Holocene Lake Fluctuations in Pine Lake, Wisconsin

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Abstract. Middle and late Holocene water level fluctuations were inferred from a comparison of fossil diatom communities found in the sediments of the main basin and a bay of Pine Lake, Wisconsin. From 7500 to around 4500 years BP the water table was low enough to have kept the bay separated from the main basin. By 3765 BP, the barrier had been overcome and the lake surface was near its present elevation. Based on an approximate 300 year subsampling interval, the water level has risen and fallen three times on a 1300 year cycle since 3765 BP but has varied less than one meter in elevation.

The surface level of a lake can be affected by a number of environmental factors. The effects of periodic drought, clearing of wooded watersheds by fires or logging, and blocking of drainage by dams last as long as half a century, but they usually persist far less than this (Charles and Norton 1986; Borman et al. 1974; Birch et al. 1980). More lasting are the changes wrought by climate, which often reach regional and even continental scale (Wright 1969, Webb and Bryson 1972, Webb 1981, Winkler et al. 1986).

Pine Lake (Fig. 1), an oligotrophic, soft water, seepage lake on the Chippewa-Rusk county line in West-Central Wisconsin, has characteristics that dampen short-term lake level fluctuations. This was evident during a three-year (1979-1981) monthly benchmark study when the surface level of Pine Lake varied less than 35 cm. Located on noncalcareous till of a stagnant ice-core moraine (Cahow 1976), Pine Lake has a surface area of 106 hectares, maximum depth of 33 meters, a small drainage basin of only 197 hectares, and a shoreline development index of 2.56 (Sather and Threinen 1963). Soils of the drainage basin are almost exclusively Amery sandy-loam (Ald), class 4e, 12–25% slope (D. Goettl, USDA SCS Chippewa County office, personal communication). Recent land usage has kept the surrounding terrain mostly wooded (95% wooded in 1963) and only approximately 50 summer homes rim the shoreline. In 1976 Pine Lake was included in the Wisconsin Department of Natural Resources Benchmark Lake Program as an example of an undisturbed lake system.

Beauty Bay (Fig. 1), 2.4 hectares with a maximum depth of 15 meters, is located on the west side of Pine Lake. It is presently united to the main basin, but access is restricted by a submerged bar across the mouth of the bay. The apex of this bar, under approximately one meter of water, is comprised exclusively of boulders, apparently washed clean by wave action. The ground water flows from Beauty Bay toward the main basin (Tinker 1985).

A number of pertinent features are apparent on the USGS topographic map for the area (Chain Lake, WI N4515 W9122.5/7.5): 1) the immediate banks of both Beauty Bay and the main basin have a steep grade, 2) the system has an intermittent outlet, 3) there is a lack of agricultural development, and 4) no boggy or low areas are shown to directly abut either basin. A 1939 lake survey map

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of Pine Lake, compiled by the then Wisconsin Conservation Department using data from the WPA Lake Survey Project, indicates the immediate shoreline was completely comprised of upland woods of oak, oak-aspen, or pine. Recent cursory inspection of the surrounding woods confirmed the presence of sizable quantities of red oak (*Quercus borealis*), quaking aspen (*Populus tremuloides*), and white pine (*Pinus strobus*) directly at the lake front. In fact, one of the more noticeable features of both Beauty Bay and the main basin is the remarkable scarcity of aquatic macrophyte, lowland, and transition vegetation at the shoreline.

The oldest historic record of Pine Lake and its drainage basin is probably found in the original land survey conducted in the Pine Lake area in 1852. Features that would have been incidentally cited when encountered by the surveyor would have included Indian trails, roads, burned-over lands, and windthrows (Bourdo 1956). None of these nor any other human-related features were cited for the immediate vicinity of Pine Lake. The surveyor’s description of Pine Lake at that time was “banks very high and steep, shores gravel and sand, water clear and deep, bottom sand, timber surrounding pond—Pine, maple, oak, and aspen.” A present-day description would differ very little.

No direct evidence of historic human alteration of the bar separating Beauty Bay from the main basin was found. The 1972 Chain Lake, Wisconsin, 7.5-minute
USGS topographic map, both the 1948 and 1950 Weyerhauser, Wisconsin, 15-minute USGS topographic maps, and the 1939 Wisconsin Conservation Department Lake Survey Map all show Beauty Bay clearly united to the main basin. Alteration by pre-European natives might be conjectured, but there was no evidence for this and the bar appears to be a naturally deposited barrier, swept clean by wave action to leave boulders. This study depended on the physical relationship of Beauty Bay to the main basin, the stability of the main basin, and the sedimentary record of fossil diatoms. The premise was quite simple. During periods of high water, when the mouth bar of Beauty Bay lay deeper beneath the surface, water would be more freely interchanged with the main basin. This would result in "contamination" of the littoral community of Beauty Bay with planktonic species adapted to the large, deep main basin. Conversely, when water levels were low, the bar would be covered by less water and could even be exposed. This restricted or blocked access to Beauty Bay would reduce, and possibly even eliminate, any similarity of the two diatom communities.

Procedure

In Beauty Bay a sediment core 320 cm long was removed using a Livingstone-style piston corer (Livingstone 1955). In the main basin the upper 115 cm were taken using a freeze-coring device (Swain 1973) while the sediment from 150 cm to 375 cm was extracted using the Livingstone corer.

During piston-coring, due to the depth of water over the study sites, a rigid pipe casing was assembled between the ice and the water-sediment interface. This casing, just slightly larger in diameter than the piston corer, was used as a guide to the proper location in the sediments and to prevent bending of the thrust rods during sampling. To increase penetration of the corer, two winches were attached, one end of each to the thrust rod of the corer and the other hooked under the ice. At maximum penetration, sufficient force was being applied to visibly flex the part of the thrust rod extending above the corer casing. Although the piston corer was forced into the sediments as far as possible, it would not penetrate a highly organic compact layer at 375 cm (7535 BP ± 135 yrs) in the main basin nor a similar layer at 310 cm (7565 BP ± 85 yrs) in Beauty Bay. This layer apparently is not a universal characteristic of Chippewa moraine lakes since the same corer was also used on nearby Oliver Lake #2 (Gont and Ohl 1985) to get sediments 14C dated at over 11,000 years (unpublished data).

The piston cores were left in the sample tubes, frozen in the field, and taken to the laboratory where they were kept frozen during removal and subsampling. The freeze core was removed from the corer in the field, immediately wrapped in foil, and transported on dry ice to the laboratory, where it was kept frozen until subsampled.

Slices of sediment approximately 0.3 cm thick were cut from each core with a hacksaw at 10.0-cm intervals. This was later determined to approximate 300-year sampling intervals over the 4500-year time span when the two basins had prevalent species in common. These subsamples were oxidized using the hydrogen peroxide and potassium dichromate method (van der Werff 1953) and strewn-mounted (Patrick and Reimer 1966) on microscope slides using Hyrax (R.I. 1.65) as the mounting medium. In the main basin, random transects from a slide from each subsample were examined at 1250X with a Zeiss research microscope until a minimum of 500 (Stockner and Benson 1967, Weitzel 1979) diatom valves were identified and tabulated. Once the main basin prevalents were discovered, it was un-
necessary to identify all frustules from the Beauty Bay subsamples, since only the “contaminants” from the main basin could affect the percent similarity index. A minimum of 500 diatom valves per slide were still inspected in the simplified count of each Beauty Bay subsample, but those species that had not appeared as prevalents in the main basin were tabulated as others. However, complete counts of 500 had been made at approximately 50-cm intervals along the Beauty Bay core in a preliminary study (unpublished data) and were available for reference. In all of the counts, the “dilution effect of dominants” (Kingston 1986) was not taken into account.

Dating was done by a 14C method on 5-cm long core sections (minimum of 10 g dry wt.) sent to the Radiation Laboratory of Washington State University (WSU sample numbers 3180-3187, 3189). Regional corrections for 14C dates are available (Grootes 1983), but the dates in this paper have been presented as uncorrected.

Results

In the 34 subsamples examined from the Pine Lake main basin core, representing the last 7500 years, only three of the 212 diatom taxa identified were found in greater than 3% relative abundance in three or more levels. The distributions of these three, Cyclotella stelligeroides Hust., Cyclotella comta (Ehr.) Kutz., and Tabellaria fenestrata (Lyng.) Kutz. are shown in Figure 3. In the 32 subsamples examined from Beauty Bay, also representing the last 7500 years, the above prevalent species of the main basin suddenly appeared in relative abundance greater than 3% approximately 4500 years BP and remained as prevalent species in varying proportions to the present (Fig. 2).

Similarities of subsamples were determined by a 2w/(a + b) percent similarity index used by Bray and Curtis (1957), where w is the summation of the lowest count of each species in the two assemblages being compared, a is the total count from one assemblage, and b is the total count from the other. This index can range from 0 to 1—it equals 0 when the two assemblages to which it is applied have no species in common and 1 when all species are in common and the relative abundance of each species is identical as well. Because linear interpolation between 14C dates was used to date many of the subsamples, correspondence between main basin and Beauty Bay basin subsamples could only be approximated. For this reason, a similarity index was calculated for two sets of data: 1) every Beauty Bay subsample and the nearest-aged main basin subsample and 2) every Beauty Bay subsample and the average of the two nearest-aged main basin subsamples. Both sets of indices were similar (r² = 0.93, p<0.01) so only the data of set 1 were used in the analysis (Fig. 3). Subsamples with the greatest similarity to the main basin were labeled as high water levels and those with the least similarity as low water levels.

Discussion

An important consideration in any fossil study is how representative the sedimentary record is. This aspect was not directly tested in Pine Lake. However, diatoms have recently become the subject of numerous fossil studies investigating acid precipitation effects, and these studies have repeatedly reported that diatom remains in surficial sediments accurately represent the living community (Charles 1985, Haworth 1980).

The problems of sediment mixing and differential preservation of frustules have also been reviewed (Binford et al. 1983). By taking cores from the deepest part of the basin, the probability of mixing is greatly reduced (Kreis 1986). But even if
Fig. 2. Species that appeared in three or more subsamples at $\geq 3\%$ relative abundance in the sediments of the main basin of Pine Lake, and their abundances in the Beauty Bay basin. Sediment age rather than subsampling interval is on the linear scale. Each horizontal hash represents one subsample. Subsamples were taken every 10 cm along the cores. Sediment ages are uncorrected $^{14}C$ dates.
Fig. 3. Inferred water level fluctuations of Pine Lake over the past 5000 years. Similarity is based on a 2wl(a+b) index. Sediment ages in parentheses were determined by linear interpolation between 14C dates. Those dates not in parentheses are uncorrected 14C dates.

Sediments were mixed on a small scale, to the order of tens of years (Davis and Smol 1986), it is unlikely that events on the scale of hundreds of years would be masked (Haworth 1980). The physical features of Pine Lake, in conjunction with the stable diatom community, also support an assumption of minimal disturbance of the sediments at the study site.

Eroded and broken frustules commonly occur in fossil diatom material. To test the extent of increasing dissolution and breakage over time all diatom valves and fragments with radial symmetry, identifiable to species or not, were counted on a sequence of eight microscope slides spanning the entire main basin core. On each slide at least 60 specimens were tabulated. Radial symmetry was used as the criterion because C. stelligeroides, a small radially symmetrical species, was the major prevalent in every core subsample. A ratio of "identifiable valves" to a total count, including "specimens not identifiable," ranged only from 0.765 to 0.821 with no trend detected from top to bottom of the core. Although it is obvious that a totally eroded valve is impossible to detect, it would be expected that valves eroded to the point of no longer being identifiable would increase with depth if dissolution over time were a problem. This did not seem to happen in Pine Lake, at least during the last 7500 years.

The remarkable simplicity and constancy of the diatom community of the main basin over the past 7500 years are evidence that any water-level fluctuations had little effect. The fact that there were only three prevalents, C. stelligeroides, C. comta, and T. fenestrata, which usually comprised 80% of the counts of 500 at all levels examined in the main basin, emphasizes this point. This has been attributed to several characteristics of the Pine Lake basin and its watershed. The lake’s position in the very headwaters of the drainage was important because it limited the area that any surface drainage disturbance could affect. The steep slopes of the sides of the lake bed gave Pine Lake a large volume in relation to its surface, which diluted incoming nutrients. Although fire and windthrow undoubtedly hit the drainage basin, the results of these forces would have been patchy and irregular due to the uneven nature of the surrounding moraine. In any case, disturbed forested watersheds provide a surge of nutrients but rapidly recover (Borman et al. 1974). Pine Lake was able to absorb any short-term surges without showing detectable effects. Even post-European settlement disturbances, restricted apparently to logging and summer home development, produced minimal changes. In short, Pine Lake probably had minimal watershed disturbance and was well insulated from any disturbances that did occur.

Apparently the three main basin diatom
species thrived only in the open water of the main basin since, in the subsamples dated c. 7500 BP to 4500 BP examined from Beauty Bay when the two basins were inferred as being separate, not a single specimen of *C. stelligeroides*, *C. comta*, nor *T. fenestrata* was found. It was not until c. 4500 BP, and continuing to the present, that these three species appeared in Beauty Bay as prevalents. Even if isolated from the main basin, the proximity of Beauty Bay makes it unlikely that accidental introduction and establishment in the basin could have been avoided for the 3000 years prior to 4500 BP if water conditions were favorable. Whether they actually thrived after this time or were merely resupplied by water flow, it is probable that the presence of the three main basin prevalents in Beauty Bay for the last 4500 years was due to significant influx of water from the main basin.

Some information is always lost when raw data is condensed. In Pine Lake, the reference basin (main basin) had only the same three prevalent species in all subsamples of the core. Since the remaining nonprevalent species not used in the analysis, amounting cumulatively to less than 20% of each count of 500, were divided among at least 30 additional species at each sediment level examined, it is unlikely that the abundance of any one of these species, or even several of them, would materially affect the similarity comparisons to Beauty Bay. This is reinforced by the index itself, which treats each individual equally and does not give weight to species out of proportion to their abundance (Kershaw 1968). Variations in similarity values of equivalently aged main basin-Beauty Bay subsamples would thus be a function of the degree of “contamination” of Beauty Bay with the three main basin prevalents.

It should be mentioned that Beauty Bay had a great many other prevalents (unpublished data), but since the focus was on Beauty Bay “contamination” by main basin species and not on the community dynamics of Beauty Bay itself, this would not create a problem—as long as productivity in Beauty Bay remained relatively constant. To determine roughly if major changes in productivity took place since the inferred water level rise that united the two basins around 4500 years BP, preliminary counts of 500 valves each for three sediment subsamples from Beauty Bay within this span were examined. *Pinnularia biceps* Greg. was recorded at 9.2%, 16.3%, and 22.5% relative abundances at 0 years BP (0 cm), c. 1616 years BP (50 cm), and c. 3157 years BP (100 cm), respectively; *Synedra tenera* W. Sm. was recorded at 8.5% relative abundance at 0 years BP (0 cm); and *Navicula papula* v. capitata Skv. and Meyer was recorded at 8.2% and 10.7% relative abundance at c. 1616 years BP (50 cm) and c. 3157 years BP (100 cm), respectively. No other species, besides the three main basin prevalents, were found in greater than 5% relative abundance during this time. The maintenance of only the same six most common species over the past 4500 years would indicate that productivity did not greatly change during this time.

Prior to c. 4500 years BP the diatom community of Beauty Bay was quite different. Instead of the six species cited in the previous paragraph, *Stauroneis aniceps* Ehr., *Melosira islandica* O. Mull., *Melosira italica* (Ehr.) Kutz., *Fragilaria construens* v. venter (Ehr.) Grun., *Synedra famelica* Kutz., and *Fragilaria brevistriata* Grun. were most prevalent, all reaching greater than 10.0% relative abundance at one time or another in the preliminary counts (unpublished data). A major difference like this would be expected if the two basins were separate prior to 4500 years ago and united after that time.

Based on the degree of similarity between the Beauty Bay and Pine Lake
diatom communities and roughly a 300-year sampling interval, dependent on sedimentation and compaction rates, the following sequence of surface fluctuations were inferred (Fig. 3):

1. From 7500 to c. 4500 years BP, the water table was low enough to keep the Beauty Bay basin separated from the main basin by a ridge. During this time span there were no main basin prevalents found in the Beauty Bay basin.

2. At c. 4400 BP main basin prevalents were first found in Beauty Bay and by 3765 BP the two communities had a similarity index of 0.469. This is comparable to the 0.444 index at present. Once the barrier between basins had been overcome at c. 4400 BP the lake level stabilized near its present level.

These first two inferences concur with the existence and timing of a Middle Holocene dry period, discussed by Winkler et al. (1986) and supported by 19 regional studies cited by them as evidence for this dry period.

3. Since 3765 BP the level has fallen and risen three times at the scale investigated. High levels occurred approximately every 1300 years as determined by linear interpolation between 14C dates. The two intervening high points had similarity indices of 0.408 and 0.412.

4. The lowest water levels after the two basins were united, around 4500 years BP, centered around 3200, 2200 and 600 years BP. The similarity indices at these three times were 0.191, 0.157, and 0.197 respectively.

5. Since c. 4500 years BP, water levels have not been low enough to reisolate Beauty Bay, nor high enough to put the mouth bar under much more water than at present. The bar is now under one meter of water, so the surface level of the lake has varied less than one meter in elevation for any extended period during this time.

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Works Cited


Holocene Lake Fluctuations in Pine Lake


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