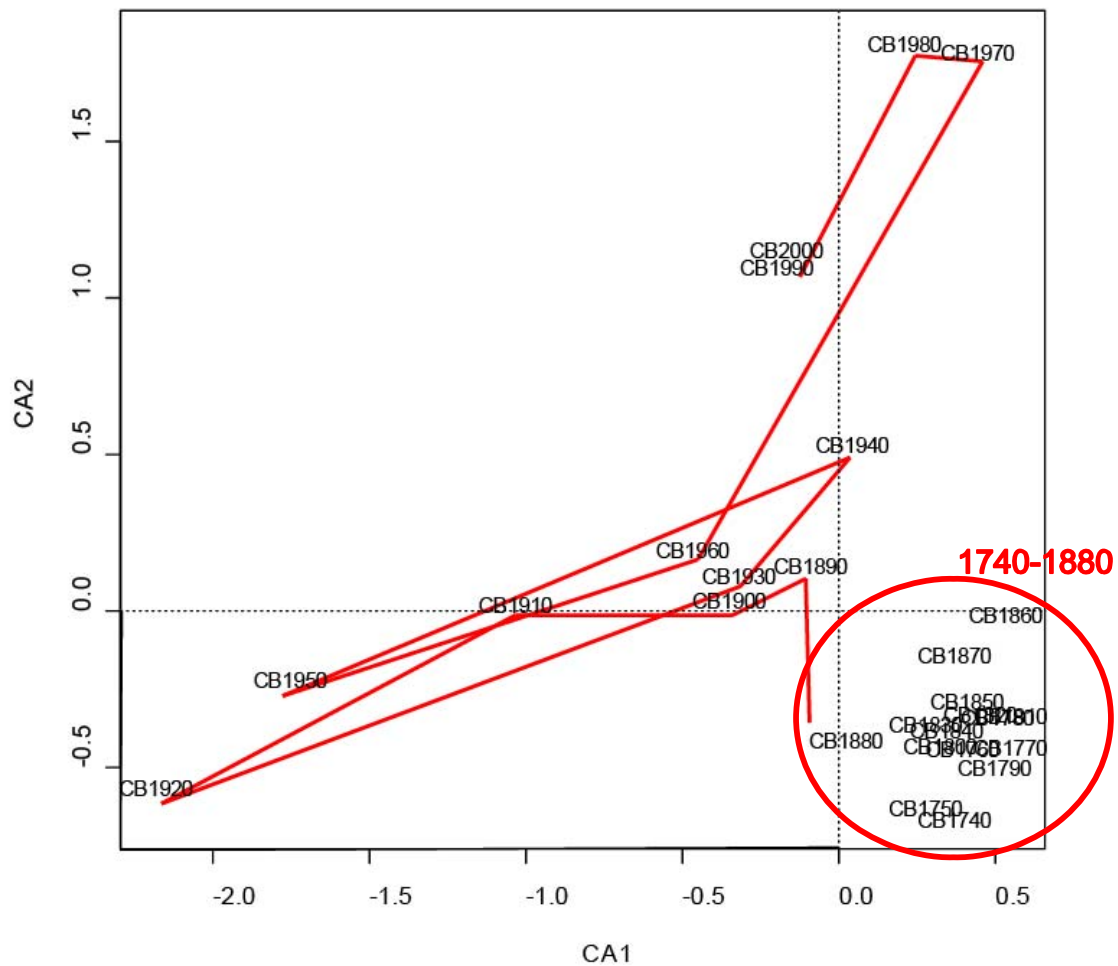


Figure 8. Stratigraphic diagram of all the diatom species which occur at 5% or greater abundance in the Cedar Bend core. Horizontal lines were drawn at the time intervals where major changes were seen in the CA (Figure 7).

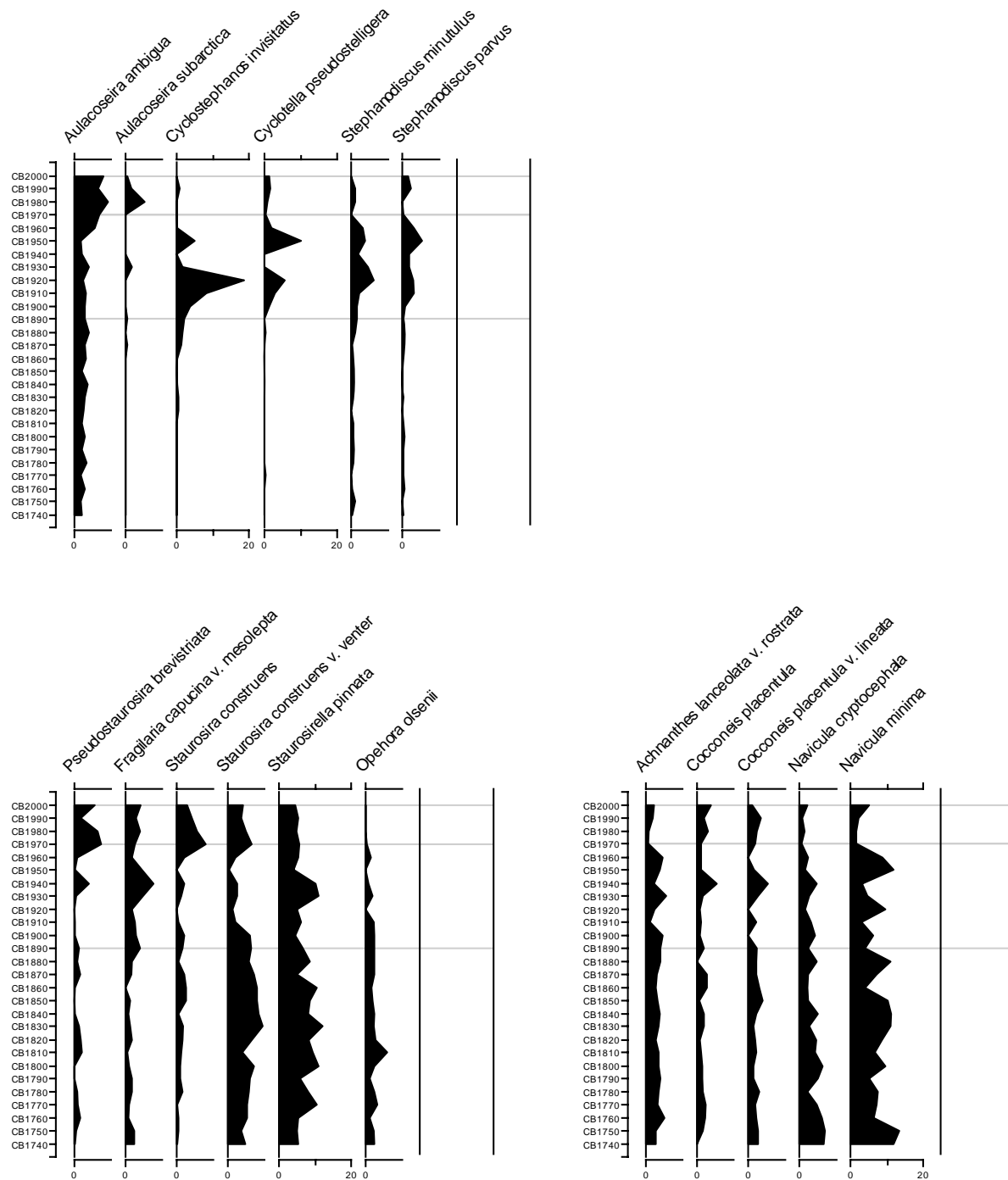


Figure 9. Correspondence analysis (CA) of the diatom communities from 1800 to the present in the Rice Lake-Osceola core. Circles and lines have been drawn to illustrate the major changes through time.

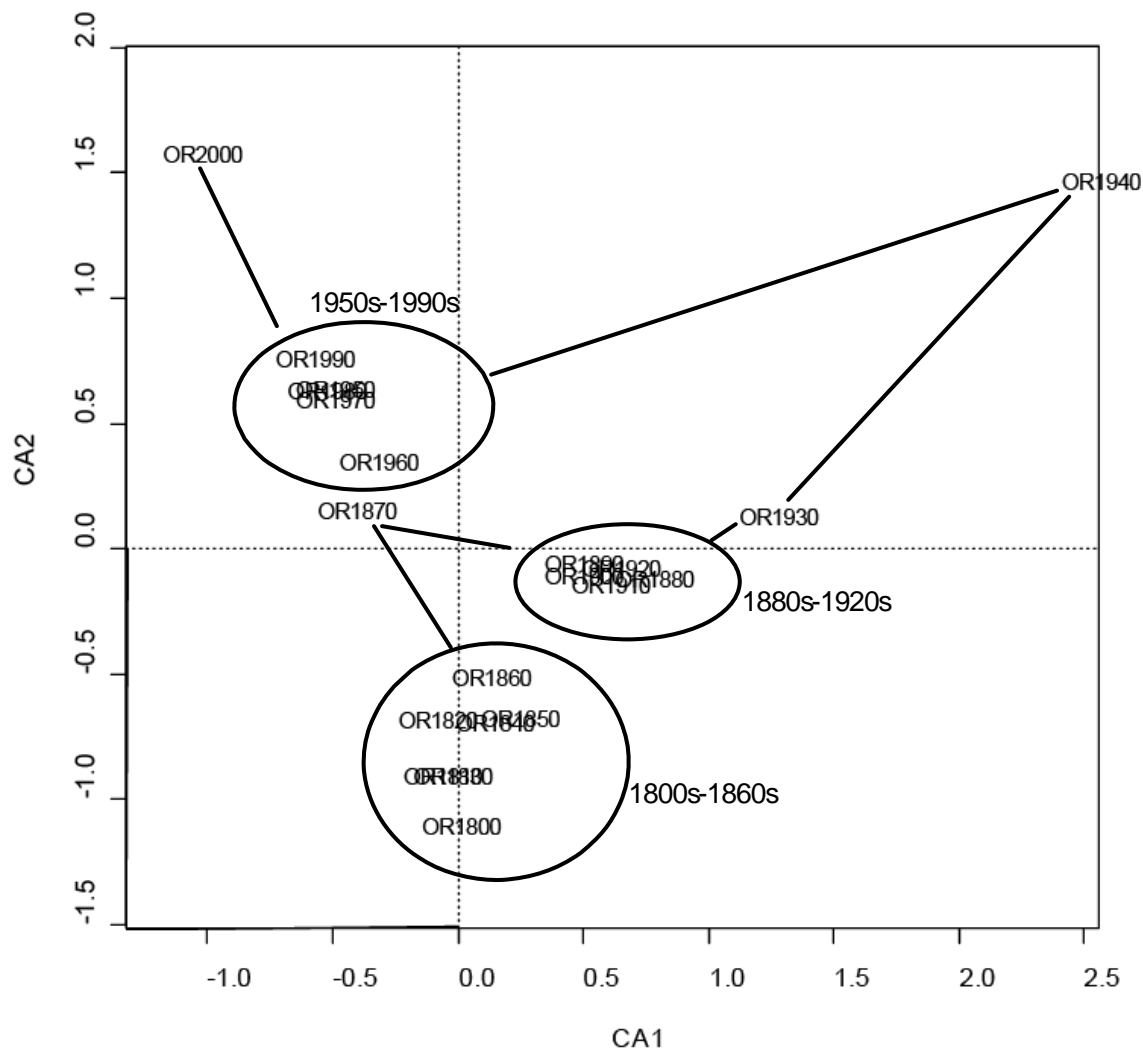


Figure 10. Stratigraphic diagram of all the diatom species which occur at 5% or greater abundance in the Rice Lake-Osceola core. Horizontal lines were drawn at the time intervals where major changes were seen in the CA (Figure 9).

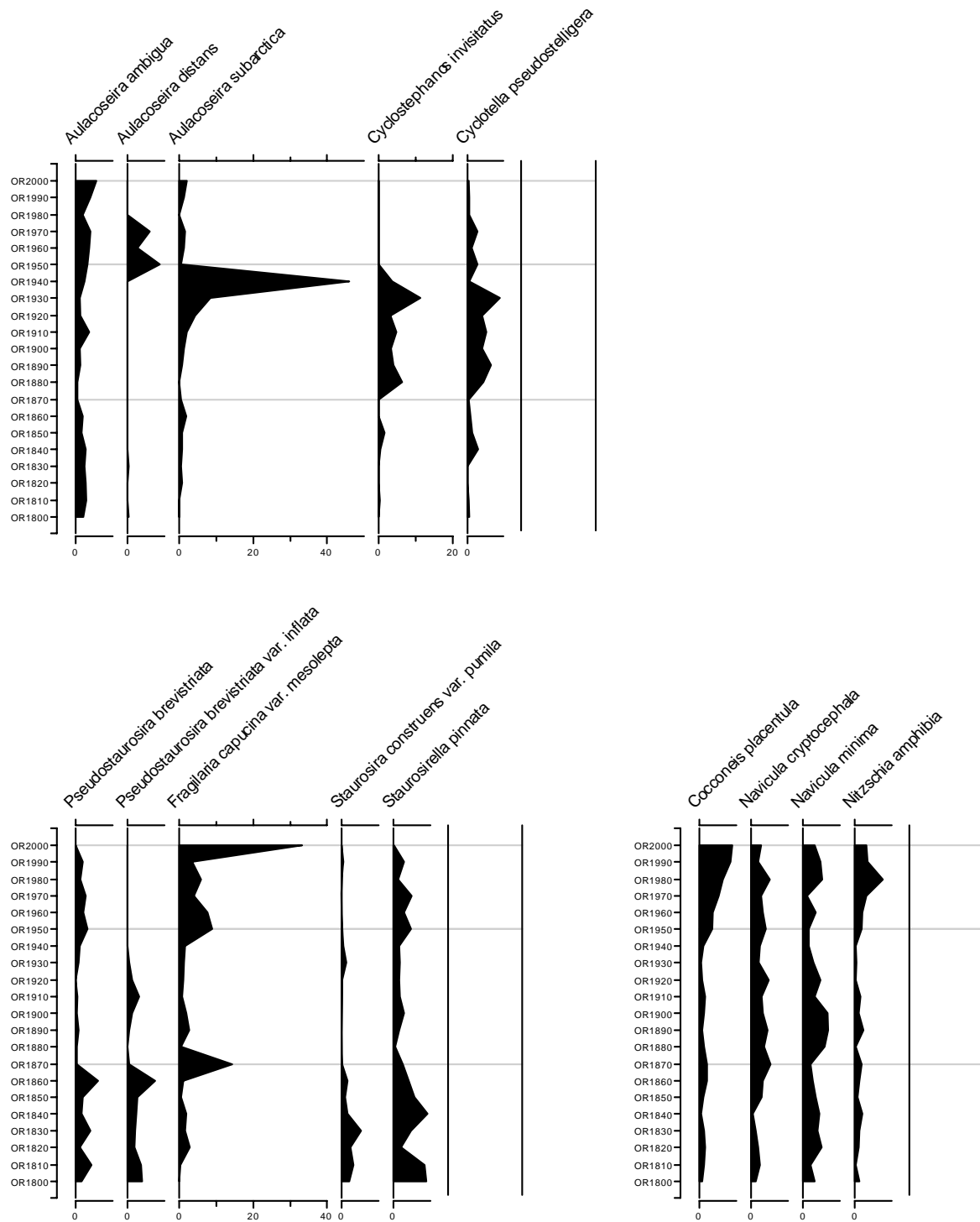


Figure 11. Principal components analysis (PCA) of the diatom communities from 1730 to the present in the St. Croix Islands 2 core.

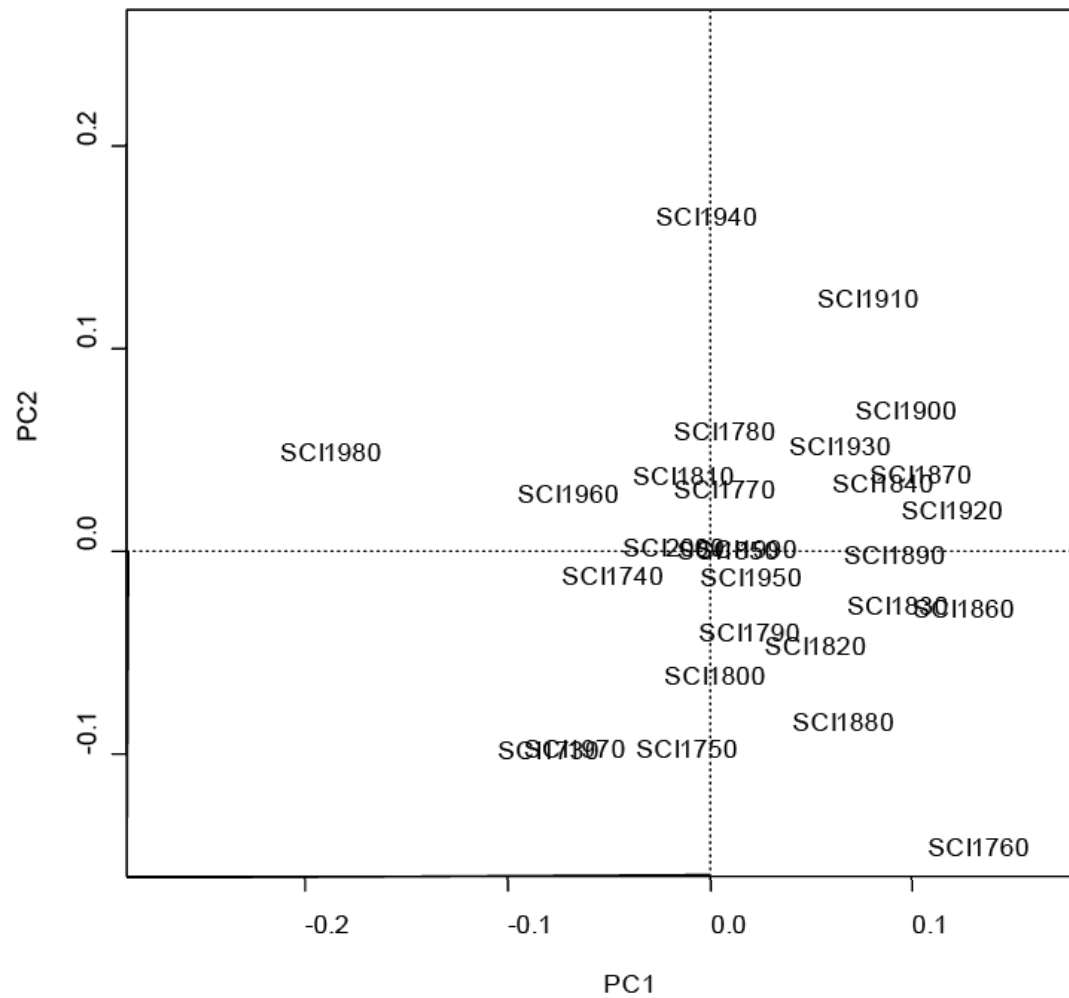


Figure 12. Stratigraphic diagram of all the diatom species which occur at 5% or greater abundance in the St. Croix Islands 2 core.

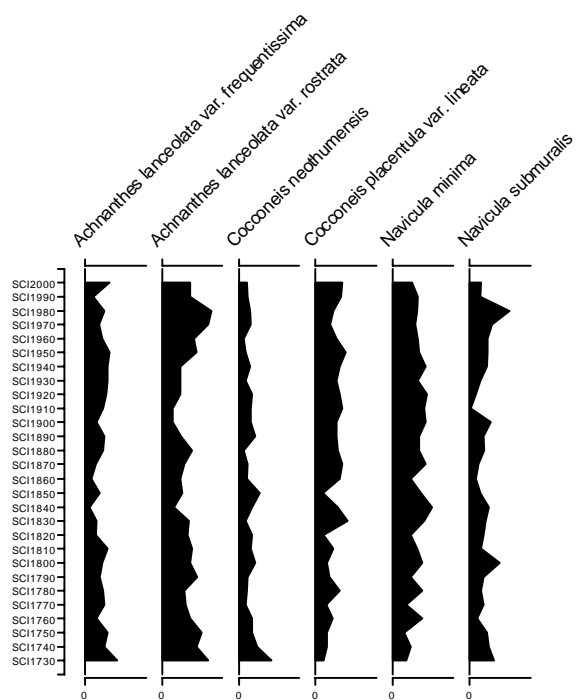
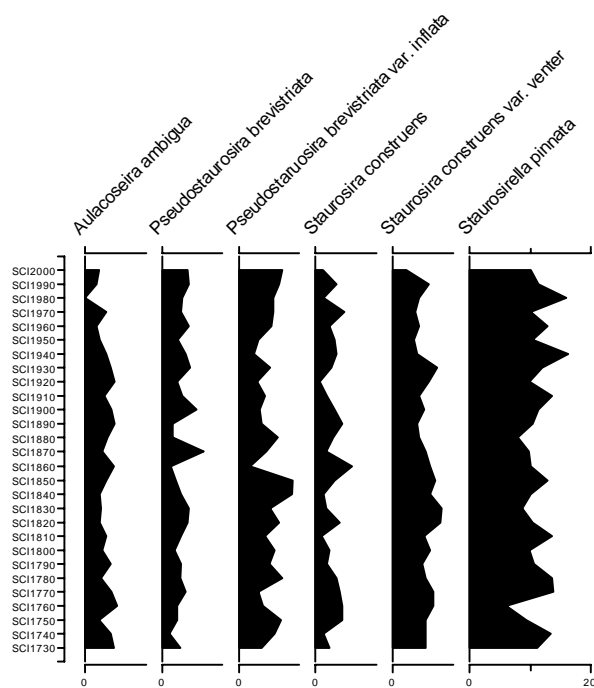


Figure 1 is a Canonical Correspondence Analysis (CCA) plot showing the relationship between environmental variables (CA1, CA2) and various plant communities. The plot includes labels for different plant communities such as OR2000, CB1970-2000, Rice 1950-2000, and others. A dashed ellipse highlights a cluster of communities, and arrows indicate the direction of environmental gradients.

Figure 14. Total phosphorus reconstruction for all three cores.

