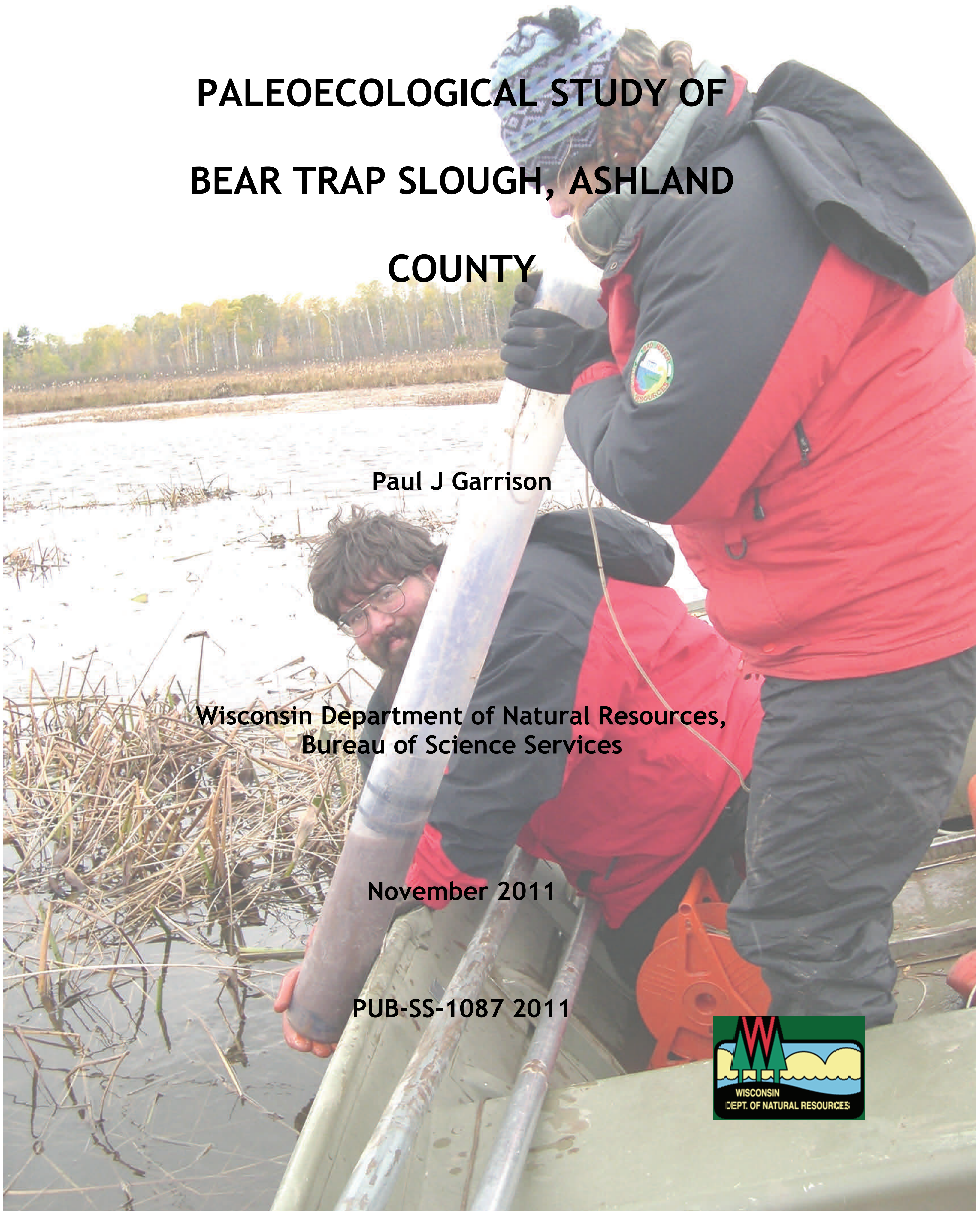

PALEOECOLOGICAL STUDY OF BEAR TRAP SLOUGH, ASHLAND COUNTY

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Bureau of Science Services

November 2011

PUB-SS-1087 2011

WISCONSIN
DEPT. OF NATURAL RESOURCES

Introduction

Questions often arise concerning how a lake's water quality has changed through time as a result of watershed disturbances. In most cases there is little or no reliable long-term data. People often wonder about how a lake has changed, when the changes occurred and what the lake was like before the transformations began. Paleoecology offers a way to address these issues. The paleoecological approach depends upon the fact that lakes act as partial sediment traps for particles that are created within the lake or delivered from the watershed. The sediments of the lake entomb a selection of fossil remains that are more or less resistant to bacterial decay or chemical dissolution. These remains include diatom frustules, cell walls of certain algal species, and subfossils from aquatic plants. The chemical composition of the sediments may indicate the composition of particles entering the lake as well as the past chemical environment of the lake itself. Using the fossil remains found in the sediment, one can reconstruct changes in the lake ecosystem over any period of time since the establishment of the lake.

Bear Trap Slough, is in the Kakagon Wetland complex on the Bad River Indian Reservation in Ashland County in northern Wisconsin. The sampling site was in Bear Trap Creek a site with low gradient flow. A sediment core was collected on 13 October 2006. The location of the coring site was 46° 37.322' north and -91° 37.754' west in 10 feet of water (Figure 1). The core was collected with a piston corer having an inside diameter of 8.8 cm. The core was sectioned into 1 cm intervals for the entire core of 24 cm. The core was analyzed for ^{210}Pb and ^{137}Cs in order to estimate dates and the sedimentation rate. The diatom community was analyzed to assess changes in nutrient levels and geochemical elements were examined to determine the causes of changes in the water quality.

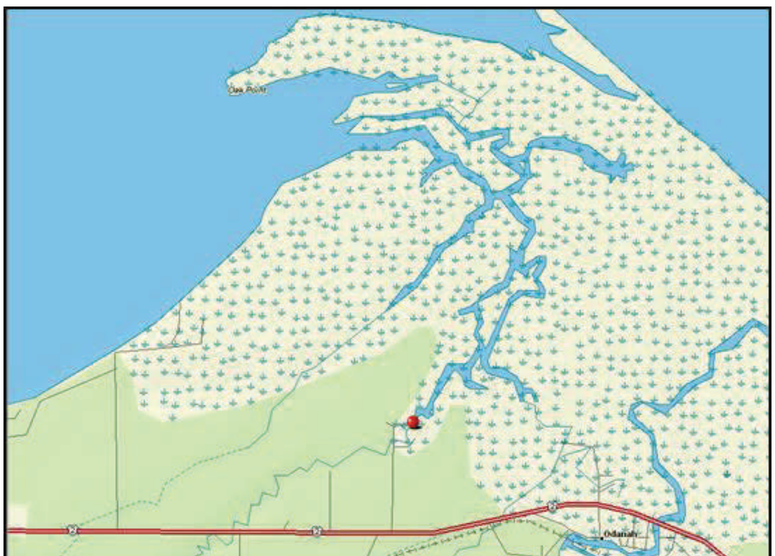

Figure 1. Map of the Kakagon wetland complex showing the Bear Trap Slough coring site.

Results and Discussion

Dating

The most commonly used method to estimate dates when the sediment was deposited and then determine the sedimentation rate is using a naturally occurring radionuclide of lead—^{210}Pb. Lead-210 is the result of natural decay of uranium-238 to radium-226 then radon-222. Since radon-222 is a gas (that is why it is sometimes found in high levels in basements) it moves into the atmosphere where it decays to lead-210. The ^{210}Pb is deposited on the lake during precipitation and with dust particles. After it enters the lake and is in the lake sediments, it slowly decays. The half-life of ^{210}Pb is 22.26 years (time it takes to lose one half of the concentration) which means that it can be detected for about 130-150 years. Once the amount of ^{210}Pb has been determined throughout the core, the resulting data is modeled either with the constant rate of supply (CRS) or the constant initial concentration (CIC) model. The latter model assumes that input of ^{210}Pb does not change over time. This may not be appropriate for sites like Bear Trap Slough where it is likely the sediment input has changed over time. The CRS is more appropriate at sites with changing sediment inputs (Appleby and Oldfield 1978). The CRS model appeared to provide reasonable dating estimates but this model can provide errors which are not readily apparent. Potential problems that could occur in sites like Bear Trap that are shallow include sediment resuspension induced be wind or motor boat activity. Another potential problem is deposition of older sediment from upstream sites during high flow events. For these reasons the accuracy of the ^{210}Pb dates is verified by other methods. These methods usually involve measuring parameters that are known to have been deposited at a certain time.

Cesium-137 (Cs^{137}) can be used to identify the period of maximum atmospheric nuclear testing (Krishnaswami and Lal 1978). The USA began atmospheric testing in 1954 and thus the first detectable amount of ^{137}Cs corresponds with this date. The peak testing occurred by the USSR in 1963 and thus the ^{137}Cs peak in the sediment core should represent a date of 1963.

In the Bear Trap core the radium and lead profiles (Figure 2a) indicate background conditions occurred at 15 cm. This means that sediment deposited below this depth is at least 130-150 years old. However, the cesium profile (Figure 2b) shows the presence of cesium below this depth. In fact the rise of cesium occurs at about 20 cm indicating this depth was deposited about 1954. The cesium peak is in the 13-14 cm slice which is much too close to the depth where background lead occurs to be realistic. This cesium data indicates that the lead modeling exercise may be flawed and therefore the date of sediment deposition could not be accurately determined. While it is uncertain whether the cesium or lead profile is the most accurate, I think the lead profile is more reliable. Cesium is known to be somewhat mobile in disturbed sediments and it is likely the dates indicated by the cesium (1963 at 13-14 cm and 1954 at 19-20 cm) are too deep in the core. For this report it is assumed that depths below 15 cm were deposited prior to the mid 1800s.

Because of the lead distribution in the core, i.e. uniform background concentrations below 15 cm and measurable concentrations over background above this depth, it is reasonable to assume the core can be used to determine changes in the water quality during the last century. It is not possible to provide a time frame when events occurred but it can be determined if changes have occurred.

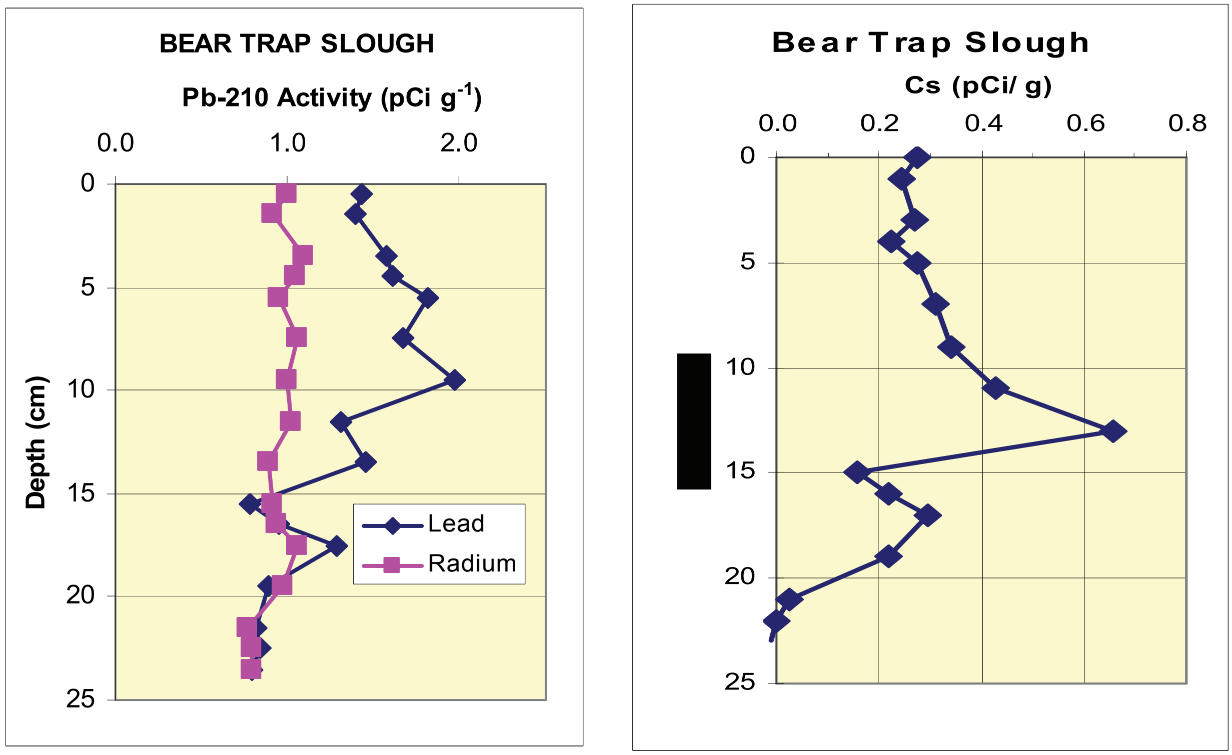

Figure 2. Profiles of lead-210, radium-226, and cesium-137 in the core. The lead and radium profiles indicate that sediment deeper than 15 cm was deposited more than 130-150 years ago. The initial rise in cesium at 19 cm should occur in the mid-1950s but this doesn't agree with the lead profile indicating the core can not be reliably dated.

Sediment Geochemistry

Geochemical variables are analyzed to estimate which watershed activities are having the greatest impact on the site (Table 1). The chemicals aluminum and titanium are surrogates of detrital aluminosilicate materials and thus changes in its profile is an indication of changes in soil erosion. Potassium is found in both soils and synthetic fertilizers. Therefore its profile will reflect changes both from soil erosion and the addition of commercial fertilizers in the watershed. Nutrients like phospho-

Table 1. Selected chemical indicators of watershed processes.

Process	**Chemical Variable**
Soil erosion	**aluminum, potassium,**
Synthetic fertilizer	**potassium**
Nutrients	**phosphorus, nitrogen**
Lake productivity	**organic matter, sulfur**

rus and nitrogen are important for plant growth, especially algae and aquatic plants. General lake productivity is reflected in the profiles of organic matter. The organic matter determination includes a number of elements, especially carbon.

The profile of loss on ignition, surrogate for organic matter, is shown in Figure 3. The concentration is lower than is often found in wetland or lake sediments and likely reflects the high input of red clay material from the watershed. There is a step increase in concentration just below 15 cm which is the depth that the lead-210 indicates is about the mid-1800s. It appears that the ecosystem's productivity had an increase at this time and for the last 150 years the productivity has steadily increased.

Unfortunately, organic matter is the only geochemical parameter that was analyzed to the bottom of the core. The other elements were not analyzed near the bottom of the core because when the samples were submitted to the laboratory it was thought that these depths were more than 200 years old and thus their composition was not important for the analysis of this core. The organic matter profile is again shown in Figure 4 for comparison with the other geochemical elements that are discussed. For all of these parameters, the bottom sample (16-17 cm) represents background conditions. None of the

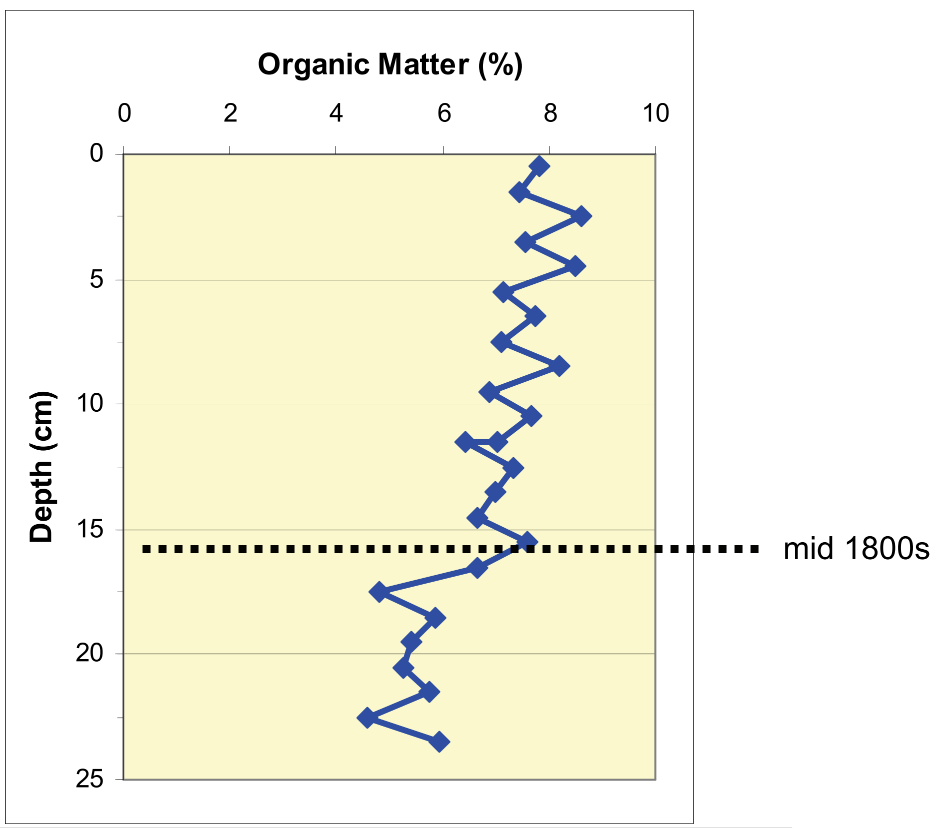

Figure 3. Profile of organic matter (loss on ignition) in the core. Beginning near the mid-1800s there was a step increase in organic matter and it slowly increased after that time.

profiles shown in Figure 4 increase at 15 cm like organic matter does indicating there was not a significant change in these elements. Aluminum, which represents sediment input, decline indicating there was likely a slug of organic matter which was delivered from the watershed. Perhaps this reflects a flood event or wetland drainage project. Between 12 and 6 cm aluminum was elevated (Figure 4)indicating increased soil erosion in the watershed. The decline in aluminum in the upper part of the core indicates a lessening of soil erosion rates. The sulfur profile is higher above 13 cm supporting the conclusion from the organic matter profile that productivity is higher now than compared with historical levels. Phosphorus concentrations appear to be related to soil erosion as this profile is similar to the aluminum profile (Figure 4). Nitrogen, in contrast, steadily increased above 12 cm indicating a continual increase in the delivery of nitrogen to the site for the last few decades. The elevated concentration of nitrogen and organic matter at the top of the core likely reflects the fact that post depositional diagenesis of organic matter and nitrogen was not complete when the core was collected. Diagenesis is the conversion of organic forms of a given element to its inorganic form

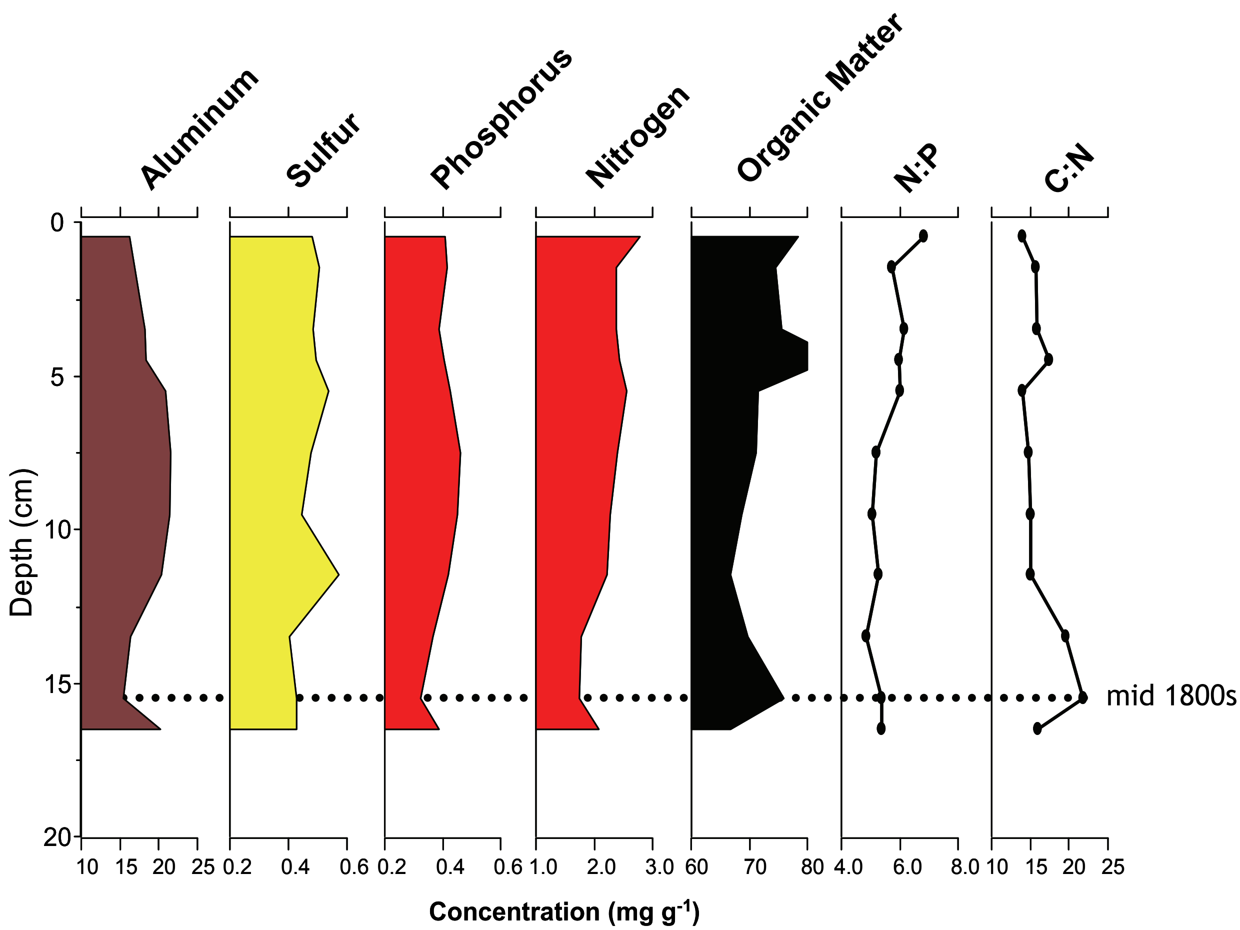

Figure 4. Profiles of the concentration of selected geochemical elements. Aluminum profile is indicative of soil erosional rates in the watershed. Nitrogen and phosphorus profiles reflect changes in nutrient deposition rates. Organic matter indicates the general productivity of the lake. Sulfur reflects production and decomposition in a way that often differs from the organic matter profile.

through bacterial action. This often happens with nitrogen, and carbon and is common in shallow lake systems and wetlands (Fitzpatrick et al. 2002, Garrison 2011b). The profiles of the ratio of nitrogen:phosphorus (N:P) and carbon:nitrogen (C:N) also reflect the increased input of nitrogen in relation to phosphorus and carbon (Figure 4). The ratio of C:N:P of 91:16:1 in the sediments reflects that the source of most of the material is aquatic vascular plants (Enríquez et al. 1993).

In summary the geochemical analyses indicates that soil erosion was highest in the mid core likely signifying a time period of a few decades ago. This trend of lesser soil erosion is been found in a number of Wisconsin lakes, including nearby Honest John Lake, reflecting improved soil conservation practices in the last few decades (Garrison 2006, Garrison 2011b). Since phosphorus concentrations are generally associated with the delivery of soil particles in this core, their concentrations have not increased in the upper part of the core. In contrast, nitrogen levels increase throughout the upper 10 cm of the core, indicating that this nutrient has been increasing in the last few decades.

Diatom Community

Aquatic organisms are good indicators of water chemistry because they are in direct contact with the water and are strongly affected by the chemical composition of their surroundings. Most indicator groups grow rapidly and are short lived so the community composition responds rapidly to changing environmental conditions. One of the most useful organisms for paleolimnological analysis is diatoms. They are a type of alga which possess siliceous cell walls and are usually abundant, diverse, and well preserved in sediments. They are especially useful as they are ecologically diverse and their ecological optima and tolerances can be quantified. Certain taxa are usually found under nutrient poor conditions while others are more common under elevated nutrient levels. They also live under a variety of habitats, which enables us to reconstruct changes in nutrient levels in the open water as well as changes in benthic environments such as aquatic plant communities. Figure 5 shows photographs of five diatom species that were found in the sediment core.

The diatom community consisted almost entirely of taxa that grow attached to substrates such as aquatic plants or directly on the sediments. This is not surprising as this site is very shallow and is essentially a low gradient stream in a wetland. Although there was not a large change in the community throughout the core there were subtle differences in the community below and above 15 cm. This depth is where the lead-210 analysis indicated a time period of the mid-1800s. Below 15 cm there were significant amounts of taxa that indicate lower nutrients, e.g. *Aulacoseira* spp., *Eolimna minima, Sellaphora seminulum*, *Pseudostaurosira brevistriata*, and *Tabellaria flocculosa* (Figure 6). The abundance of these taxa declined above 15 and they were replaced by taxa that prefer higher nutrient levels, e.g. *Cocconeis placentula*, *Fragilaria capucina* var. *capucina* and *Nitzschia* spp. (Figure 6).

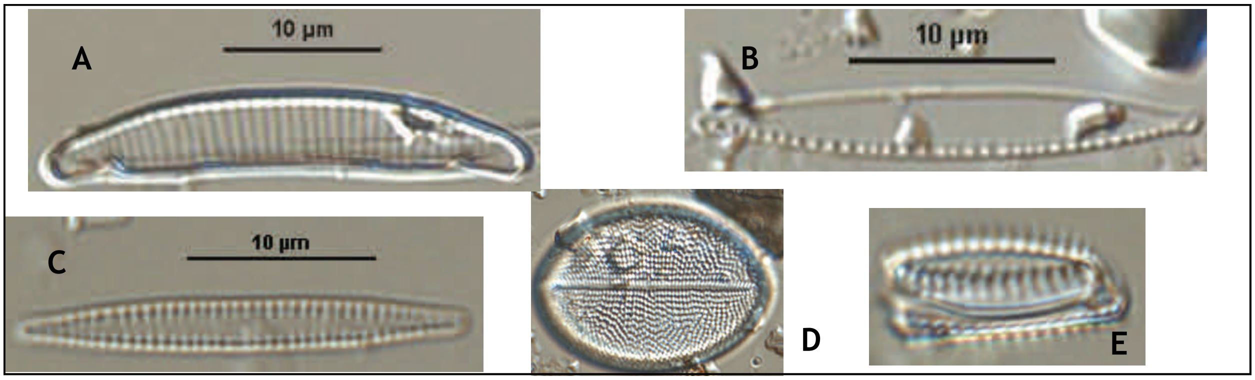

Figure 5. Photomicrographs of common diatoms found in the sediment core. The diatom at the top left (A) is *Eunotia incisa,* the diatom at the top right (B) is *Nitzschia palea var. debilis*. The diatom at the bottom left (C) is *Fragilaria capucina* var. *gracilis*. The diatom at the bottom center (D) is *Cocconeis placentula* and the diatom on the bottom right (E) is *Pseudostaurosira brevistrata,* All of these diatoms grow attached to substrates such as aquatic plants and on the sediment bottom.

Above 15 cm there is relatively little change in the diatom community indicating nutrient levels have been fairly stable. The geochemical analysis indicates a trend of increasing nitrogen concentrations during the last few decades, this is not reflected in the diatom community.

In previous studies of the Bad River Wetlands (e.g. Garrison 2011a) the diatom community was used to compute a trophic ranking for the wetlands. This Diatom Trophic Index (DTI) was developed by assigning individual diatom taxa to appropriate trophic status following van Dam et al. (1994). The DTI is computed by applying the numerical trophic classification to the abundance of a particular taxa and these are summed for the sample. Throughout the core the DTI was mesotrophic indicating little change in the nutrient levels during the time period represented by the sediment core.

Summary

The sediment core indicates that there have been few changes in the nutrient levels throughout the time period represented by the core. Unfortunately it was not possible to date the core because apparently the sediment had been disturbed. This may have been the result of high flow events or wind or motor boat induced waves. Although the radiochemical analysis failed it did indicate that the disturbance was not so great that inferences could not be made about water quality changes.

The only geochemical parameter that was analyzed throughout the core showed a step change at about 15 cm which was the depth where the lead-210 analysis indicated was the mid-1800s. None of the other elements showed this step increase at 15 cm. There was some indication that soil erosion rates were somewhat higher a few decades ago compared with the last decade or so. Nitrogen concentrations have steadily increased in the last few decades but not phosphorus.

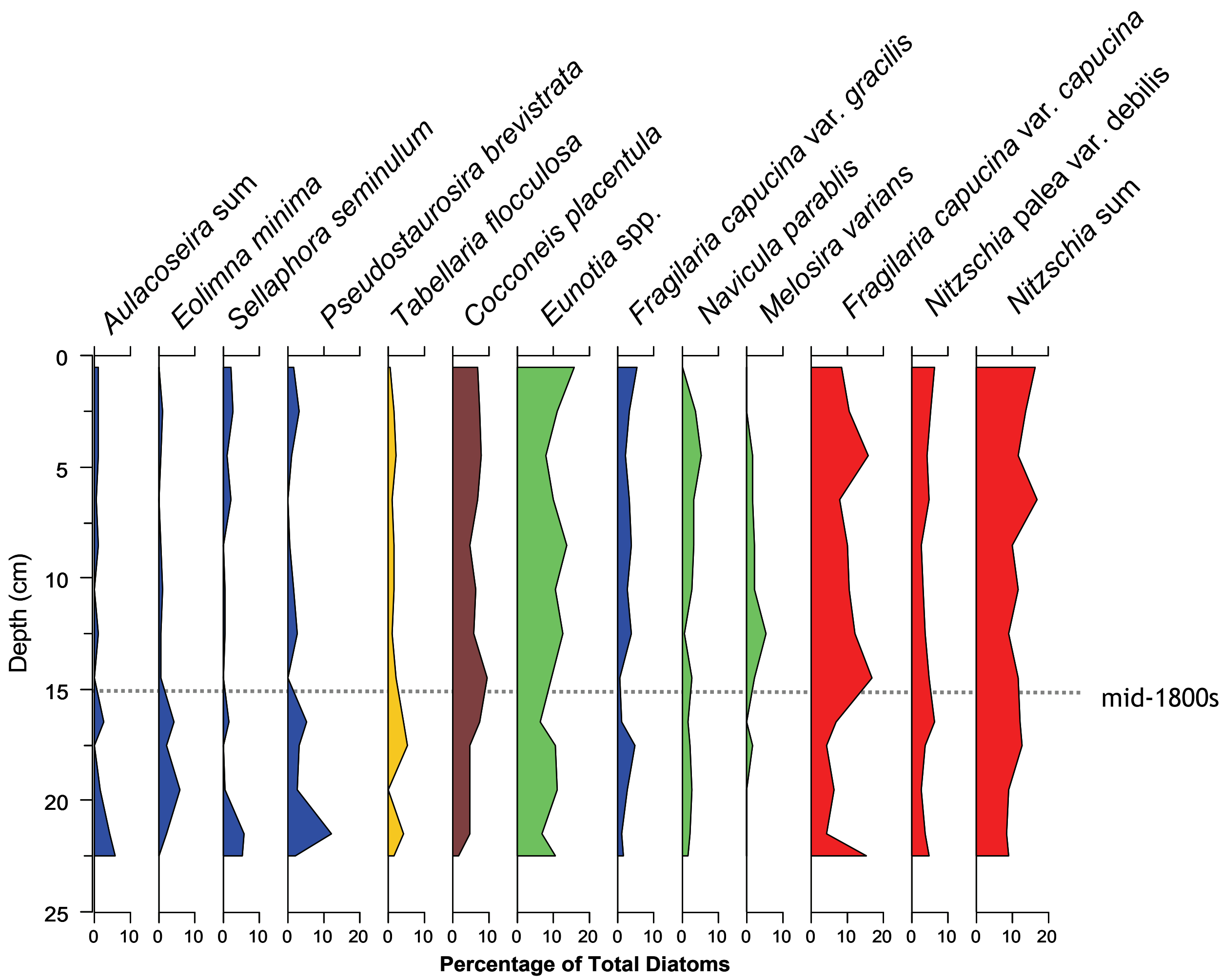

Figure 6. Profiles of common diatoms found in the core. The diatoms in blue are indicative of low nutrients while those in green are indicative of moderate nutrient levels. The red colored diatoms indicate higher nutrient levels.

The diatom community showed a subtle shift at 15 cm with those taxa that prefer lower nutrients being more common below 15. Generally the change in nutrient levels indicated by the diatom community above 15 cm was only a small amount. The Diatom Trophic Index indicated that this site was historically mesotrophic and this has not changed in the last century.

In contrast to the minimal changes in nutrient levels that are indicated in the Bear Trap Slough core, a core from nearby Honest John Lake clearly indicated increased phosphorus levels in the last few decades compared with the late ninetieth and early twentieth centuries (Garrison 2011b).

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Funding for this study was provided by Bad River Band of the Lake Superior Tribe of Chippewa Indians. Field work help was provided by Kirsten Cahow. Radiochemical analysis was provided by the Gary Krinke and Lynn West at the Wisconsin Laboratory of Hygiene. Geochemical analyses was provided by University of Wisconsin, Soil and Plant Analysis Laboratory.