Lake Management Programs:

The Importance of Sediment Assessment Studies

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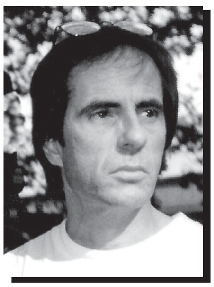
Lake sediments are the most important source of information about pre-disturbance water quality conditions and restoration targets for lakes, and they are a primary focus for studies that evaluate long-term environmental patterns of water level, climate and global warming, and the effects of acid-rain deposition.



Lake sediments are often perceived as undesirable, however, by people who encounter them during recreational activities in freshwater systems. Lakefront homeowners frequently prefer sandy beaches to soft accumulated mucks that make wading unpleasant or that encourage the growth of aquatic plants that obscure their view and limit access to the water.

Organic sediments, nevertheless, are an important aspect of freshwater ecosystems. Organic remains of algae, aquatic plants, and animals that are not decomposed in the water column or lost through outflows accumulate on lake bottoms. These sediments provide habitat for benthic organisms, and they are a foothold and nutrient source for plants that stabilize the bottom, sequester nutrients, and provide fish and wildlife habitat.

Lake sediments can constitute a source of internal nutrient loading to lakes and can significantly influence lake nutrient status and the presence of oxygen in water columns. Nutrients in sediments can be returned to the water column from anoxic lake bottoms or by wind-generated resuspension of sediments.

Filling of lakes by progressive sediment accumulation is a natural process that leads to the creation of wetlands, but lakes can be subject to accelerated filling because of increased erosion caused by land clearance and other human activities in the watershed. Cultural eutrophication also can increase rates of organic sediment deposition.

A common element of lake restoration programs involves the removal of organic sediments from lake bottoms in order to reduce internal nutrient loading or counteract rapid filling of sediments. A primary value of lake assessment studies, therefore, is often thought to be locating and quantifying sediments for removal operations.

There are two important factors to consider, however, before sediments are removed from lakes. The first is that under certain conditions, sediment removal activities can exacerbate water quality problems. The second is that once sediments are removed from lakes in a given region, the important information that they contain about past water quality conditions is gone for future assessments.

Some Instances When Sediment Removal Might Exacerbate Problems

Nutrients that are present in deeper sediments can be in forms that are more available biologically than they are in surface sediments, and their exposure following partial removal of overlying sediments can increase internal nutrient loading to a lake for a period of time. In addition, buried sediments can contain higher levels of toxic contaminants than recent sediments that were deposited during a time of improved environmental regulation. Exposure of older sediments, for example, might increase water column concentrations of persistent organic pollutants, herbicides that were used previously for weed control, or metal contaminants that were deposited from inputs to the lake in the past. Studies that investigate toxic components of underlying sediments can be valuable for determining potential consequences of sediment removal programs. Studies that document the distribution of contaminated sediments are helpful for evaluating the feasibility of their removal.

The Value of Sediments for Past Environmental Information

Sediments are deposited in an orderly manner that records inputs to a lake over time from atmospheric sources, pollen from surrounding plant communities that reflect natural and human-mediated change, soil erosion from watersheds, and microorganisms that indicate past water quality conditions within the lake. The scientific discipline that is concerned with lake history as indicated from sedimentary evidence is called *paleolimnology*.

For the majority of lakes throughout the country, there is a lack of long-term water quality data that are necessary to establish appropriate lake restoration goals. Although many excellent citizen and agency monitoring programs now exist, monitoring data rarely extend back more than a few decades. Most significant changes in water quality occurred before the establishment of these monitoring programs, and pre-disturbance water quality conditions tend to be poorly understood. Pre-disturbance water quality information can be important, however, for restoration programs to be cost effective (Brenner et al.1993). Attempts to manage lakes at limnetic nutrient concentrations that are less than pre-disturbance conditions, for example, would prove costly and ineffective because such efforts would attempt to reduce nutrients below the levels at which they are supplied naturally from watershed and groundwater sources.

Field Methods for Sediment Assessment

Several questions can be addressed directly by the field component of sediment studies. Field procedures reveal the areal distribution and thickness of sediments, which are necessary for estimating the volume of organic sediments for sediment removal operations. Sediment distribution data are used to document the location of sediment contaminants and the volume of affected sediments. Field assessments also can indicate the location of optimal coring sites for historical studies.

Sediment thickness and location can be assessed in a simple manner at few to many stations that are located with approximate equal area coverage over a lake's area. For simple field operations, sampling sites can be approximated on a map in advance, transects maintained using a hand bearing compass, and site locations recorded with a hand-held global positioning system. In many lakes, organic sediments can be situated in unexpected locations, with sediments lacking even in deep portions of the lake. In our studies of Florida lakes, sediment location is often so variable that we routinely use sediment surveys to help locate appropriate coring sites for our historical studies (Whitmore et al 1996). On large lakes or for studies that are intended to yield high-resolution maps of sediment location, numerous sampling sites can be placed along carefully planned transects, and more sophisticated guidance systems used.

Sediment thickness at a given site can be assessed in several ways. The simplest method involves measuring water depth by lowering a weight, such as a Secchi disk, on a line to the sediment surface. Metal rods, such as those used to operate a coring device, are inserted then as deep into the sediments as possible to determine the maximum depth of soft-sediment thickness. The difference between the measured water depth and the maximum depth of rod insertion is the thickness of sediments at that location. A second method involves the use of a sediment coring device, essentially a tube with a piston that helps retain sediments (Figure 1). The advantage of using a coring device to assess sediments is that sediments retrieved with this method can be analyzed in the laboratory. A disadvantage of using a coring device is that sediment thickness can exceed the length of a simple sediment corer (~1.5 m), and retrieval of the entire sediment profile in such locations might require a more elaborate coring device and coring operations. However, a sediment core of 1-m length, in most instances, will retrieve sediments that are older than 100 years, which represents the period of greatest environmental interest for studies that address water quality changes in recent times.

An additional method of constructing sediment maps involves acoustic profiling of the sediment lens along continuously recorded transects. This method requires a more sophisticated operation than is practical for most simple paleolimnological studies, and contaminant presence still must be determined from sediment grab samples.

Laboratory Methods Used to Date Sediments and Assay Constituents

Basic laboratory assessment of sediment samples includes combustion of samples to measure organic matter content. Organic matter content of sediments in a given lake can be high or low depending upon many factors, but an increase in the proportion of organic matter in a sediment core might indicate that eutrophication occurred. In contrast, a relative increase in the inorganic component might indicate that greater amounts of eroded soils entered the lake from the watershed because of land clearance.

The timing of events at various levels in a sediment core can be determined by radiometric dating techniques. The method most pertinent to events in the past 100-120 years, which documents the period of greatest acid-rain effect, environmental contamination, or trophic state change in North America, is the ^{210}Pb (Lead 210) dating method. ^{210}Pb is a naturally occurring radioisotope that is a decay product in the radium decay series, and it enters lakes at a constant rate with atmospheric precipitation. As ^{210}Pb decays, it leaves a typical profile of radioactive activity in sediments that allows assignment of dates to samples through the use of mathematical formulas. ^{210}Pb occurs naturally in lake sediments as well, and this background activity must be subtracted in order to reveal the atmospheric component that is used for calculation of dates.

Two principal ^{210}Pb dating methods are alpha and gamma spectrometry of radioisotope activity. Although gamma detection requires more elaborate instrumentation, this method measures background activity directly, and it is

Figure 1. This sediment core from Lake Jesup, Seminole Co., Florida, represents more than 100 years of depositional history. A coring device of this size permits all analyses to be performed on material from a single core.

more suitable in areas where radium occurs at significant levels in catchment soils. Background ^{210}Pb activity can vary throughout a sediment core if radium-bearing soils have washed into a lake, which would violate the assumption of constant background activity that applies to dates obtained using alpha spectrometry (Schelske et al. 1994).

Radiometric dating and knowledge of the inorganic and organic content of samples permits the calculation of accumulation rates of sediments, which is an important way to assess changes in filling rates of lake basins caused by eutrophication or increased erosion from watersheds. When dates are assigned to levels in a sediment core, paleolimnolgists often can relate water quality changes to specific events that took place in a lake's watershed during the past.

Sedimentary concentrations of nutrients, including carbon, nitrogen, and phosphorus, typically are measured with elemental analyzers. Nutrient accumulation rates can be calculated using nutrient concentrations and sediment accumulation rates. Timing of changes in nutrient deposition can provide information about which nutrient sources have effected changes in trophic state.

Contaminants in sediment samples can be assayed by elemental analyses. Metals, such as mercury, lead, and arsenic are typically assessed by methods such as ICP-atomic emission spectroscopy or atomic absorption spectroscopy, whereas organic contaminants such as herbicides, pesticides, polycyclic aromatic hydrocarbons, and PCBs can be assessed by methods such as gas chromatography, gas chromatography/mass spectrometry, or high-performance liquid chromatography. ^{210}Pb dates can reveal the timing of the introduction of contaminants to a lake, which can provide potential information about the contaminant sources.

Assessing Baseline Conditions and Water quality Change

Many lake sediment studies have documented global patterns of acid precipitation and its effects on surface waters during the last century. Lake acidification studies typically rely on estimating past water quality values in lakes using fossil remains of microscopic organisms including diatoms and chrysophycean cysts. Sophisticated statistical methods have been developed that permit estimation of past values for variables such as pH, limnetic nutrient concentrations (e.g., total P), and measures of dissolved solutes that reflect past patterns of water-level change in lakes (Stoermer and Smol 1999). Statistical methods that are based on sedimented diatoms are particularly sensitive indicators of past water quality.

In addition to direct estimates of past water quality obtained with diatoms, stable isotope values of $\delta^{13}C$ in sedimented organic matter are informative about eutrophication. $\delta^{13}C$ values are essentially a ratio of the concentration of ^{13}C, a heavy form of carbon isotope, to ^{12}C, a lighter form. ^{12}C is used preferentially during photosynthesis in the water column until it becomes depleted by photosynthetic demand, at which point ^{13}C becomes utilized increasingly. An increase in $\delta^{13}C$ values of sedimented organic matter over time, therefore, indicates that a lake has experienced an increase in primary productivity (Brenner et al. 1999). Another stable isotope, $\delta^{15}N$, can increase when septic or agricultural fertilizer influx to lakes increases, whereas $\delta^{15}N$ values decline toward zero when nitrogen-fixing cyanobacteria begin to dominate.

Sedimented algal pigments can be evaluated in a general manner using spectrophotometry to document changes in algal populations that occurred during a lake's past. High-performance liquid chromatography is useful for documenting the presence of specific groups of cyanobacteria. When diatom, algal-pigment, and stable isotope studies are applied in conjunction with sediment chemistry and ^{210}Pb dating, these lines of investigation provide comprehensive assessment of pre-disturbance water quality conditions and the timing and extent of subsequent water quality changes in a lake.

Lake Haines Case Study

Several paleolimnological methods can be used simultaneously to provide corroborative assessment of eutrophication over time (Table 1). Our recent study of Lake Haines for Florida's Department of Environmental Protection is a simple example that shows how sediment studies provide information that is useful for lake management. Lake Haines is hypereutrophic, but pre-disturbance water quality conditions and the timing of changes were unknown. Sedimented chlorophyll and myxoxanthophyll (a cyanobacterial pigment) were measured, and ^{210}Pb dates were obtained by gamma detection. Diatom inferences of past water quality (limnetic total P and chlorophyll *a*) documented a period of distinct eutrophication, and sedimented pigments showed that algal and cyanobacterial blooms became more prevalent after that time (Figure 2). ^{210}Pb dates indicated that eutrophication began around 1941, a period when surrounding cities expanded rapidly.

The range of modern limnetic total P in Lake Haines is 74-115 µg/L, which is considerably higher than our pre-disturbance estimate of 41 µg/L total P. Our pre-disturbance estimate, however, is substantially higher than the value of 20 µg/L total P that was recently thought to be an appropriate pre-disturbance value for calculating total maximum daily loading to Florida lakes such as Lake Haines. Our sediment studies indicate that restoration goals for lakes in the vicinity of Lake Haines should not be less than 40-42 µg/L total P if management efforts are to succeed and be cost effective.

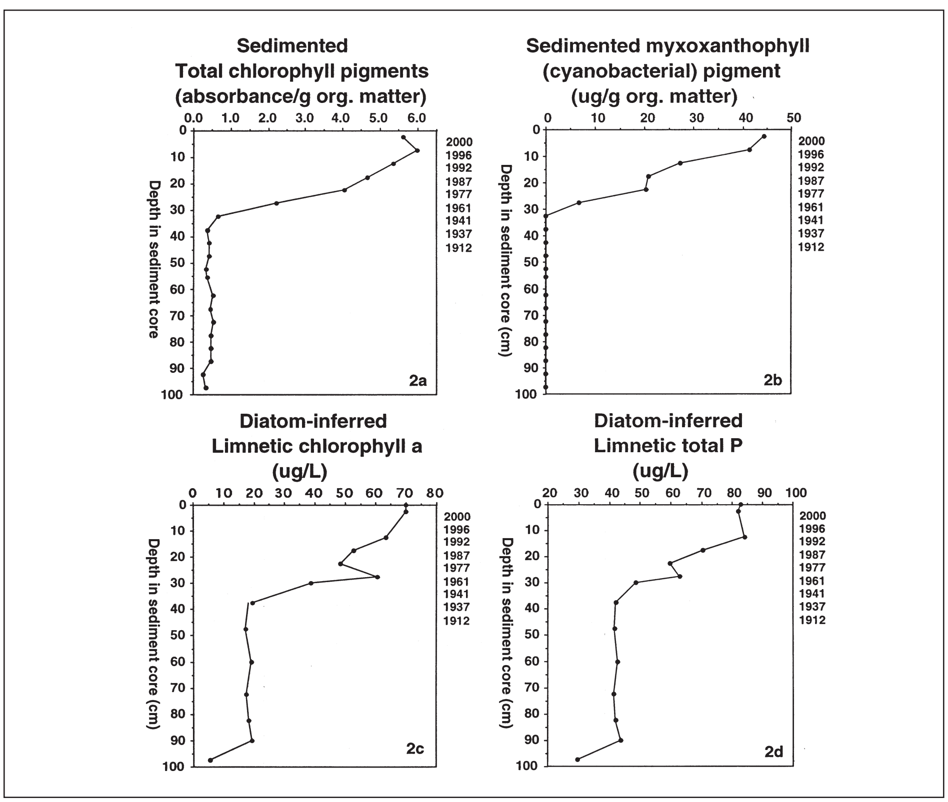
Concusion

Sediment assessment is a powerful tool for answering many questions that are pertinent to lake management. It can provide a framework for understanding the nutrient or contaminant history of a lake, and water quality restoration goals for lakes and regions that are based upon empirical information rather than assumption. Because sediment studies show how water quality changes relate to the timing of specific changes and events in a watershed, they can help determine causality of water quality changes, and identify priorities for lake management programs.

Table 1. Questions That Can be Answered with Sediment Assessment.

Question	Suggested Methods
Sediment removal operation	
What is the location and mass of sediments?	Sediment distribution survey
Trophic state	
Has the lake undergone eutrophication?	Diatoms, Nutrient chemistry, Stable isotopes
How have algal/cyanobacterial populations changed?	Algal pigments
What is the timing of these changes, and how have sediment and nutrient accumulation rates changed?	^{210}Pb dating
pH	
Has the lake been affected by acid precipitation?	Diatoms, Chrysophycean cysts
What is the timing of these changes?	^{210}Pb dating
Contaminants	
What contaminants (PAH, PCB, lead, mercury, etc.) are present in sediments?	HPLC, AA, GC, GC/MS, ICP
What is the spatial distribution and mass of contaminated sediments?	Sediment distribution survey
When did contaminants enter the lake?	^{210}Pb dating

Figure 2. Sedimented algal pigments and past limnetic nutrient values estimated from sedimented diatoms. ^{210}Pb dates were provided courtesy of Joseph Smoak, USF-St. Petersburg.



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