Investigating Adirondack Lakes

J. Curt Stager

J. Curt Stager is Associate Professor of Biology at Paul Smith's College

ABSTRACT

When the subject of human impacts on Adirondack lakes is raised, most people think first about acidification. In fact, only about a fifth of all Adirondack lakes, mostly at high elevations, suffer from acidification. The majority of Adirondack lakes lie below 3,000 feet, have circumneutral pH, and are easily accessible. As a result, most human impacts on Adirondack lakes are local, having more to do with sewage inputs, road salt, introductions of non-native species, and rotenone treatment than with atmospheric deposition. Direct long-term ecological data concerning past lake conditions in the Adirondacks are few, but sediment core studies are important sources of insight into the ecological histories of these lakes.

INTRODUCTION

The story of the acidification of Adirondack lakes is familiar to many through extensive media coverage and scientific study. It is now generally accepted that atmospheric fallout from anthropogenic sources has led to widespread declines in pH and the deposition of heavy metals, soot, and other airborne pollutants in Adirondack lakes throughout this century. It is less generally known that until recently these assumptions of chemical change rested upon a relatively sparse historical data base, because of the scarcity of direct, continuous chemical measurements in these lakes over long time periods. The final bits of evidence showing that most Adirondack lakes above 3,000 feet elevation have indeed experienced pH changes in recent times came not from direct measurements but from the study of sediment cores and the microscopic remains of organisms preserved in them (Whitehead, *et al.*, 1986; Kingston, *et al.*, 1990; Sullivan, *et al.*, 1990; Charles, et al., 1990; Cumming, et al., 1992). This analytical technique, called "paleolimnology" (the study of lakes of the past), has been used around the world in the study of topics ranging from climate change (Halfman and Johnson, 1984; MacDonald, *et al.*, 1993) to fish evolution (Stager, *et al.*, 1986). Here in the Adirondacks, paleo-limnological investigations that focus on lake issues other than acidification are few but increasing in number. These issues have yet to receive the degree of public attention afforded the "acid rain" problem and include eutrophication (nutrient enrichment with associated nuisance algal blooms), liming, rotenone treatment, fish introductions, and road salt contamination (Fleck, *et al.*, 1988; Rhodes, 1991).

In this paper, I will provide an introduction to the technique of paleolimnology, followed by a summary of preliminary results from two current studies in the northern Adirondacks.

PALEOLIMNOLOGY

In essence, paleolimnology can be described as "the science of reading mud." Much if not most of the life in and around a lake ends up, sooner or later, leaving some sort of trace in the sediments underlying the lake. Examining a smear of lake mud under a microscope makes this readily apparent. Uncountable millions of single-celled algae, such as diatoms and chrysophytes, die and drop their glassy shells to the bottom, where they may lie perfectly preserved for many thousands of

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years. Sponges leave their needle-like skeletal spicules, midge larvae their head capsules, fish their scales, cyanobacteria their photosynthetic pigments, and terrestrial plants their pollen, seeds, and leaves.

Every year a new layer of mud is laid down, perhaps a millimeter or so in thickness. Each successive layer contains a collection of biogenic debris that reflects the biological goings-on of the entire year. These layers are sometimes distinct enough to be visible to the naked eye, stacked like pages in a book, an archive of ecological information that can stretch back to the very origin of the lake itself. Some of the large, ancient lakes of East Africa's Great Rift Valley, for example, contain well over a vertical mile of annually laminated sediments, dating back 20 million years or more. In the Adirondacks, as in other glaciated areas of North America, the sediment record is more likely to extend back only to the last glacial retreat, roughly 10,000 years ago.

In order to read these sedimentary pages, one simply plunges a tubular sediment coring device into the bottom of the lake, pulls it up full of mud, and extrudes the mud core layer by layer for analysis. Depending on what happens to be present in the mud, one might be able to reconstruct the algal history of the lake, or the vegetational history of the surroundings, or the history of climate change as reflected in shifting lake chemistry and depths. The fossil and chemical records are usually calibrated by lead-210 or carbon-14 dating methods, but other methods can include paleomagnetism and visual counting of annual layers known as "varves."

Different lakes, and different locations within a single lake, deposit their sediments at different rates. In general, the less terrestrial runoff a site receives, the lower the sedimentation rate. Sediments collected by my former colleagues at Duke University from several miles offshore in Lake Victoria, East Africa, were laid down at a rate of just over a half millimeter per year for the last 10,000 years; a meter of mud represented between 600 and 700 years. At the opposite extreme, Lake Turkana (Kenya) receives a heavy load of silt from a river entering its north end; with sedimentation rates close to 300 mm/year, a 10 meter sediment core from midlake covers only about 3,000 years. Most moderate-sized Adirondack lakes typically range between 50 and 100 mm per year. In such a lake, the entire hundred-odd-year history of human settlement in the region may be represented in the uppermost 10 or 20 centimeters of mud.

ADIRONDACK LAKES AND ACIDIFICATION

Relatively recent paleolimnological investigations have provided our most complete records of atmospheric pollutant deposition in the Adirondack region. Previously, most of the reliable chemical data dated back only a few years, and it was argued, quite reasonably that the acidic status of the high elevation lakes was not a recent development due to acid deposition but simply the natural condition. But over the last ten years or so, the development of sophisticated statistical methods, such as canonical correspondence analysis and weighted averaging (Siver and Hamer, 1989; Sullivan, *et al.*, 1990; Agbeti, 1992; Hall and Smol, 1992) have allowed diatom data to be converted to chemical data, often with surprising precision. For example, pH levels in Ontario lakes have been accurately calculated from sedimentary diatom assemblage data to within a fraction of a pH unit (Cumming, *et al.*, 1992).

This same quantitative approach was taken in the study of core samples taken from 36 Adirondack lakes. The application of statistical analyses to the diatom records of these lakes led to the conclusion that virtually all lakes in this region which are currently acidic have become more so since the turn of the century (Cumming, *et al.*, 1992). Lakes now close to neutral pH, on the other hand, have generally been that way since before the Industrial Revolution. This is not surprising, as most of these lie below the 3,000 foot cloud line. The sensitivity of this technique is such that the uppermost sediments of many Adirondack lakes record a recent shift towards higher pH levels that correspond in time to recent tightening of air emission standards in the United States.

BEYOND ACID RAIN

Only about one fifth of all Adirondack lakes lie in the heavily acidified high elevations. The vast majority have pHs close to neutral and lie at lower elevations. Thus, despite the enormous attention paid to it, the acidification issue is more limited in extent here than one might expect. More significant to the majority of Adirondack lakes is the impact of local human activities. Road salt contaminates roadside waters, especially since institution of a "clear roads" policy during the 1980 Winter Olympics.

The New York State Department of Environmental Conservation (NYSDEC) has treated many lakes with piscicidal rotenone to make way for sport-fish introductions. Non-native yellow perch continue to spread to lakes once inhabited by native fishes.

Perhaps the most widespread human impact on Adirondack lakes is that of nutrient enrichment from sewage and fertilizers, which leads to eutrophication and its associated unpleasant algal blooms and lake anoxia.

These issues have received surprisingly little attention from scientists, perhaps because they are of local rather than regional extent. Nonetheless, after conducting a preliminary survey of waters in the Saranac Lake region, I have found a wide array of scientifically interesting stories preserved in the sediments of mid-elevation lakes, two of which I will summarize in the next section.

EUTROPHICATION

Upper Saranac Lake is the largest and westernmost of a chain of three moderately large lakes that drains via the Saranac River into Lake Champlain. The north and west shores of the lake have been heavily settled since the turn of the century, first primarily by luxury hotels like the Saranac Inn, then by private residences. A state-operated fish hatchery, which provides trout and salmon to much of New York, opened in 1885 on a small tributary that drains into the lake's north basin. It became a year-round operation in 1953.

In the summer 1990 Upper Saranac Lake experienced a dense bloom of the cyanobacterium, *Anabaena*, much to the distress of lakeshore residents who draw their drinking water directly from the lake. That fall, an even denser bloom of bright green, potentially toxic cyanobacteria, *Aphanizomenon*, occurred. No such blooms had occurred within living memory, suggesting that they were the result of recent nutrient enrichments. The fish hatchery had flushed an exceptionally large amount of organic waste into the lake during the previous winter, and members of the local lake association blamed the hatchery for the eutrophication of the lake. Hatchery representatives denied responsibility, and acrimonious debate ensued.

I was approached by the lake association to conduct a sediment study to provide the necessary historical background to the debate. At the time, there was little information available about past water chemistry, and it was not even certain that the lake was not normally eutrophic. I collected a sediment core from the north basin, analyzed its diatom record, and had it dated with lead-210 isotopes.

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I found that the upper 20 centimeters of mud in the center of the north basin were laid down since 1850. From well before that date and into the early 1900s, the diatom assemblages were typical of moderately productive lakes throughout the region. However, by the 1920s light-loving bottom dwelling species began to die out and be replaced by species that thrive best in murky, nutrient-enriched waters. After 1953, the abundance of *Fragilaria crotonensis*, a diatom widely recognized as an indicator of nutrient enrichment (Smol and Boucherle, 1985; Christie, 1993), increased to about 30 per cent of the diatom assemblage and fluctuated at that level to the present. Other diatoms typical of productive lakes (*Asterionella formosa* and *Tabellaria flocculosa*) also became much more prominent over the last forty years. Additional cores from the north and south basins showed similar patterns of change in the sediment record.

The results of this study showed conclusively that the eutrophication of Upper Saranc Lake is a relatively recent phenomenon, that it is lakewide, and that it increased markedly in severity in concert with the start of full-time operations at the hatchery. After obtaining the results of this and other studies, the lake association filed suit against the NYSDEC with the goal of stopping all effluent discharge into Upper Saranac Lake.

LAKE RECLAMATIONS

Rotenone has been used by the NYSDEC to poison undesirable fish such as non-native yellow perch in local lakes, to "reclaim" the lake for fish such as native trout, which are more desirable to anglers. Reclamations have been the focus of much rancor in recent years. Many people object to the application of rotenone to wild lakes, fearing that it may cause unwanted damage to non-target species. Proponents of reclamation counter that it is necessary to prevent non-native species from crowding out native fish, and often tend to play down the impacts of rotenone on non-target biota.

In fact, relatively little is known of the impact of rotenone on gill-bearing animals other than fish (all available data suggest that animals which lack gills are unaffected by rotenone), and even fewer data are available for studies of aquatic species found in the Adirondacks. Clearly, much work remains to be done in this area, if reclamations are to continue unopposed.

Even if fish were the only animals affected directly by rotenone, changes in fish community structure may lead to changes in the rest of the lake ecosystem. Young fish feed on zooplankton (Mills, *et al.*, 1984), which in turn graze on algal phytoplankton. Different kinds of fish eat different kinds and amounts of zooplankton, and recent evidence suggests that fish predation has a sort of "trickle-down" effect on the structure of plankton communities (Mills and Forney, 1983; Carpenter, *et al.*, 1987; McQueen, *et al.*, 1992).

Replacement of one type of zooplankter with another, as when one is suddenly eliminated in the course of reclamation, can reduce grazing pressure on certain types of phytoplankton and lead to changes in algal communities (Mazumder, *et al.*, 1990; Carpenter, *et al.*, 1991).

Alternatively, phytoplankton composition can also help determine the composition of the zooplankton (Infante and Abella, 1985). Phytoplankton have also been shown to affect water temperature by increasing absorption of solar radiation through changes in water clarity (Mazumder, *et al.*, 1990). It might therefore be expected that replacing perch with trout, or even temporarily wiping out a zooplankton community, could lead to significant changes in the physical and biological structure of a lake. Black Pond, a small pond at Paul Smiths surrounded by undeveloped forest, has been reclaimed several times since the 1950s; each time yellow perch have recolonized the pond to the exclusion of trout. In the fall of 1991, Black Pond experienced a dense bloom of *Anabaena*, similar to that which appeared at Upper Saranac Lake during the previous year.

The cause of this bloom was a mystery, as there are no human-made structures in the watershed, other than two lean-tos, that could contribute wastes or other nutrient sources to the lake. The most likely explanations for the bloom, therefore, were that Black Pond is naturally eutrophic, or that the reclamations and fish introductions have had something to do with it.

Preliminary analysis of a 20 centimeter sediment core collected from the middle of the pond indicates that Black Pond's diatom community experienced a dramatic shift in the recent past; assemblages change from those typical of moderately productive lakes to those typical of more productive lakes around the 6 centimeter level. Lead-210 dates have yet to be obtained for this core, but if sedimentation rates are only slightly higher than in the middle of Upper Saranac Lake (as Black Pond's shoreline is closer to the coring site), the 6 centimeter level should correspond roughly to the late 1950s, when the first reclamation took place.

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Although work continues on the Black Pond core, it is already apparent that the pond has not always been so productive. This leaves rotenone and fish as the most likely agents of change here. Diatom analysis is not likely to identify the precise mechanisms behind the change, but it is likely that shifts in food chain dynamics have played a major role. From the preliminary results of this study, it appears that the ecological reality of fisheries management at Black Pond involves more than the simple elimination and introduction of fish.

CALIBRATION SETS

The diatom studies presented here are essentially qualitative in nature. In either case, a relatively small number of "indicator species" were used to show that the lake became more productive in the last few decades, but they did not show how much more productive. In theory, it is also possible to use such data to reconstruct past concentrations of algal nutrients, such as nitrate and phosphate, and other limnological features of interest.

In order to do so, however, it is first necessary to develop a detailed database ("calibration set") of local diatom taxa and the limnological conditions under which they are found. This has already been done for acidic Adirondack lakes with great success (Charles, 1985). I am currently working on a similar calibration set by compiling water chemistry and sediment data from 50 lakes of pH close to 7 in the northern Adirondacks.

These data will be evaluated with the help of computer programs developed and used by other investigators (Hall and Smol, 1992) in order to determine which chemical conditions are most strongly correlated with each diatom assemblage.

Once this calibration set is completed, it can be used to infer chemical conditions from diatom assemblages preserved in sediments from lakes whose chemistry is unknown, as well as from diatoms in cores.

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