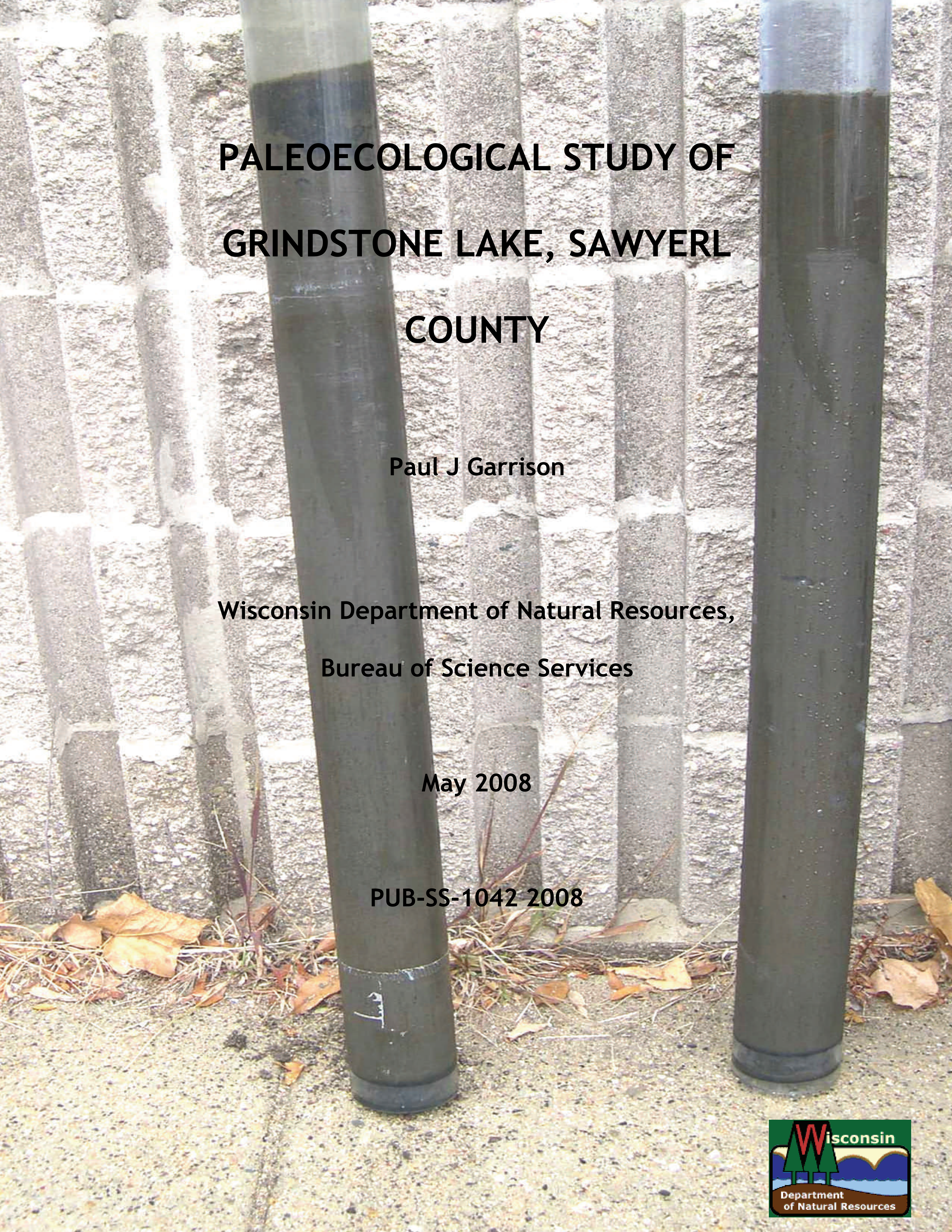

PALEOECOLOGICAL STUDY OF GRINDSTONE LAKE, SAWYERL COUNTY

Paul J Garrison

Wisconsin Department of Natural Resources,
Bureau of Science Services

May 2008

PUB-SS-1042 2008

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. Questions often asked are if the condition of the lake has changed, when did this occur, what were the causes, and what were the historical condition of the lake? 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.

Grindstone Lake is a 3111 acre lake located in Sawyer County. The maximum depth is 60 feet with a mean depth of 30 feet. Two sediment cores were collected from the deepest area of the lake on 8 July 2004. The cores were collected with a gravity core with a plastic tube having an inside diameter of 6.8 cm. The cores were sectioned into 1 cm intervals with the longest core being 48 cm. The core was dated by the ^{210}Pb method and the CRS model used to estimate dates and sedimentation rate. The diatom community was analyzed to assess changes in nutrient levels and changes in the macrophyte community and geochemical elements were examined to determine the causes of changes in the water quality and changes in oxygen conditions in the bottom waters.

Results and Discussion

Dating

In order to determine when the various sediment layers were deposited, the samples were analyzed for lead-210 (^{210}Pb). Lead-210 is a naturally occurring radionuclide. It is the result of natural decay of uranium-238 to radium-226 to radon-222. Since radon-222 is a gas (that is why is sometimes is 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 it 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 of ^{210}Pb) which means that it can be detected for about 130-150 years. This makes ^{210}Pb a good choice to determine the age of the sediment since European settlement began in the mid-1800s. Sediment age for the various depths of sediment were determined by constant rate of supply (CRS) model (Appleby and Oldfield, 1978). Bulk sediment accumulation rates (g cm^{-2} yr^{-1}) were calculated from output of the CRS model. Accumulation rates of geochemical vari-

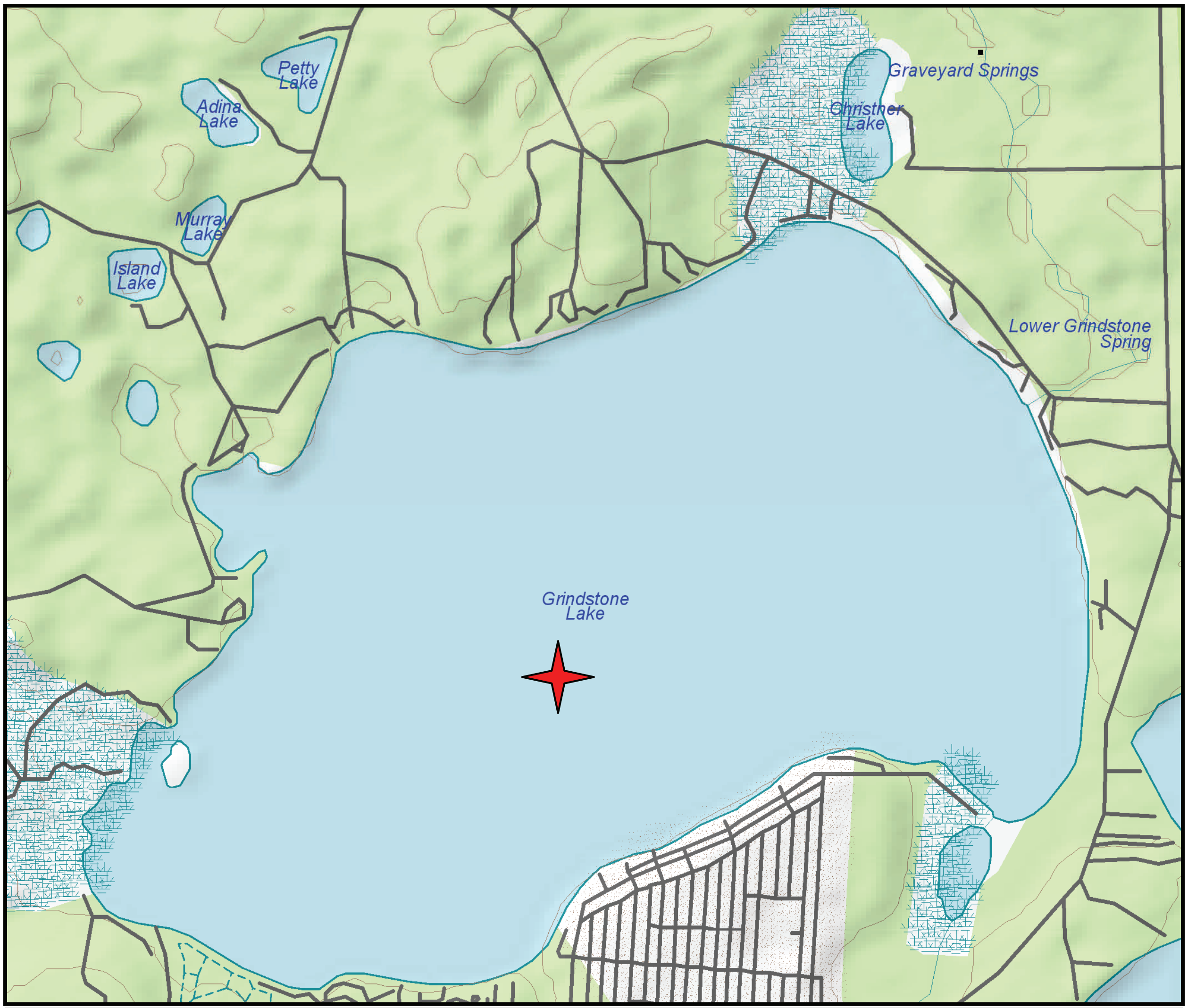

Figure 1. Map of Grindstone Lake showing the coring site. The water depth at the site was 55 feet.

ables were computed for each sediment depth by multiplying the bulk sediment accumulation rate (g cm^{-2} yr^{-1}) by the corresponding concentration (mg g^{-1}) of each constituent in the bulk sediment.

There can be problems with this dating technique. For example, when sediment has moved after it was deposited, large changes in sediment deposition over the last 150 years, and errors associated with lab analysis with sediments that are over 100 years old. 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 and comparing stratigraphic changes in the core in Whitefish Lake with other lakes in the region.

Cesium-137 (Cs^{137}) can be used to identify the period of maximum atmospheric nuclear testing (Krishnaswami and Lal, 1978). 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. The United States began testing in 1954 and thus the rise in ^{137}Cs corresponds with this date. Another element that can be used to verify the dating model is the profile of stable lead. Stable lead has an historical pattern of deposition that is very consistent among lakes, with lead concentrations increasing from around 1880 to the mid-1970s, and decreasing to the present. The decline of lead is largely the result of the discontinued use of bonded leaded gasoline in the mid-1970s (Gobeil et al. 1995; Callender and Van Metre 1997).

The CRS model of the peak for stable lead was placed at a depth that was too young. The peak for cesium-137 was not well defined (Figure 2) indicating that there has been some migration of the cesium after deposition. This does occasionally happen. The rise in the cesium-137 concentration was well defined. This should correspond with a date of 1954 but the CRS model placed this at a depth that was too old.

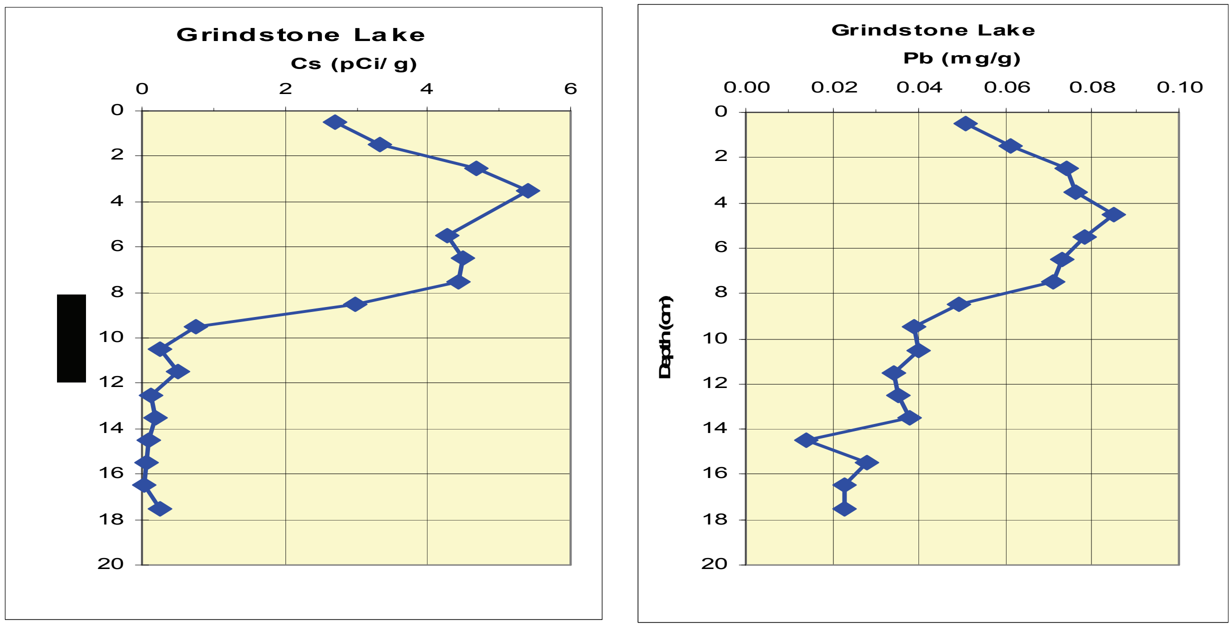

Figure 2. Profiles of ^{137}cesium and stable lead in the sediment core. The rise in the cesium corresponds to a date of 1954. The stable lead profile largely reflects the use of bonded leaded gasoline and the peak corresponds to a date of 1976.

Because if the problems with the CRS model, a piecewise CRS model was constructed by calculating the ^{210}Pb flux for independently dated intervals determined by other chronostratigraphic markers (Appleby 1998, 2001). Three independently dated intervals were used: (1) stable lead peak at 4-5 cm (1976), (2) rise in cesium-137 at 9-10 cm (1954), and (3) changes in the organic matter profile at 17-18 cm (1850).

Sedimentation Rate

The mean mass sedimentation rate for Grindstone Lake during the last 150 years was 0.007 cm^{-2} yr^{-1} (Figure 3). This is one of the lowest rates I have measured for 48 Wisconsin Lakes. This is below the median sedimentation rate of 0.027 cm^{-2} yr^{-1} of these same lakes. The average linear rate for the same time period was 0.12 cm yr^{-1} which equates to about 0.05 inch of sediment per year. Grindstone Lake has a lower rate than either Whitefish, Round, or Sand lakes although the sedimentation rate of all of these lakes is relatively low.

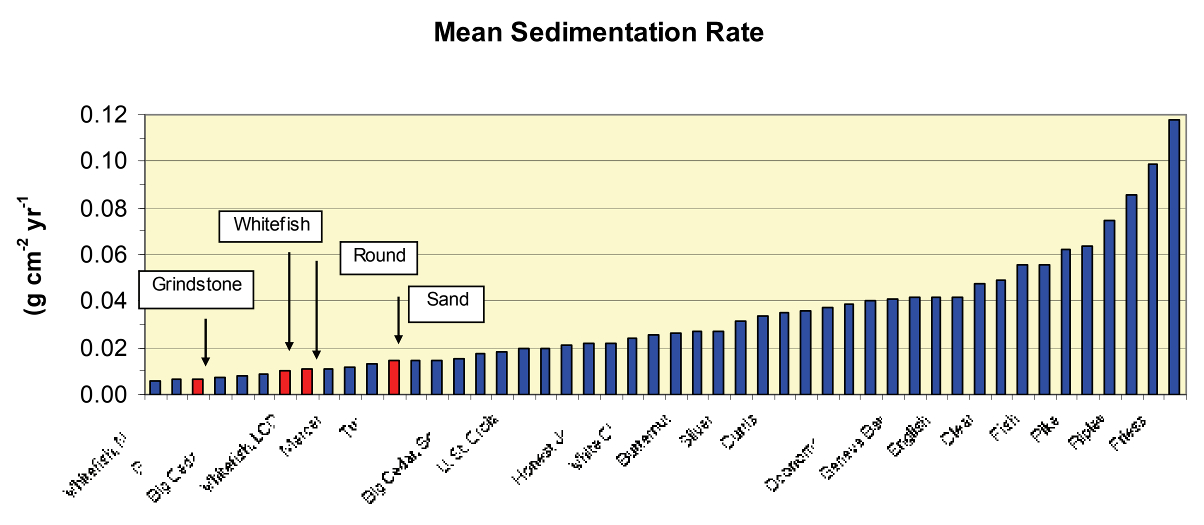

Figure 3. Mean sedimentation rate for the last 150 years for 48 Wisconsin lakes. The arrows indicate the Lac Courte Oreilles lakes.

To account for sediment compaction and to interpret patterns of sediment accumulation during the last 150 years, dry sediment accumulation rates were calculated. The background sedimentation rate was 0.006 cm^{-2} yr^{-1}. By the 1880s the rate was increasing to a subsurface peak of 0.010 cm^{-2} yr^{-1} during the mid-1940s. The rate steadily declined until around 1980 and then it increased to the top of the core where the rate was twice as high as the background rate (Figure 4). It appears that watershed activities have impacted the sedimentation rate over two time periods. The increase during the last 2 decades indicate that current activities around the lake are adversely impacting the lake.

Sediment Geochemistry

Geochemical variables are analyzed to estimate which watershed activities are having the greatest impact on the lake (Table 1). The chemical titanium (Ti) is found in soil particles, especially clays. Changes in Al are an indication of changes in soil erosional rates throughout the lake's history. Nutrients like phosphorus and nitrogen are important for plant growth, especially algae and aquatic plants.

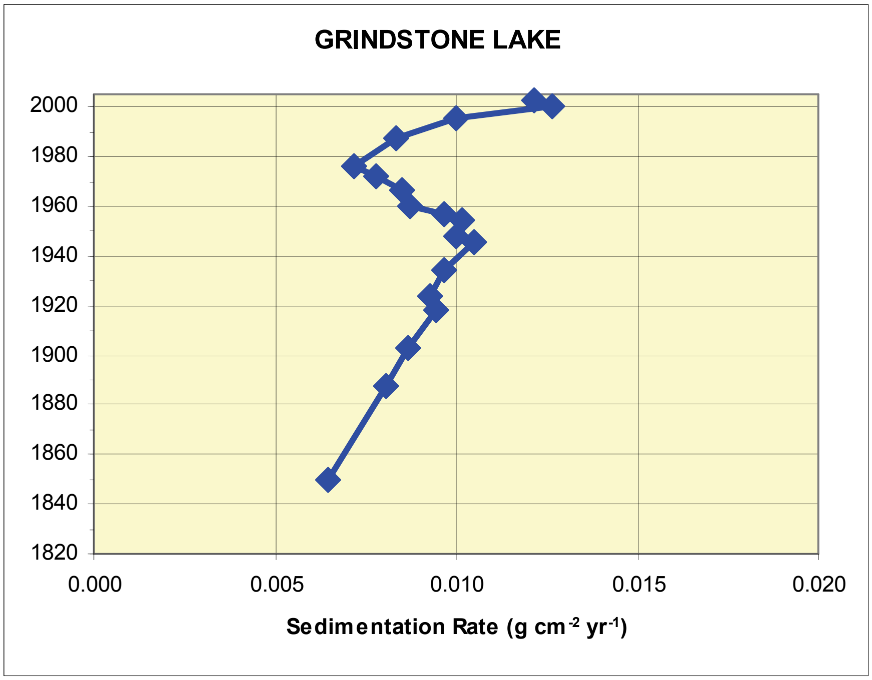

Figure 4. Sediment accumulation rate for Grindstone Lake since 1850. Apparently there have been two periods of significant watershed activies that have affected the sedimentation rate (1930-50s and 1980-2000). The increase in the rate the last two decades indicates that recent activities are adversely impacting the lake.

Calcium is an indication of the use of soil amendments for lawns. Manganese is an indication of changes in oxygen levels in the bottom waters.

Table 1. Selected chemical indicators of watershed or in lake processes.

Process	**Chemical Variable**
Soil amendment	calcium
Soil erosion	aluminum, titanium
Urban	zinc, copper
Anoxia	manganese
Nutrients	phosphorus, nitrogen

The accumulation rate of the selected geochemical variables was largely unchanged throughout the nineteenth century (Figure 5). After a brief increase around the turn of the century, there was a significant decline around 1915 for most of the parameters. Only organic matter increases at that time. It is likely there was an episodic event in the watershed which resulted in the delivery of a slug of material. It is likely this was not inorganic material or there would have been increases in titanium and calcium. Instead, the increased sediment may have been from flushing of a wetland since organic matter increased. It is interesting that the decline in most of the parameters was not reflected in a decline in the bulk sedimentation rate (Figure 4).

After 1920 there was an increase in the deposition rate of titanium which indicates increased soil erosion in the watershed (Figure 5). This soil erosion rate remained elevated and peaked around 1955. After that the rate declined through the 1980s. Since 1990, the rate has again increased.

The calcium profile is similar to the titanium profile which reflects that a good portion of the calcium being deposited in the lake comes from soils in the watershed. Unlike titanium, the rate is highest at the top of the core which likely indicates an additional source of calcium. This may be evidence that calcium is being used as a soil amendment on lawns along the lake shore.

The profile of both of the nutrients, phosphorus and nitrogen, change only a small amount throughout the core until near the top. The highest deposition rates occur at the top of the core. It is likely that part of this increase at the top is because recycling of these nutrients is not complete. It is not un-

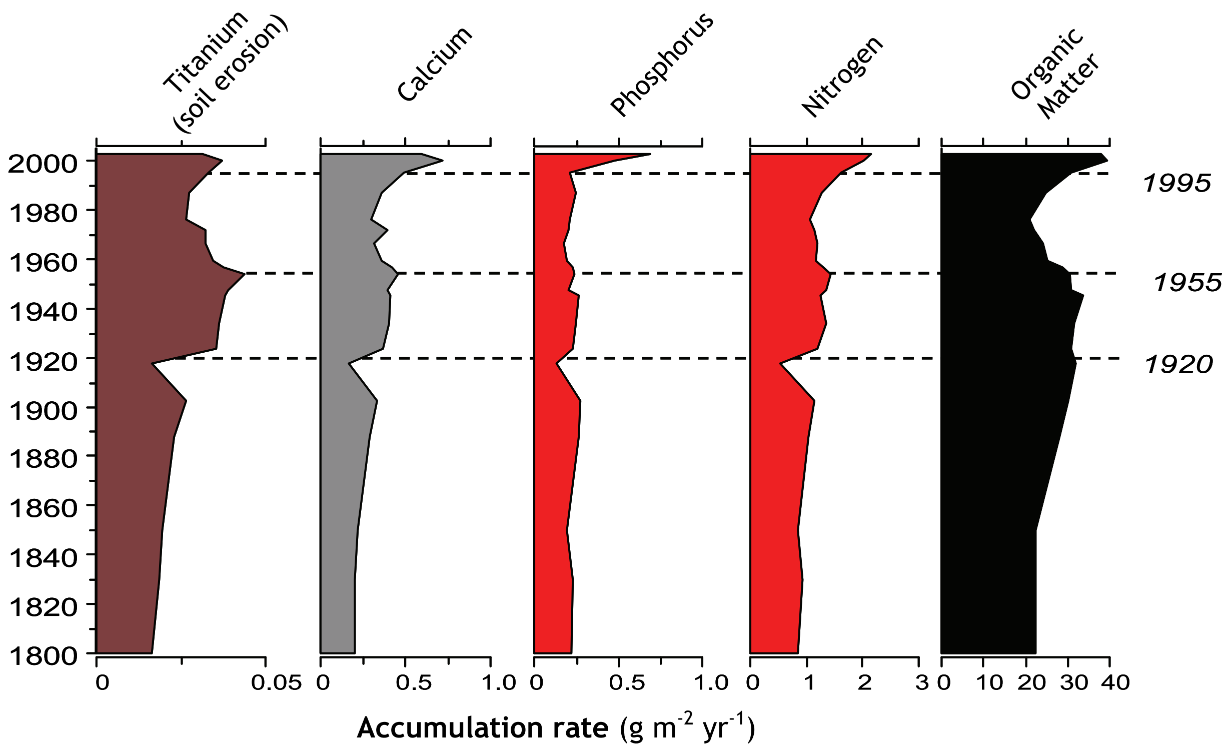

Figure 5. Profiles of selected geochemical elements. In part, the increased deposition of P, N, and organic matter reflects ongoing recycling.

common for the organic component of phosphorus and nitrogen to partially breakdown into inorganic components after deposition in the sediments. Some of these elements then may be recycled into the water column or leave the lake entirely. This was demonstrated in Musky Bay in nearby Lac Courte Oreilles (Fitzpatrick et al. 2003). It is also possible that some of this increase may reflect increased deposition of these nutrients.

The organic matter profile shows an earlier increase in deposition than other parameters (Figure 5). Deposition is higher during the first part of the twentieth century and then declines from the period 1955 through 1980. In the last two decades there has been a significant increase in organic matter deposition. Part of the increase probably reflects ongoing recycling as with nutrients.

In order to better understand changes in deposition of geochemical elements in the core some elements are compared using ratios. For example, to understand the importance of different sources of calcium, the ratio of titanium to calcium (Ca:Ti) is used to separate sources of calcium such as soil particles and the use of calcium as a soil amendment. Since both calcium and titanium are delivered to the lake in the form of soil particles, their deposition rates should be similar when soils are the only source of calcium. Any increase in the ratio of Ca:Ti indicates a source of calcium other than soild particles. After 1995, the ratio increases (Figure 6) which likely indicates that calcium is being applied as a soil amendment in the form of lime.

As the bottom waters become increasing devoid of oxygen, manganese (Mn) is mobilized from the sediments. This manganese then moves into the deepest waters resulting in enrichment of manganese in the sediments of the deeper waters. While this also occurs with iron, it happens sooner with manganese as manganese tends to stay in solution longer (Jones and Bowser 1978). Therefore as the bottom waters loose oxygen, manganese is preferentially moved with respect to iron (Engstrom et al. 1985). The result is that with the loss of oxygen, the ratio of iron to manganese (Fe:Mn) declines (Mn increases). Figure 6 shows the profile of Fe:Mn in the core. The ratio increases after 1950 as a result of the increase in soil erosion. Iron, and to a lesser extent manganese, are found in soils so their concentrations increase with higher soil erosion rates. Since 1995, the ratio has declined. This indicates that during the last 10 years, the bottom waters are beginning to lose oxygen. The decline in hypolimnetic oxygen is a classic sign of increased eutrophication of a lake. Although oxygen is present in the bottom waters of the lake throughout the year, the sediment core indicates that there is a loss of oxygen very near the sediment water interface for at least part of the year. This loss has only been occurring during the last decade and is an indication an increase in the lake's productivity.

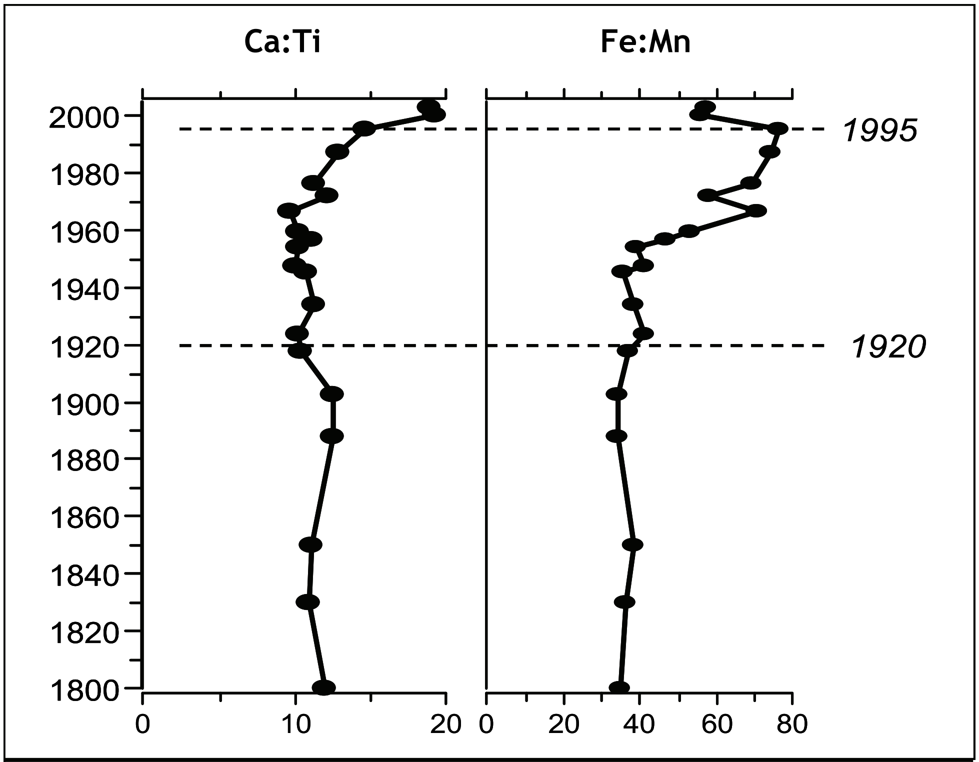

Figure 6. Profiles of Ca:Ti and Fe:Mn. The increase in Ca:Ti at the top of the core indicates an additional source of calcium other than soild particles, e.g. lime. The increase in Fe:Mn from 1955 to 1995 is from soil erosion but the decline during the last 10 years indicates the loss of oxygen in the bottom waters of the lake.

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 7 shows photographs of four diatom species that were found in the sediment core.

Changes in the diatom community in the core were relatively small until the very top of the core. The dominant diatom until the mid-1990s was the planktonic diatom *Aulacoseira ambigua* (Figure 7). This

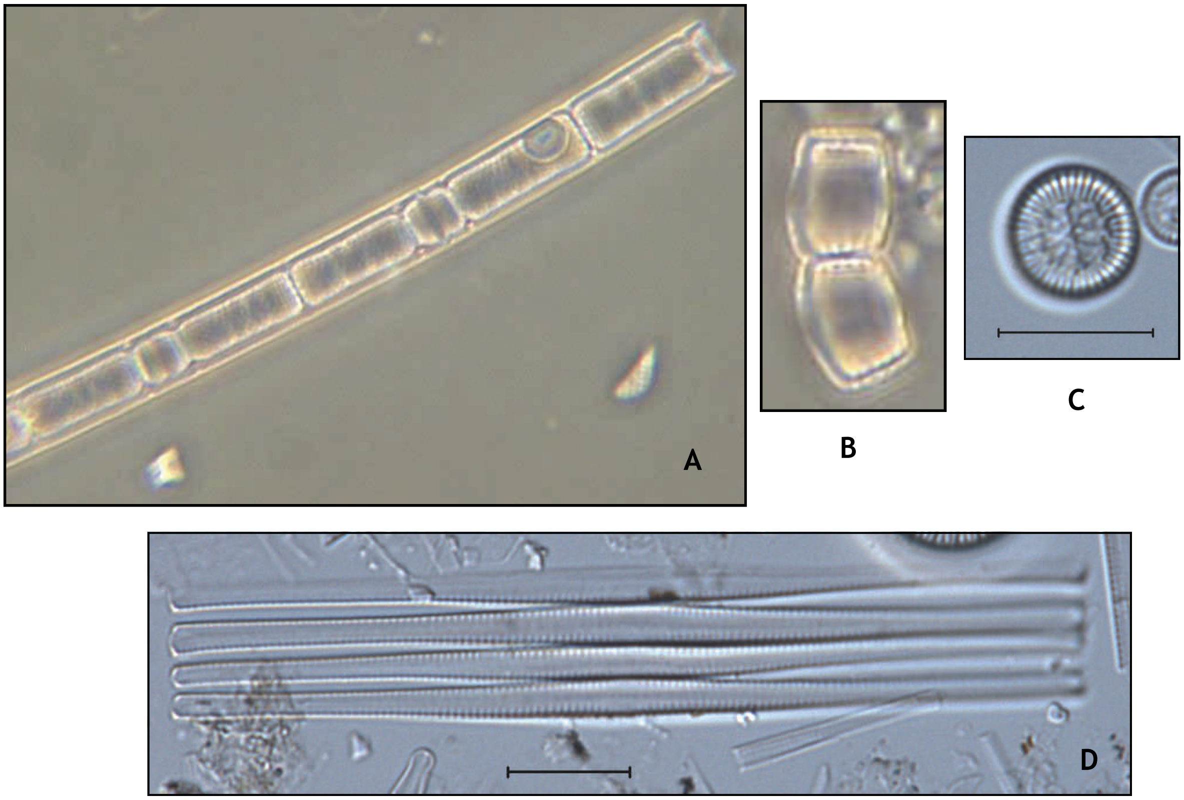

Figure 7. Photomicrographs of diatoms found in the sediment core. The diatom on the top left (A) *Aulacoseira ambigua* typically is found in open water environments while the picture to the right (B) is *Staurosirella pinnata* which is commonly found attached to substrates such as downed trees and aquatic plants in lakes. The diatom in at the extreme right (C) is *Cyclotella comensis* which is thought to be an invasive from northern Europe. The diatom at the bottom (D), *Fragilaria crotonensis* is also found in the open water and indicates higher nutrient levels than *A. ambigua*.

is a common diatom in lakes in the Upper Midwest that possess low nutrients (Camburn and Kingston 1986; Kingston et al. 1990, Garrison 2005 a,b; Garrison 2006). Other planktonic diatoms were present in lesser amounts throughout the core. After 1930 there was a small increase in the diatoms *Fragilaria crotonensis* and *Tabellaria flocculosa* IIIp. These diatoms typically indicate slightly higher nutrient levels. Their increase signals a very small increase in phosphorus after 1930. After 1995 there was a significant decline in *A. ambigua* and an increase in other planktonic diatoms e.g. *T. flocculosa* IIIp, *Cyclotella michiganiana*, and *Fragilaria capucina*. These taxa are usually found in somewhat higher nutrient levels than *A. ambigua*.

One diatom of note is *Cyclotella comensis* which was found near the top of the core. This diatom is thought to be an invasive from northern Europe (Stoermer et al. 1985, 1990, 1993). It is thought to have arrived during the 1950s via Great Lakes shipping. *C. comensis* seems to indicate slightly elevated phosphorus levels (Schelske et al. 1972; Wolin and Stoermer 2005). Although present in recent

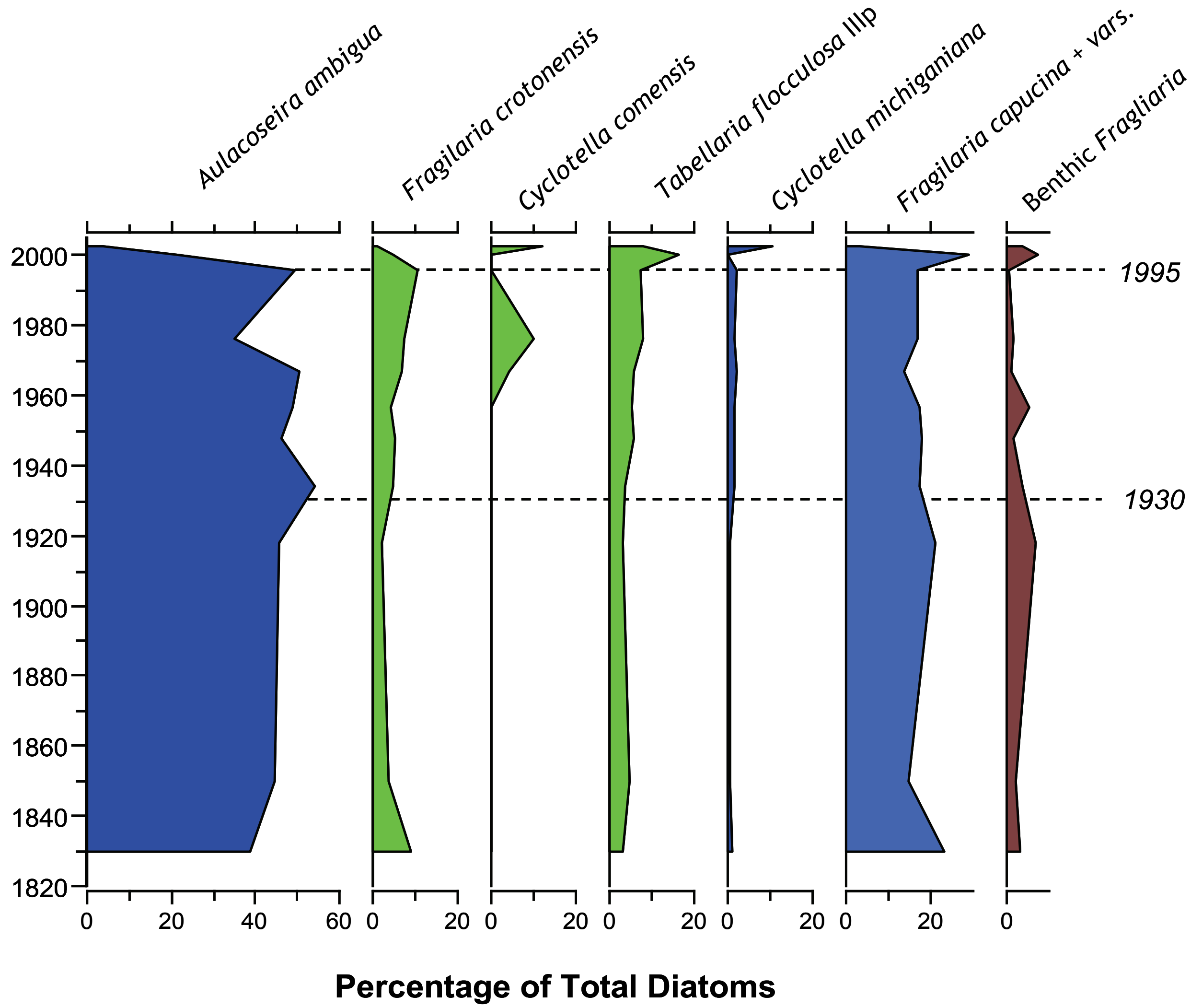

Figure 8. Profiles of common diatoms found in the core. The taxa in blue are indicative of low nutrient levels while the taxa in green indicate slightly higher nutrient levels.

years, the numbers are relatively low reflecting the low nutrient status of Grindstone Lake.

Diatoms in the group benthic *Fragilaria* were a small portion of the diatom community. These diatoms typically grow attached to aquatic plants (macrophytes). Increases in these taxa indicate the increased presence of aquatic plants. Cores from other lakes in northern Wisconsin have shown that one of the most common impacts of shoreline development has been an increase in macrophyte growth (Fitzpatrick et al. 2003; Garrison 2005a, b; Garrison 2006). It appears that the watershed activity that resulted in an increase in soil erosion (titanium in Figure 5) caused an increase in the plant community. Unlike other nearby lakes, the plants declined during the period 1960-1995. Since 1995 there has been an increase in these diatoms which indicates there may be an increase in the benthic plant community in recent years.

The water quality of Grindstone Lake during the last 150 years has not changed nearly as much as many other Wisconsin lakes. In fact, the water quality of the lake changed little until recent years. The lake possesses one of the lowest mean sedimentation rates of 46 lakes in WI where the rate has been measured. Sedimentation rate first peaked around 1940 but the highest rate occurred at the top of the core. Soil erosion rates were somewhat elevated during the period from the 1930-1950s but at the top of the core they are not higher than during this earlier period.

The diatom community was largely unchanged until the mid-1990s. Prior to this time the diatom community was more stable than most other lakes I have cored. In the last few years, the change in the diatom community signals that phosphorus levels are starting to increase.

It is important to note that although the lake has been quite stable throughout most of the last 150 years, since the mid-1990s the lake ecosystem is showing significant changes. The sedimentation rate at the top of the core was the highest and the diatom community showed the greatest change. The diatoms indicate that phosphorus levels are starting to increase. This increased productivity is resulting in a reduction in the oxygen levels in the deepest waters. It appears that the source of these nutrients may be from shoreline development. This partially indicated by the rise in calcium at the top of the core. Calcium is often used as a soil amendment for urban lawns.

- The mean sedimentation rate for the last 150 years in Grindstone Lake was one of the lowest measured in Wisconsin lakes.

- The sedimentation rate first peaked in the 1940s but then declined until the late 1970s. Since that time it has steadily increased so that at the top of the core the lake is experiencing its highest rate in the last 150 years.

- Titanium, which is indicative of soil erosion, was highest during the period 1925-1955. Even though the sedimentation rate at the top of the core was the highest this is not completely the result of soil erosion.

- It appears that the elevated sedimentation rate at the top of the core is the result of anthropogenic activities around the lake; probably from shoreline development. This is indicated but higher deposition rates of calcium, phosphorus, nitrogen, and organic matter.

- The higher calcium is probably indicative of it use as a soil amendment in lawns near the lakeshore.

- Although the elevated levels of nutrients and organic matter at the top of the core is partly the result of incomplete recycling of these elements, it is also the result of increased nutrient runoff.

- The evidence of this increase in nutrients since the mid-1990s is the change in the diatom community. Prior to this time the community was remarkably unchanged in the previous 150 years. Since about 1995 there has been a decline is diatoms found under low phosphorus levels and an increase in species that are indicative of higher phosphorus levels.

- The increase in nutrient levels at this time is small but trend is towards higher levels. This increased productivity is already adversely impacting the lake as oxygen levels in the bottom waters are declining. The loss of oxygen in the deep waters is one of the earliest signs of eutrophication.

References

Appleby P.G. 1998. Dating recent sediments by ^{210}Pb: Problems and solutions. Proc. 2nd MKS/EKO-1 Seminar. Helsinki. 2-3 April 1997. STUK. Helsinki: 7-24.

Appleby P.G. 2001. Chronostratigraphic techniques in recent sediments. In: Last, W.M. and Smol, J.P. (eds.), Tracking Environmental Change Using Lake Sediments. Volume 1: Basin Analysis, Coring, and Chronological Techniques. Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 171-203.

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

Bradbury, J.P., 1975. Diatom stratigraphy and human settlement in Minnesota. Geol. Soc. America Spec. Paper. 171:1-74.

Callender E. and P.C. Van Metre. 1997. Reservoir sediment cores show U.S. lead declines: Environ. Sci. and Tech. 31:424-428.

Camburn K.E. and Kingston J.C. 1986. The genus *Melosira* from soft-water lakes with special reference to northern Michigan, Wisconsin and Minnesota. In: Smol, J.P., Battarbee, R.W., Davis, R.B. and Meriläinen, J. (eds), Diatoms and Lake Acidity. Dr. W. Junk.Publishers, Dordrecht, The Netherlands. pp. 17-34.

Engstrom, D.R., E.B. Swain, and J.C. Kingston, 1985. A paleolimnological record of human disturbance from Harvey's Lake, Vermont: geochemistry, pigments, and diatoms. Freshwat. Biol. 15:261-288.

Fitzpatrick F.A., P.J. Garrison, S.A. Fitzgerald, and J.F. Elder. 2003. Nutrient, trace-element, and ecological history of Musky Bay, Lac Courte Oreilles, Wisconsin, as inferred from sediment cores. U.S. Geological Survey Water-Resources Investigation Report 02-4225. 141 pp.

Garrison, P.J. 2005a. Paleoecological Study of Round Lake, Sawyer County. Wisconsin Department of Natural Resources. PUB-SS-1011 2005

Garrison, P.J. 2005b. Assessment of water quality in Lake Owen, Bayfield County, Wisconsin by the use of fossil diatoms. Wisconsin Department of Natural Resources. PUB-SS-1014 2005.

Garrison, P.J. 2006. Paleoecological Study of Butternut Lake, Price/Ashland Counties. Wisconsin Department of Natural Resources. PUB-SS-1020 2006.

Gobeil C., W.K. Johnson, R.W. MacDonald, and C.S. Wong. 1995. Sources and burdens of lead in the St. Lawrence estuary sediments—isotopic evidence: Environ. Sci. and Tech. 29:193-201.

Jones, B.F. and C.J. Bowser. 1978. The mineralogy and related chemistry of lake sediments. In Lerman, A. (ed.), Lakes:Chemistry, Geology, Physics. Springer, New York. 179-235.

Kingston J.C., Cook R.B., Kreis R.G. Jr., Camburn K.E., Norton S.A., Sweets P.R., Binford M.W., Mitchell M.J., Schindler S.C., Shane L.C.K. and King G.A. 1990. Paleoecological investigation of recent lake acidification in the northern Great Lakes states. J. Paleolim. 4:153-201.

Krishnaswami, S. and D. Lal. 1978. Radionuclide limnochronology. In: Lerman, A. (ed.), Lakes: Chemistry, Geology, Physics. Springer-Verlag, NY: 153-177.

Schelske, C.L., L.E. Feldt, M.A. Santiago, and E.F. Stoermer. 1972. Nutrient enrichment and its effect on phytoplankton production and species composition in Lake Superior. In: Proceedings 15th Conference of Great Lakes research. Int. Assoc. Great Lakes Res., Ann Arbor, MI, pp. 149-163.

Stoermer, E.F., J.A. Wolin, and C.L. Schelske. 1993. Paleolimnological comparison of the Laurentian Great Lakes based on diatoms. Limnol. Oceanogr. 38:1131-1316.

Stoermer, E.F., J.A. Wolin, C.L. Schelske, and D.C. Conley. 1985. An assessment of changes during the recent history of Lake Ontario based on siliceous microfossils preserved in the sediments. J. Phycol. 21:257-276.

Stoermer, E.F., J.A. Wolin, C.L. Schelske, and D.C. Conley. 1990. Siliceous microfossil succession in Lake Michigan. Limnol. Oceanogr. 35:959-967.

Wolin, J.A. and E.F. Stoermer. 2005. Response of a Lake Michgan coastal lake to anthropogenic catchment disturbance. J. Paleolimnol. 33:73-94.

Funding for this study was provided by Lac Courte Oreilles Indian Tribe and Wisconsin Department of Natural Resources. Field help was provided by Dan Tyrolt. Radiochemical analysis was provided by the Lynn West at the Wisconsin Laboratory of Hygiene. Geochemical analyses was provided by University of Wisconsin, Soil Testing Laboratory.