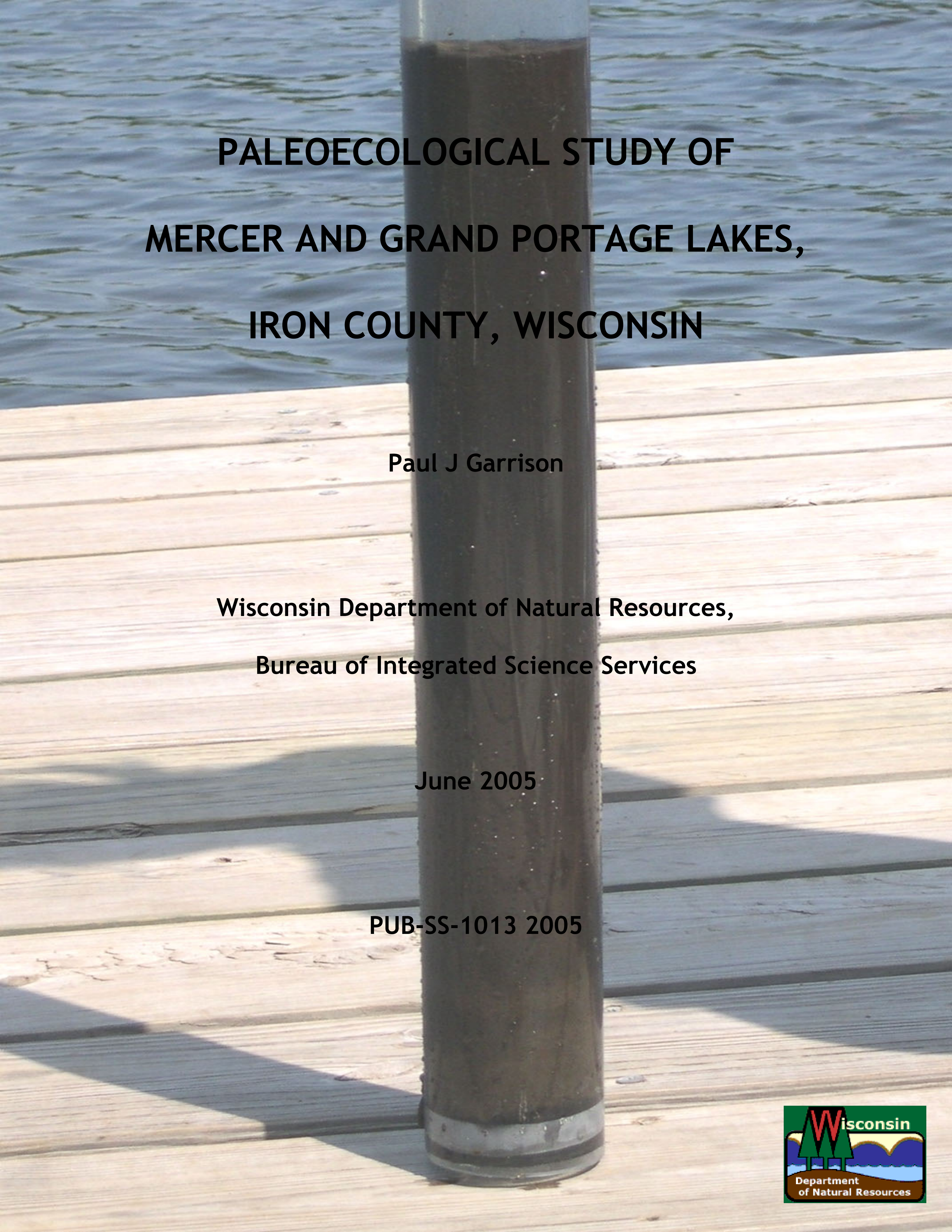

PALEOECOLOGICAL STUDY OF MERCER AND GRAND PORTAGE LAKES, IRON COUNTY, WISCONSIN

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June 2005

PUB-SS-1013 2005

Wisconsin Department 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. 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.

A sediment core was collected from the deep area of Mercer Lake on 9 July 2003 in 20 feet of water. On this same day a core was also collected from in the northern basin of Grand Portage (Tank) Lake in 32 feet of water. The location of the Mercer Lake core was 46° 09.762' North, 90° 04.166' West and the location of the Grand Portage core 46° 10.502' North, 90° 02.654' West (Figure 1). These cores were collected with a piston core and sectioned into 2 cm intervals. The core from Mercer Lake was 88 cm (2.9 ft) long and the core from Grand Portage Lake was 50 cm (1.6 ft) in length. The water quality history of Mercer Lake was the main core of interest for this study in order to estimate the input of nutrients from the town of Mercer including the discharge from the sewage treatment plant. Grand Portage Lake is being examined to separate the impact of the sewage treatment plant from shoreland development. Both lakes have shoreland development but only the downstream lake, Mercer, received input from the sewage treatment plant.

The cores were 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.

The original land survey for this area occurred in 1865. The original notes indicate that the land cover in the area around Mercer was forest, dominated by conifers. As shown in Figure 2,

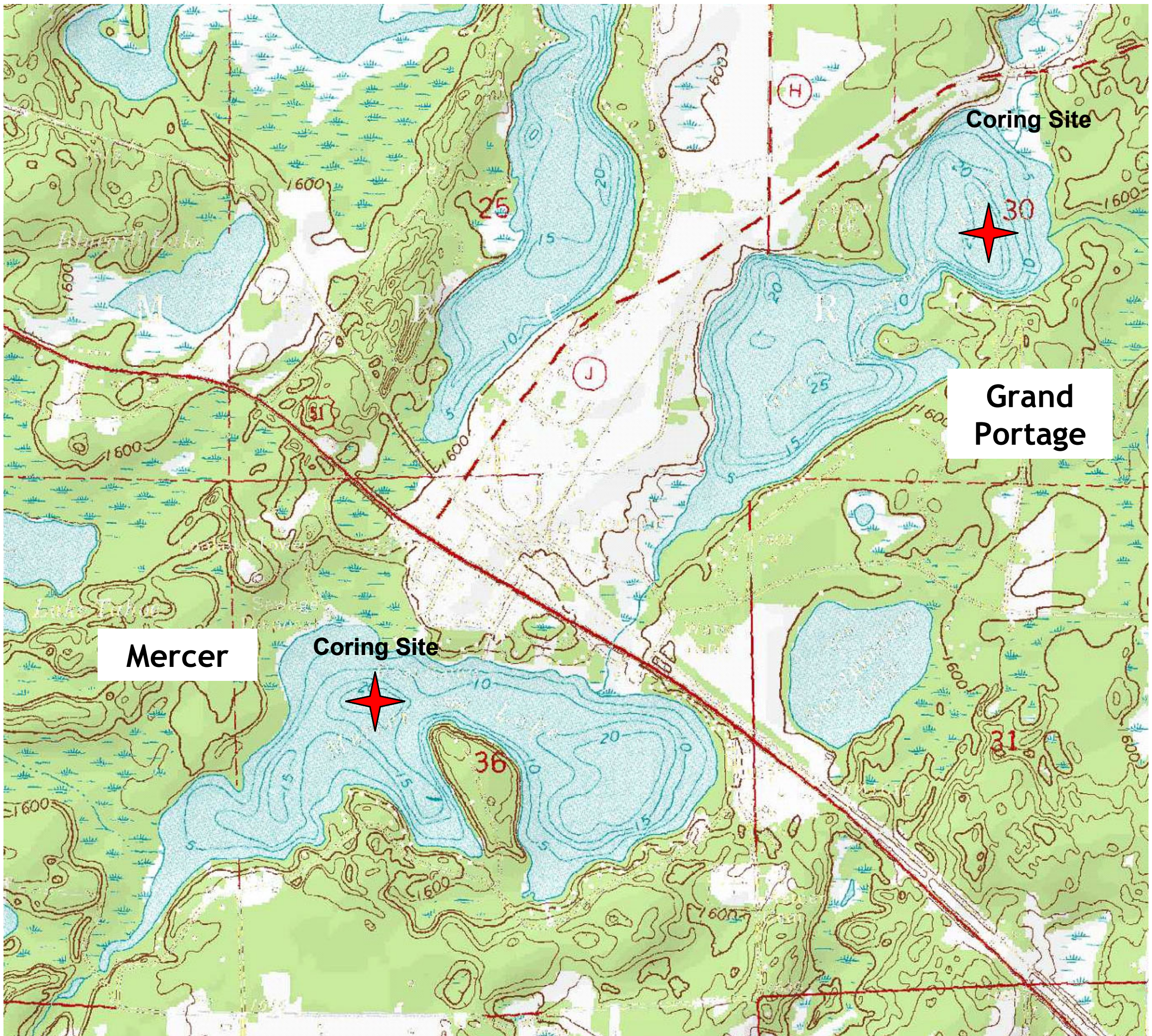


Figure 1. Coring sites in Mercer and Grand Portage lakes. The cores were collected 9 July 2003.

the land around both of the lakes had already been platted. The town of Mercer was established in 1889 with the arrival of the railroad. Logging was the main economic activity in the area with a sawmill being established on the shores of Mercer Lake. The last sawmill closed in 1945.

Results

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

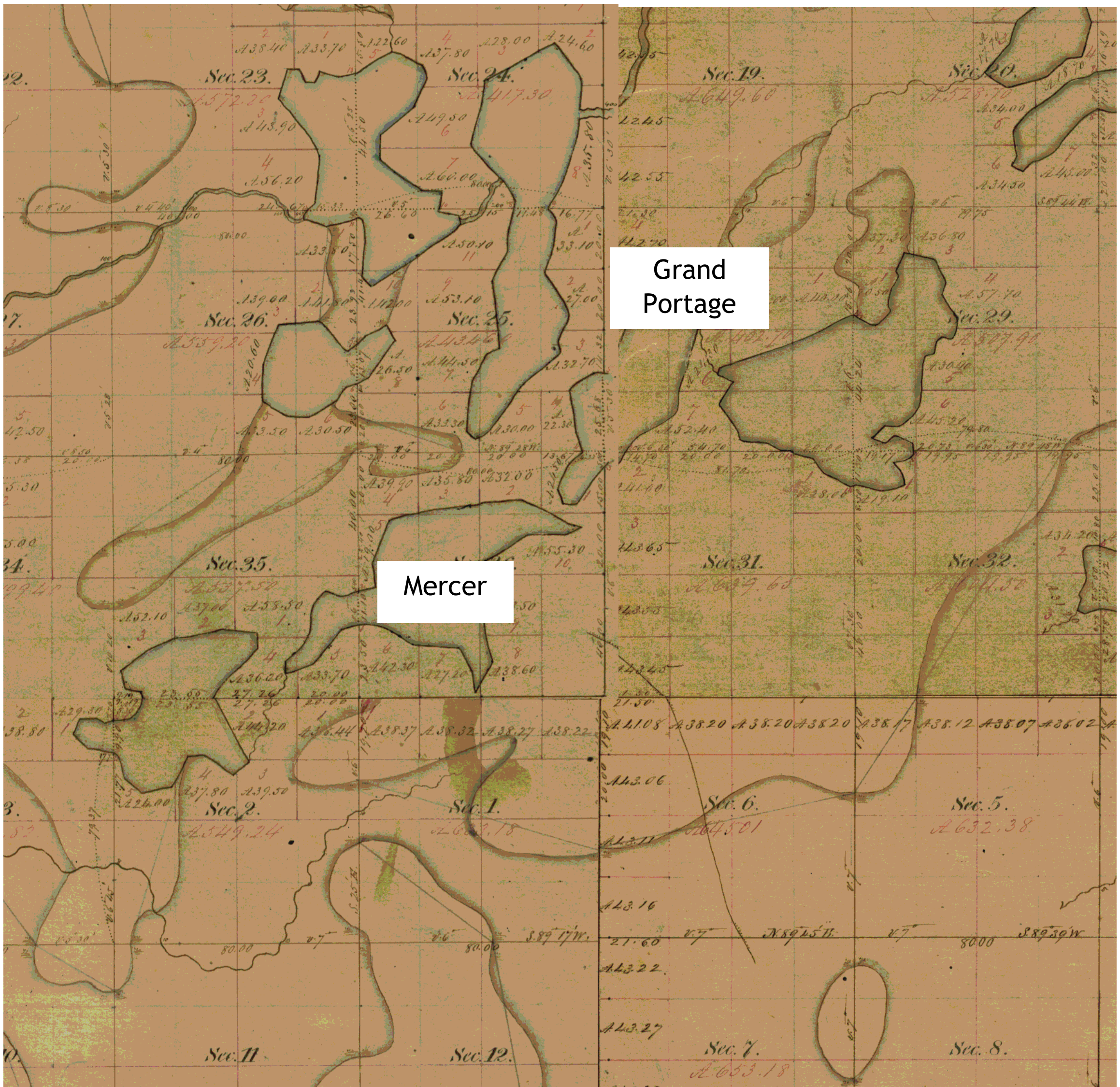


Figure 2. Map of the orginal land survey performed in 1865. The land around Mercer and Grand Portage lakes had already been platted at that time.

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 the 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 (Appleby and Oldfield, 1978). Accumulation rates of geochemical variables 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 Mercer and Grand Portage cores 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. In the cores from both lakes, the depth of the cesium-137 peak is very close to the date of 1963 calculated by the ^{210}Pb model indicating that the model results are very good in both cores.

Another element that can be used to verify the dating model is the profile of stable lead. The profile of stable lead is largely the result of the usage of lead in gasoline. Bonded leaded gasoline was discontinued in the mid-1970s (Gobeil et al. 1995; Callender and Van Metre 1997) and thus the peak in the profile should correspond with a date in the mid to late 1970s. The stable lead peak in both cores was close to the late 1970s which is further verification of the accuracy of the ^{210}Pb model derived dates.

Mercer Lake

The mean sedimentation rate of Mercer Lake for the last 200 years is 0.011 g cm^{-2} yr^{-1}. This is one of the lowest rates that has been measured in Wisconsin lakes (Figure 3). Part of the reason for the low rate is this is a relatively softwater lake. Since hard water lakes contain elevated levels of calcium which is deposited on the lake bottom, their sedimentation rates are often higher. Even though Mercer Lake has relatively soft water, the low sedimentation rate is very good.

More important than the mean sedimentation rate is the trend in this rate during the last century and especially in the recent decades. While the sedimentation rate during the early 1800s was 0.003 g cm^{-2} yr^{-1}, it has increased to 0.022 g cm^{-2} yr^{-1} in recent years (Figure 4).

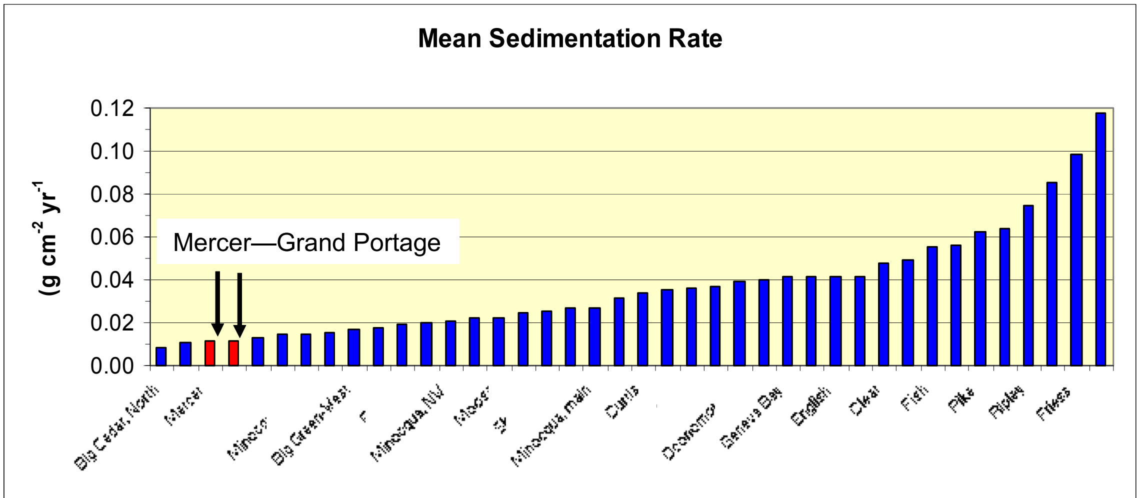


Figure 3. Mean sedimentation rates for the last 150-200 years of a number of Wisconsin Lakes. The mean sedimentation rates for the study lakes is some of the lowest measured in Wisconsin lakes.

This is likely the result of shoreland development as well as runoff from the town of Mercer. At the present time the sedimentation rate is about seven times higher than it was during pre-settlement times during the 1800s. This is a significant increase and is an indication that watershed activities may be adversely affecting the lake.

Geochemistry

Geochemical variables are analyzed in order 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 Ti are an indication of changes in soil erosional rates throughout the lake's history. Zinc (Zn) is one of the most common metals in urban runoff because of it is a component in tires and galvanized roofs and downspouts (Bannerman et al. 1993; Good 1993;

Table 1. Selected chemical indicators of watershed or inlake processes.

Process	Chemical Variable
Productivity	organic matter
Soil erosion	aluminum, titanium
Urban	zinc, copper
Anoxia	manganese
Nutrients	phosphorus, nitrogen

Steuer et al. 1997). Nutrients like phosphorus and nitrogen are important for plant growth, especially algae and aquatic plants. Calcium and uranium are indications of use of soil amendments for lawns. Manganese is an indication of changes in oxygen levels in the bottom waters.

While levels of the geochemical variables were very low in the early 1800s, they did increase slightly during the last half of the 1880s (Figure 4). This likely was the result of early development in the area, although the town of Mercer was not established until 1889. The most significant increase in the deposition of the geochemical variables occurred after 1930. At this time there was an increase in soil erosion (titanium) as well as urban runoff (zinc). This was not reflected as much in the phosphorus as it was in nitrogen and organic matter deposition. Most significantly, there has been a decline in soil erosion and urban runoff since 1970 which should translate into improved conditions in the lake. The core indicates there has been a slight reversal of the trend in the last few years. This should be taken as an indication that soil erosion has recently increased and steps should be taken to reduce this. Phosphorus, nitrogen, and organic matter increased significantly near the top of the core. This is most likely an artifact of incomplete decomposition of plant material that has been recently

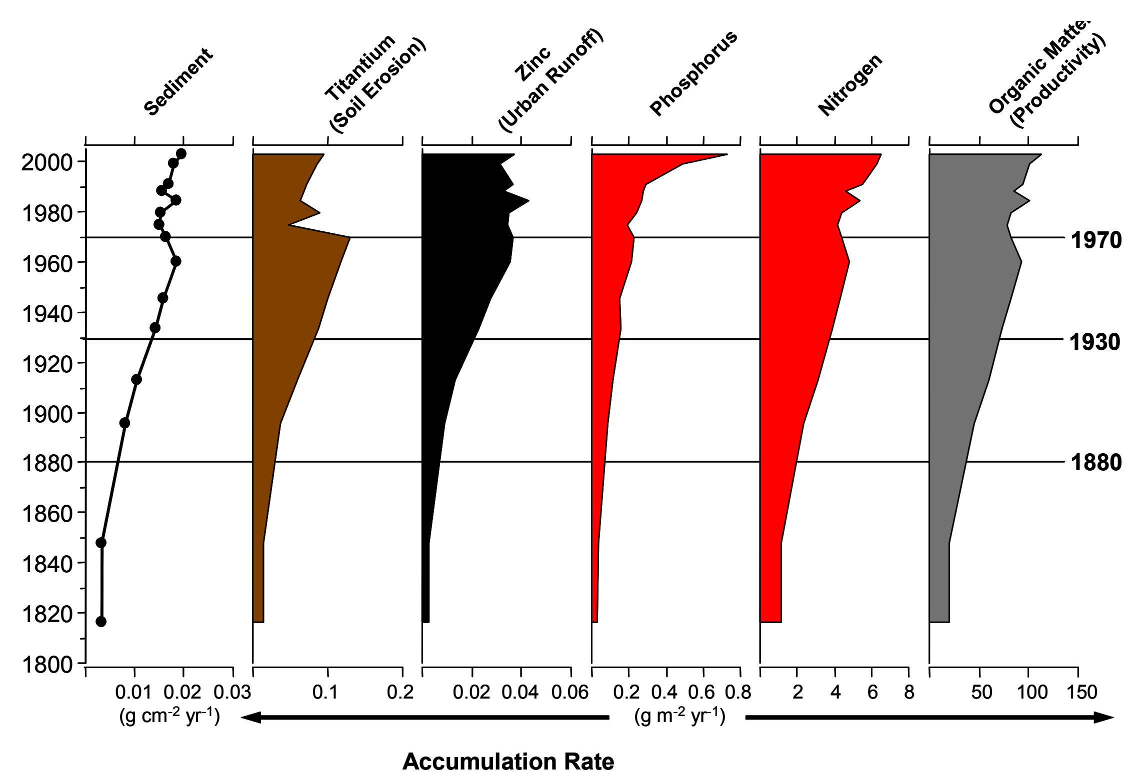


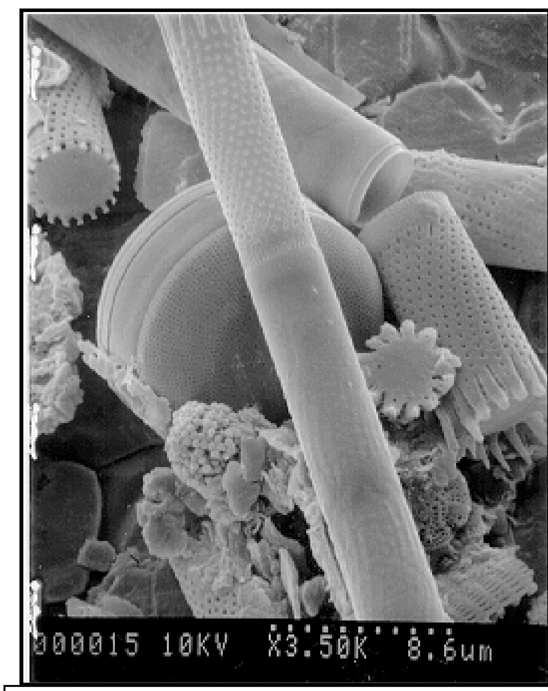
Figure 4. Profiles of the sedimentation rate and selected geochemical elements. Soil erosion and urban runoff increased after 1950 with peak deposition during the 1970s.

deposited. This is common in lakes like Mercer Lake that contain abundant aquatic plants (macrophytes) (Fitzpatrick et al. 2002).

Diatom Community

Aquatic organisms are good indicators of a lake's water quality because they are in direct contact with the water and are strongly affected by the chemical composition of their surroundings. One of the most useful organisms for paleolimnological analysis is the diatom community. These are a type of algae which possess siliceous cell walls, which enables them to be highly resistant to degradation and are usually abundant, diverse, and well-preserved in sediments. They are especially useful, as they are ecologically diverse. Diatom species have unique features as shown in Figure 5, which enable them to be readily identified. Certain taxa are usually found under nutrient poor conditions while others are more common under elevated nutrient levels. Some species float in the open water areas while others grow attached to objects such as aquatic plants or the lake bottom.

The diatom community at the bottom of the core was completely composed of diatoms that grow attached to plants (Figure 6). This clearly indicates that in the 1800s Mercer Lake



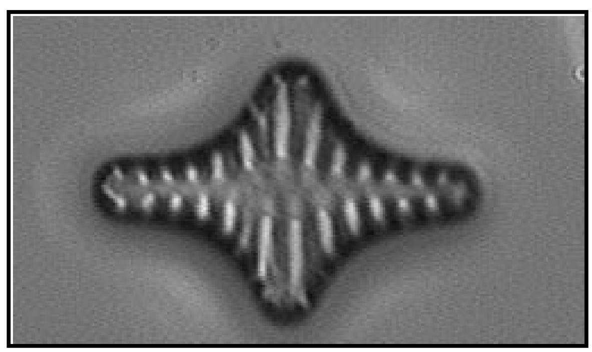


Figure 5. Micrographs of diatoms *Aulacoseira* (left) and *Staurosirella* (right). The diatom on the right is an example of the diatom group "Benthic *Fragilaria*." The diatom on the left is typically found floating in the open water and the diatom on the right is found attached to substrates such as submerged plants.

contained abundant macrophytes. The lack of diatoms that float in the open water (planktonic diatoms) indicates that nutrient levels were low and water clarity was very good. Although diatoms that live on plants are the most common types throughout the core, the number of planktonic diatoms significantly increased after 1900. This indicates that nutrient levels began to increase, providing enough phosphorus to enable the growth of these algae. The highest growth of these free-floating algae occurred during the period 1965-1985. This likely is the result of the sewage treatment plant into the lake which discharged into the lake from 1964-95. Even though the discharge was near the lake's outlet, a sufficient amount of nutrients were distributed throughout the lake to stimulate algal growth. The diatom community indicates that after the sewage plant discharge was discontinued, phosphorus levels declined and this resulted in less algal growth in the lake.

While the diatom (*Aulacoseira ambigua*) that responded to the increased nutrients from the sewage treatment plant input remains low at the present time, other planktonic diatoms increased near the top of the core. This evidence, along with the increase in soil erosion indicators (titanium) point to the fact that phosphorus input to the lake may again be increasing. The increased rate of phosphorus input most likely is at a lower level than when

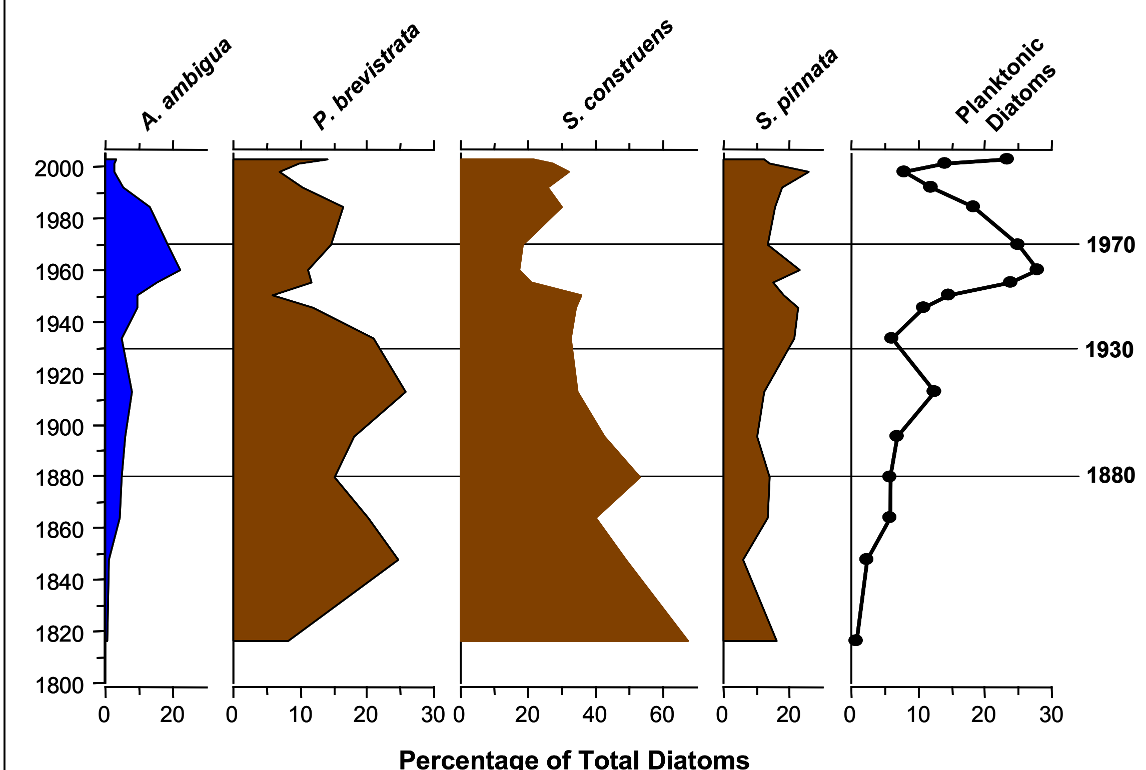


Figure 6. Profiles of selected diatom taxa. *Aulacoseira ambigua* grows in the open water while other diatoms grow attached to plants.

the sewage treatment plant discharged into the lake, it is a disturbing trend and efforts should be made to reduce the nutrient inputs.

Diatom assemblages historically have been used as indicators of nutrient changes in a qualitative way. In recent years, ecologically relevant statistical methods have been developed to infer environmental conditions from diatom assemblages(Birks et al. 1990). These methods are based on multivariate ordination and weighted averaging regression and calibration. Ecological preferences of diatom species are determined by relating modern limnological variables to surface sediment diatom assemblages. The species-environment relationships are then used to infer environmental conditions from fossil diatom assemblages found in the sediment core.

The diatom community was used to estimate changes in the summer Secchi disc depths throughout the core. This analysis indicates that mean summer Secchi levels prior to 1880 were about 3.5 meters (11.5 ft) (Figure 7). Water clarity declined after 1880 and for the period of 1900-1960 the Secchi level was about 3.0 m (10 ft). For the period 1965-1985 water clarity declined further to around 2.5 m (8 ft). The decrease in water clarity coincides with the peak levels of the planktonic diatom *Aulacoseira ambigua*. This decreased water clarity

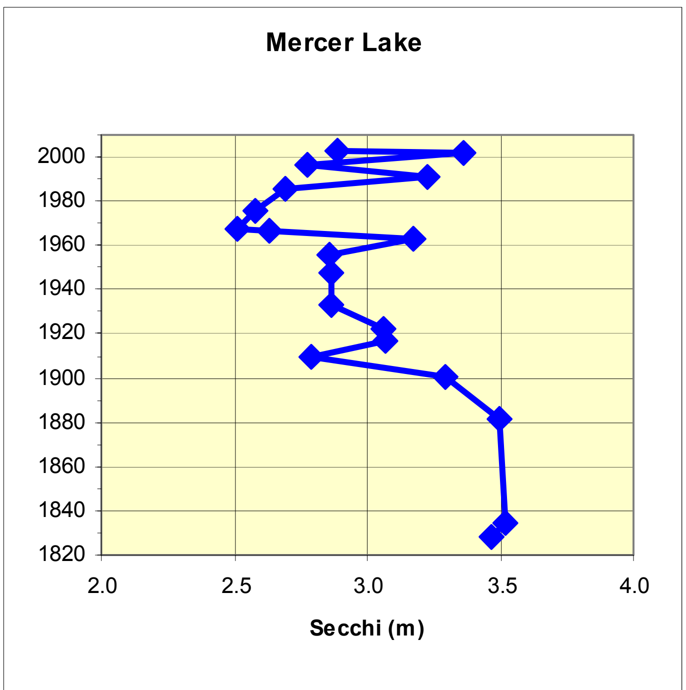


Figure 7. Estimated summer Secchi depth throughout the core based upon the diatom community.

was the result of increased algal growth because of the discharge from the sewage treatment plant. With the cessation of this discharge into the lake, water clarity has improved and the diatom community indicates it has returned to levels experienced during the first half of the twentieth century (3.0 m).

Grand Portage Lake

The mean sedimentation rate of Grand Portage Lake for the last 150 years was nearly identical to that of Mercer Lake with the rate being 0.012 g cm^{-2} yr^{-1}. This is one of the lowest rates that have been measured in Wisconsin lakes (Figure 3). Part of the reason for the low rate is this is a relatively softwater lake. Since hard water lakes contain elevated levels of calcium which is deposited on the lake bottom, their sedimentation rates are often higher. Even though Grand Portage Lake has relatively soft water, the low sedimentation rate is very good.

More important than the mean sedimentation rate is the trend in this rate during the last

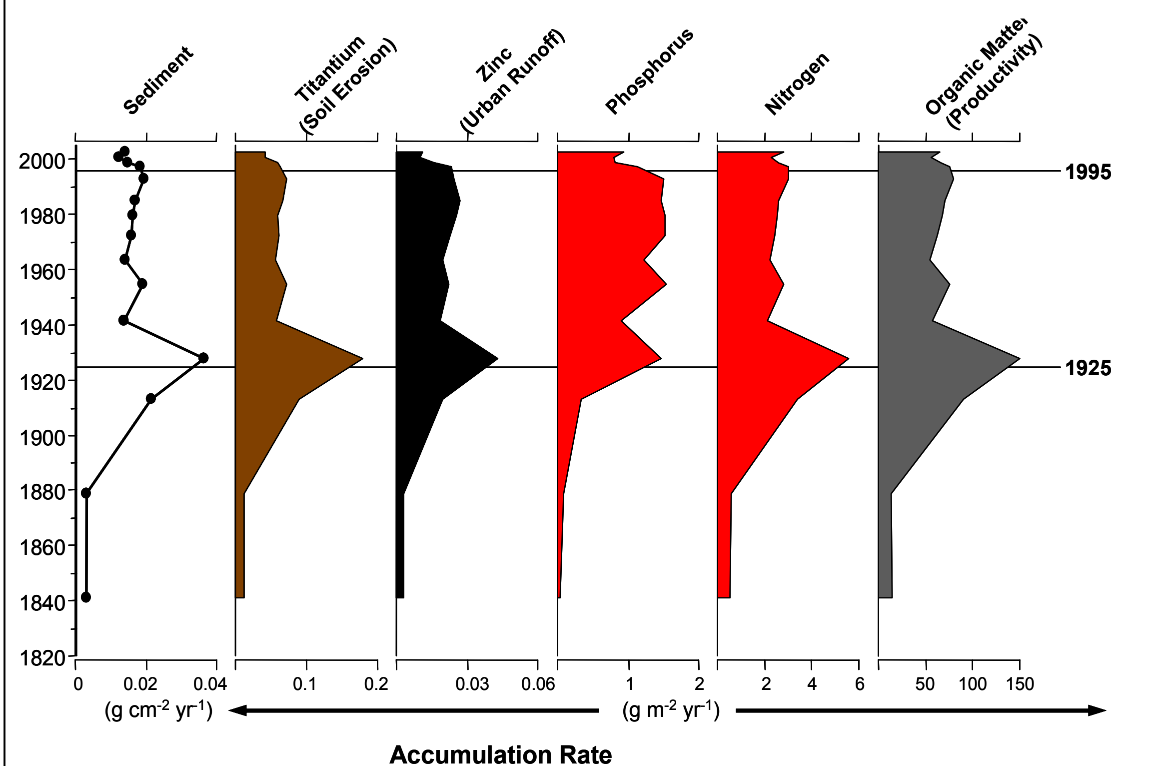


Figure 8. Profiles of the sedimentation rate and selected geochemical elements. The greatest impact on depostion rates occurred as a result of forest fires in the 1920s.

century, especially in recent decades. The highest sedimentation rate in the core occurred during the early part of the twentieth century (Figure 8). This likely was caused by runoff following forest fires in the 1920s that occurred in the lake's watershed. The sedimentation rate was nearly constant between 1940 and 1990 and has declined during the last 10 years. The recent decline in the sedimentation rate is a good sign although it is still about 4 times higher than it was in presettlement time.

Geochemistry

The highest deposition rate of all the measured geochemical variables with the exception of phosphorus was during the early part of the twentieth century (Figure 8). It appears that during this time a major land disturbance occurred in the watershed since soil erosion elements, e.g. titanium increase during this time period. This may likely was caused by a forest fire. This disturbance was not evident in the Mercer Lake core. After 1940, deposition of all the geochemical variables declined from earlier levels and remained constant until the mid 1990s, with the exception of phosphorus. Phosphorus deposition rates did not decline after 1925 and remained elevated until the mid-1990s. All of the variables, including sediment declined during the last decade. Unlike Mercer Lake, the rate of organic matter degradation was not high at the top of the core. This means that organic matter, phosphorus and nitrogen apparent deposition rates were not elevated at the top of the core. This is because there are much less aquatic plants in Grand Portage Lake and thus less organic matter deposition.

Phosphorus deposition was highest during the period 1925-1995. This elevated rate was likely associated with soil erosion only during the early part of this period. During the rest of the period the high phosphorus deposition may have been associated with groundwater entering the lake. This region of the state has very high iron and manganese levels in the soils and rocks and thus high levels in the groundwater (Krohelski et al. 2002). This high iron level is what

gives the county its name. Apparently during the last 60 years iron and phosphorus input from the groundwater increased. This probably does not adversely affect the lake's water quality since phosphorus attached to the iron is insoluble in the presence of oxygen. Thus when the high phosphorus groundwater enters the lake it falls to the bottom of the lake. The increased phosphorus and iron could also enter the lake from the inflowing stream. The diatom community doesn't indicate increased input of taxa typically found in wetlands. Therefore if the increase in phosphorus comes from the inflowing streams it likely is not from increased flows but instead increased concentrations.

Diatom Community

The diatom community indicates that historically, Grand Portage Lake was much different from Mercer Lake. While Mercer Lake was dominated by aquatic plants, Grand Portage Lake had much fewer plants and the diatom community was composed of a much higher percentage of planktonic taxa (Figure 8). Prior to 1925 the diatom community indicates that Grand Portage Lake was typical of many northern lakes. Water clarity was excellent and aquatic vascular plants were present but in general not in large numbers. The most common diatom was the planktonic species *Aulacoseira ambigua*. This diatom was historically very common in low nutrient lakes in the Upper Midwest (Camburn and Kingston 1986; Kingston et al. 1990). Around 1925 this diatom declined (Figure 9) and *Fragilaria crotonensis,* which favors higher nutrients (Ennis et. al. 1983, Engstrom et al. 1985, Christie & Smol 1993, Stager et al. 1997)

significantly increased. The increase in nutrients in the lake is related to watershed

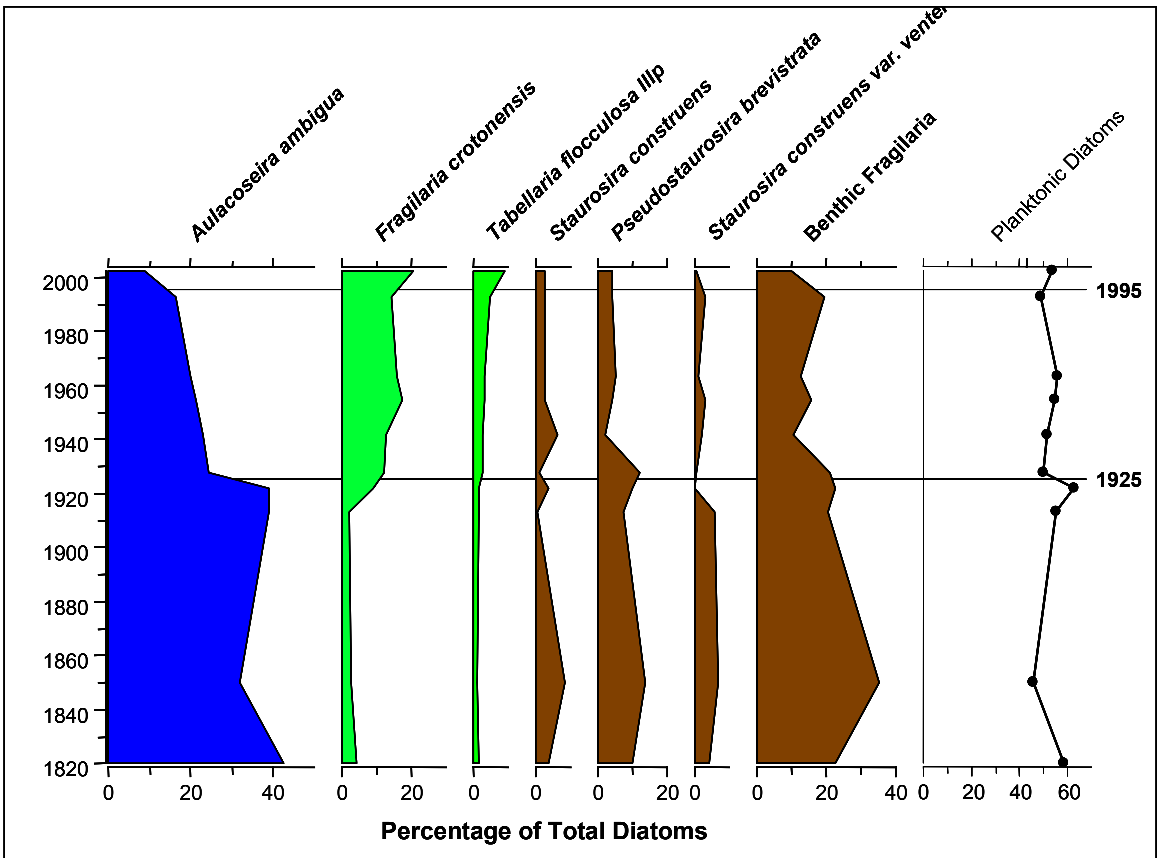


Figure 9. Profiles of selected diatom taxa. *Aulacoseira ambigua* grows in the open water while other diatoms grow attached to plants. The diatoms shaded green prefer higher phosphorus levels.

disturbance discussed in the geochemical section. This activity resulted in an increase in the nutrient levels in the lake which is reflected in the diatom community.

After the increase in nutrients during the 1920s, the diatom community indicates little change in the lake's nutrient status during the last 75 years. 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. The diatom community would reflect this with an increase in the benthic *Fragilaria* diatom taxa. This does not occur in Grand Portage Lake. The diatom community indicates that conditions in the lake, both nutrients and rooted plants, have largely been unchanged since 1930. Since the core was retrieved from the north basin of the lake which doesn't have the density of homes as the south basin, an additional core was extracted from the deep area of the south basin on 23 June 2005. A sample from the top of the core, representing present conditions, was compared with a sample downcore, representing pre-settlement conditions. This core confirmed the results from the north basin indicating minimal impact of shoreland development on the lake's nutrient status or rooted plant community.

Both the geochemical profiles and the diatom community show little impact from shoreline development. Core studies on other northern Wisconsin lakes have indicated increased deposition of elements associated with lawn maintenance e.g. fertilizer, lime, as well as loss of dissolved oxygen in the deeper waters (Garrison and Wakeman 2000; Garrison 2005). This was not found in Grand Portage Lake. In these lakes there has been a significant increase in rooted plants but the diatom community indicates this has not occurred in Grand Portage Lake.

Discussion

Mercer and Grand Portage lakes were different types of lakes prior to the arrival of European settlers in 1800s. The diatom community indicates that Mercer Lake was dominated by rooted aquatic plants (macrophytes) while Grand Portage Lake possessed macrophytes; they played a less dominant role in the lake's ecology. As settlement developed in the area, both lakes were impacted. Forest fires in the watershed of Grand Portage Lake likely resulted in the highest deposition rates of material from soil erosion as well as organic matter during the time period 1925-1940. In contrast, Mercer Lake experienced a more gradual increase in soil erosion (titanium) and chemicals resulting from urban runoff e.g. zinc, aluminum, copper. While the ecology of Grand Portage did not change after 1940, this was not the case in Mercer Lake. Runoff from the town of Mercer continued to adversely impact the lake and with the discharge of the sewage treatment plant into the lake beginning in 1964, the lake further degraded. Algal blooms became more frequent and the deposition of chemicals indicative of urban runoff continued to increase. Even though soil erosional rates (titanium) declined after 1970, the lake’s water quality continued to be degraded until the discharge from the sewage treatment plant was diverted away from the lake.

The cores from these lakes clearly demonstrate the adverse impact of the town of Mercer has had upon Mercer Lake. Even though both lakes have significant amounts of shoreland development, pollutants from the town has a greater impact. The only activity in the watershed of Grand Portage Lake that had a significant impact on the lake’s ecology occurred during the period 1925-1940. This likely was not a result of cottage development. In fact, unlike many other northern Wisconsin lakes with cottage development, Grand Portage Lake at the present time is similar to pre-settlement conditions. In contrast, Mercer Lake at the present time has poorer water clarity than it did historically even though the sewage treatment plant no longer discharges into the lake. It appears that runoff from the town continues to add nutrients, e.g. phosphorus and nitrogen to the lake with the result that there are occasional algal blooms and rooted plant growth is prolific.

- Prior to the arrival of Europeans in the mid-1800s, Mercer Lake contained abundant aquatic plants, although phosphorus levels were low.

- The mean sedimentation rate of both lakes during the last 200 years is some of the lowest measured in the state.

- In Mercer Lake the sedimentation rate peaked around 1970 and then declined until the last few years. This recent increase in the sedimentation rate is the result of increased soil erosion, most likely from shoreline homes and the town of Mercer.

- During the period when the Mercer sewage treatment plant discharged into the lake, phosphorus levels were elevated and algal blooms occurred.

- In Mercer Lake the diatom community indicates that summer Secchi values were around 3.5 meters (11.5 ft) during the 1800s but declined to a low of 2.5 m (8 ft) during the time when the sewage plant discharged into the lake. The current estimated summer Secchi depth is similar to what the lake experienced in the early 1900s.

- In Grand Portage Lake, the activity that had the greatest impact upon the lake were forest fires in the 1920s. This resulted in increased soil erosion and deposition of organic matter.

- In Grand Portage Lake, for the period 1940-95 soil erosion and deposition of organic matter and nitrogen were relatively low. During the last decade deposition of most geochemical elements declined.

- In Grand Portage Lake, phosphorus and iron depostion remained elevated after 1925 but this was a result of increased input of these elements from groundwater and the inflowing streams. This increased nutrient input did not adversely affect the lake.

- The diatom community of Grand Portage Lake indicates that historically, this lake was much different than Mercer Lake. The plant growth was not as dense and water clarity was good. The forest fires in the 1920s resulted in a slight degradation of the lake's water quality but it has not gotten worse since then.

- Comparison of the cores from these lakes clearly shows that Mercer Lake has been more adversely impacted by watershed activities. This is largely the result of runoff from the town of Mercer as well as the sewage treatment plant when it still discharged into the lake.

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Funding for this study was provided by the Mercer Lake Association and Wisconsin Department of Natural Resources. 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.