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Department of Horticultural Science
University of Minnesota, St.Paul, MN

Effects of Liming on the Flora and Fauna of Acidic Lakes

Eleanor M. Lease

ABSTRACT

Will adding limestone to streams or lakes which have become acidified be of benefit to the flora and fauna in the environment? Research conducted over 4-5 year periods was recently published in the Restoration Ecology Journal, September 1996 (Zurbuch et al. 1996, Menendez et al. 1996, Clanton et al. 1996, Wright et al. 1996, Hagley et al. 1996, Pop et al. 1996). A calcium carbonate slurry treatment was added continuously to a stream and on a one time surface basis to a lake. The treatments were successful in reducing acidity, increasing the calcium in sediments, and increasing desirable populations of fish. Changes occured in the composition of plant and plankton populations which, while different than those in acidic waters, may or may not be beneficial. The changes in populations have been observed on a relatively short term basis and may or may not be permanent and/or beneficial.

INTRODUCTION

Rain is naturally acidic. When atmospheric carbon dioxide is dissolved in rain water carbonic acid is formed giving uncontaminated rain a pH of about 5.6. Most lakes have a natural buffering balance of plant photosynthesis and air CO_2 exchange with the water that maintains the pH between 6.5 and 9. Lakes also receive buffering from the calcium carbonate (limestone) in the soil of their watershed areas. However, some lakes, particularly those in the in the northeastern United States, Canada, and the Scandinavian countries are on low calcium soil and are naturally below the 6.5 pH range. Sometimes rain falls which is more highly acidic than natural rain. While it is possible for acid rainfall to occur from the addition of sulfates from volcanic eruptions or nitrogen oxides formed during lightening storms, much of the acid rain is created by human consumption of fuels that contain sulfur and nitrogen. Industrialization coupled with the prevailing winds is responsible for the sulfuric acid and nitric acid becoming part of the rainfall. Lakes with high soil buffering capacity are usually not severely affected by acid rain, but lakes which lack a capacity to be buffered by their watersheds may be severely damaged (Horne 1994). Plants and animals that live in the water, from the smallest bacteria to largest fish, are affected by a change in water pH. Schrieber (1996) reports that researchers in Scandinavia found that aquatic systems with low alkalinities and poorly buffered soils were vulnerable to damage from acid rain and as a result the United States initiated a 10 year federal research program known as the National Acid Precipitation Assessment Program (NAPAP). The goals of NAPAP were to determine the extent of damage from acidic deposition and to better understand the associated changes in the physical, chemical, and biological processes in aquatic and terrestrial environments (Irving 1991). Sites were selected which had annual average precipitation pH of less than 5.6 and pH of surface water less than 6.0 during critical periods (Schrieber 1996). One of the processes being investigated for the mitigation of low pH in aquatic systems is liming (addition of base materials, usually in the form of limestone). Several decades of liming in Norway, Sweden, Scotland, Canada and the USA show that it is effective at protecting threatened fish stocks (Shindler 1997). Dogway Fork was chosen to have lime added to the stream because it met United States Fish and Wildlife Service (USFWS) study prerequisites and because it is a major tributary to the Cranberry River which had become acidified by acid precipitation (Zurbuch et al. 1996). Thrush Lake was stressed, but not yet severely degraded by acidic deposition and was chosen to be a study of the efficacy of base addition to prevent the loss of valuable sport fisheries in a sensitive, mildly acidic lake (Haglen et al. 1996). The following is a summation of the effects of liming on Dogway Fork in West Virginia and Thrush Lake, Minnesota.

COMPARISON OF PROJECT TECHNIQUES

Dogway Fork: A stream which is a tributary of Cranberry River in West Virginia and which has been shown to have contained native brook trout (*Salvelinus fontinalis*) in 1935 was becoming increasingly acidic according to a West Virginia Department of Natural Resources (WVDNR) survey in 1959. In 1985 the WVDNR entered into an agreement with the USFWS to acquire scientific information on the mitigation of surface waters acidified by atmospheric deposition (Zurbuch et al. 1996). By 1966, USFWS surveys found that Dogway Fork contained no trout. A small tributary near the mouth of the stream was found to contain a remnant brook trout population. The WVDNR has conducted research since the 1950's on methods to neutralize acid stream flow (Zurbach 1984) and the self-feeding rotary drum system was a result of these efforts (Zurbach 1989).

A self-feeding rotary-drum system which is capable of dispensing a controlled slurry of $CaCO_3$ designed to provide a dosage necessary to maintain a pH of 6.5 was installed in Dogway Fork in 1988. The drum station was able to operate with only weekly attendance for maintenance and refilling of limestone storage bins. Limestone was quarried at the Germany Valley Limestone Company, Riverton, West Virginia, and crushed to a size of 3.8 to 1.3 cm. Chemical composition, relative hardness and slurry particle analyses were conducted on the limestone. Calcium and pH samples were collected from the stream every other day during the first year of treatment. Stream flow was recorded and sediment samples were collected (Zurbuch et al. 1996).

Menendez et al. (1996) collected fishery pretreatment data in from 1986 through November 1988 and treatment data from December 1988 through December 1992. Responses of macroinvertebrate populations to liming were examined by conducting seasonal samplings and bioassays by Clayton et al. 1996.

Thrush Lake: Thrush Lake is a acid-sensitive lake located in Cook County, Minnesota, in the Superior National Forest amid mixed conifers and hardwoods. It has no permanent inlets and one outlet with a water-retention time of approximately 4.5 yrs. Prior to 1987, the Minnesota Department of Natural Resources managed a put, grow, and take recreational fishery in the lake using lake trout (*Salvelinus namaycush*) and brook trout (*Salvelinus fontinalis*). A one-time application of limestone was sprayed on Thrush Lake, May 24, 1988. It was applied as a slurry, from a small boat, in concentric circles (starting at mid-lake) onto the lake over a 5-hour period. Measurements were take of dissolved oxygen, temperature, long and short term transparency, turbidity, dissolved inorganic carbon, pH, acid neutralizing capacity, and total monomeric aluminum were taken from the water. Sediment samples for calcium and pH analyses were collected (Wright et al. 1996).

Hagley et al (1996) collected date on changed in macrophytes after liming. The researchers did qualitative surveys in 1987, 1989, 1990, 1991, and 1993 to assess changes in the plant community. Data on the effects on the fishery of liming were investigated by Walter, et al., 1996. The researchers did both a pre- and post-treatment study in Thrush Lake. Bioassays and population estimates were combined with assessments of change in brook trout growth.

COMPARISON OF PROJECT RESULTS

Dogway Fork: Cost of operation of the slurry drum station ran from $42,067 in 1989 to $33,107 in 1992 with an average yearly cost of $32,232. The cost of installation of the station were $315,926. A total of 921 tonnes of limestone was used over the reported years which left 256.5 tonnes of calcite fines in the sediment for a 70.7% dissolution rate (Zurbuch et al.1996).

Pretreatment pH ranged from 4.32 to 5.00. After treatment began pH in the treated stream segments ranged from 5.22 to 7.14. Although the drums were calibrated to take amount of stream flow into consideration, pH range was influenced by the amount of water flow. Lowest pH reading occurred during times when the flow exceeded the capacity of the drum station.

Total aluminum remained the same in two sampling areas and was significantly reduced in another. Calcium, both total and dissolved, increased significantly. Other chemical variables did not show a significant deviation between stations, sampling periods, or pretreatment data (Zurbuch et al. 1996).

No fish were observed or collected before the 1988 limestone treatment. Only a small tributary of Dogway Fork contained a reproducing brook trout population. During the summer of 1989 three species of fish were collected (brook trout, creek chub, and fantail darter). In the fall of 1989 brook trout were observed spawning in the area below the drum station; the young fish were observed in April of 1990. Four species were collected in the spring of 1990 (the three of 1989 plus white suckers); in the spring of 1991 six species were collected (add brown trout and longnose dace); and in 1993 seven species were collected (one young-of-the-year rainbow trout). Rainbow trout were stocked in Dogway Fork in August 1989 and in October 1993 the first young-of-the-year were collected (Menendez et al. 1996).

Clayton et al. (1996) collected extensive data on mayfly (*Epeorus, Ameletus and Eurylopnella*), caddisfly (*Rhyacophilia and Neophylas*), and stonefly (*Amphinemura, Acroneuria and Paragnelina*) populations both prior to and after limestone treatment. The found that there was not a significant different in the numbers of individuals, but that there was a change in species found. The mayflies, the stonefly *Amphinemura* and the caddisflies were the most common taxa collected prior to treatment which were negatively affected by liming. The caddisfly *Neophylax* was replaced by the caddisfly *Glossosoma*. Both are primarily scrapers and would fill the same habitat. It appeared that the mayfly *Ameletus* was being replaced by mayfly *Baetis* and other acid sensitive mayflies (*Habrophlebia, Paraleptophlebia and Ephemera*) have appeared since liming treatment began.

Zurbuch et al. (1996) stated that during the 4 year study the treatment station was completely operational 95% of the time. The two drums added nearly 875 tonnes of $CaCO_3$ to the stream.

During high water flows which exceeded drum capability calcite sediments were capable of maintaining pH and Ca levels that protected fish. Upon completion of the study the station was enlarged and continues its operation. "An analysis by the WVDNR showed that by 1995 the treated river supported over 100,000 additional angler days, annually valued at $2 million to the state's economy" Overall annual operational costs are figured to be $135,000 justifying the economic benefits and increased recreational opportunity the river provides.

Thrush Lake: The researchers at Thrush Lake wrote that "This technique is designed not to maintain "natural conditions" but rather to minimize changes in the biotic community that would occur if acidification progressed" (Wright et al. 1996). After the May, 1988, limestone application, surface waters of Thrush lake showed rapid and dramatic changes in pH, acid neutralizing capacity, calcium, dissolved inorganic carbon and specific conductance. These changes did not, however, affect the lake below the thermocline. Transparency decreased immediately after treatment from 8.5 to 0.35 m due to undissolved calcite particles, but was enhanced (approx. 10 m) after a transition phase of a little over a month. Long-term changes in the transparency were not observed. The pH of the epilimnion increased from 6.0 to 9.8 in May when the lime was added, gradually fell as the epilimnion deepened during the summer, and did not stabilize at about 7.0 until fall turnover in October "produced uniform concentrations throughout the water column" (Wright et al. 1996). Total dissolved aluminum (TDA) increased in the epilimnion during the first few weeks after treatment. Significant long-term reduction of TDA was observed after treatment. Calcium increased in sediments by spring 1989, but sediment pH values of the sediments did not change from those observed before treatment. Dissolved inorganic carbon (DIC) appeared to increase gradually over the 1989-1990 period when measurements were taken. Sodium concentrations also increased during the study period (Clayton et al. 1996).

Zooplankton and phytoplankton were also measured by Clayton et al (1996). Wright et all (1996) discussed some changes in zooplankton species, but stated that no overall change in total zooplankton density could be associated with base addition. Some species increased while others decreased or disappeared. The changes may be related to the increase in population of fathead minnow or changes in competition between zooplankton populations. Hagley et al. (1996) measured the changes in aquatic plant communities that could be accounted for by addition of limestone. As noted above, Hagley (1996) found changes in macrophytes from species which can live in acidic environments to acid sensitive species, but no definitive changes in relative cover or depth ranges in the near shore (0-2m) aquatic plant community. In the deeper machrophyte communities (depths greater than 2 m) *Nitella* sp. at depths of 1-5 m and was the only species found between 3-5 m. prior to liming. An extensive bed of *Sphagnum platyphyllum* (40-60% cover) was found in 5-10 m of water in the southern portion of the lake (Wright et al. 1991). One year after liming, *Potamoglton pusillus*, which was previously unreported in Thrush Lake, dominated the 2-3.5 m depth range around much of the perimeter of the lake. By 1990, however, *Nitella* and *P. pusillus* were found interspersed among the *S. platyphyllum* and *S. platyphyllum* did not display much new green growth. In 1993, *S. platyphyllum* was no longer found in Thrush Lake, *Nitella* had increased an estimated 80-100%, and *N. flexilis* and *P. pusillus* were present but sparse.(Hagley et al. 1996)

Popp et al. (1996), stated their objectives were to test whether or not population size, age-class structure, growth, and recruitment of sport and forage fish in a small brook-trout lake were affected by protective liming. They found that the population of brook trout increased from the preliminary estimate in 1987 of 220 to an estimate of 663 in 1990. Brook trout are not known to reproduce naturally in Thrush Lake. While it appears that brook trout populations increased, the 663 in 1990 when compared the 2000 yearlings dropped into the lake annually (1987-1990 = 4 x 2000 or 8000 fish stocked) does not seem reasonable, especially since Thrush Lake was closed to fishing in January 1987 (Popp, et al., 1996). The low population may be a result of dropping the trout from the air. Fraser (1968) found very low survival of brook trout when stocked by air drop. The forage fish community found in Thrush Lake prior to liming was made up of three species, fathead minnow (*Pimephales promelas*), pearl dace (*Margariscus margarita*), and brook stickleback (*Culaea inconstans*). After liming fathead minnows increased significantly, pearl dace also showed an increase in population and change in numbers of brook stickleback were said to constitute an unknown but perhaps significant portion of biomass in the lake.

The study done by Wright et. al. (1996) found that there was no indication that base addition altered the post-treatment physical properties in Thrush Lake (other than conductivity). Treatment did not directly increase the alkalinity of hypolimnetic sediments and that zooplankton communities changed but the implication of those changes was not clear. The researchers suggested that when a preventative treatment is planned, guidelines should be used to provide the minimum dose of base at a constant rate to minimize the magnitude of the chemical alterations induced by treatment.

DISCUSSION

The liming of acidic surface waters has been done for several decades in Sweden, Norway and Scotland and is effective at protecting threatened fish stocks (Shindler 1997). The introduction of lime to Dogway Fork raised the pH and corrected the overacidic conditions caused by atmospheric acidifying of the water enough to allow the establishment of a fishery. The introduction of lime to Thrush Lake (a stressed, but not severely degraded lake with low acid-neutralizing capacity) (Hageley et al. 1996) created changes in the macrophytic and fish communities, but it's difficult to say if they changes are good, bad or indifferent. Addition of lime is, however, a temporary solution to restoration or "protection" of water acidified by or in danger of being acidified by atmospheric deposition. In eastern Canada several liming projects were undertaken in the early to mid 1970's. These projects were rejected in favor of rapid cuts in acidifying emissions. Lakes in the Sudbury, Ontario, area are gradually becoming less acid since the removal of the majority of acid producing emissions (Schindler 1997).

Dogway Fork appears to be an example of successful mitigation of excess acidity in one tributary of Cranberry River. This method of treatment provides the pH to create an environment in which fish can reproduce in a public stream and provide enough adult fish for sport fishing. Future studies should be done to determine what effect addition of 30-40 tonnes of $CaCO_3$ to the sediments per year will have on the future of the river and/or the watershed both in Dogway Fork and downstream. Zurbuch et al. (1996) mentions that a disadvantage of the slurry drum station on Dogway Fork is that a dam is required. No consequences of the dam are discussed. It would be of interest to study the effect on the river upstream of the dam to compare those effects with the results downstream from the dam.

The use of liming at Thrush Lake to "minimize changes that would occur if acidification progresses" (Wright et al. 1996) does not seem to be the outcome of the experiment. Changes were caused by the addition of lime. Those changes did not seem to be of benefit to the ecosystem, nor did they seem to not be of benefit. Since Thrush Lake was not in danger of becoming overly acidic the high, sustained pH produced by surface liming combined with the possibility of aluminum in the lake becoming toxic at turnover makes this type of experiment with an otherwise healthy lake appear to be an unnecessary experiment.

In a recent commentary Schindler (1997), suggests that the best way to control acidifying of lakes is to control the source of the acidification. He sites the results of the Sudbury, Ontario, Canada, restoration. Thousands of tonnes of toxic trace metals were emitted over the Sudbury area, mostly during the first 70 years of the 20th century. The only restoration treatment applied to most of the lakes was to control acidifying emissions. In the 20 years since acid deposition has been declining trees and shrubs have returned and most lakes have become noticeably less acid. Twenty-five lakes which could not support lake trout in their acidic condition are again supporting lake trout and many other original species. Schindler says, "There is a reference point which restoration ecologists should always have in mind: if we simply remove the human insult, what unassisted natural processes would restore the ecosystems, and how long would it take? Can our interventions improve on theses, by restoring equal, if not natural, diversity and biogeochemical integrity at equally rapid rates?"

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