New York State Energy Research and Development Authority

Effects of Acidic Deposition and Soil Acidification on Sugar Maple Trees in the Western Adirondack Mountains.

Summary Report

February 2013

No. 13-04b

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Effects of Acidic Deposition and Soil Acidification on Sugar Maple Trees in the Western Adirondack Mountains

Summary Report

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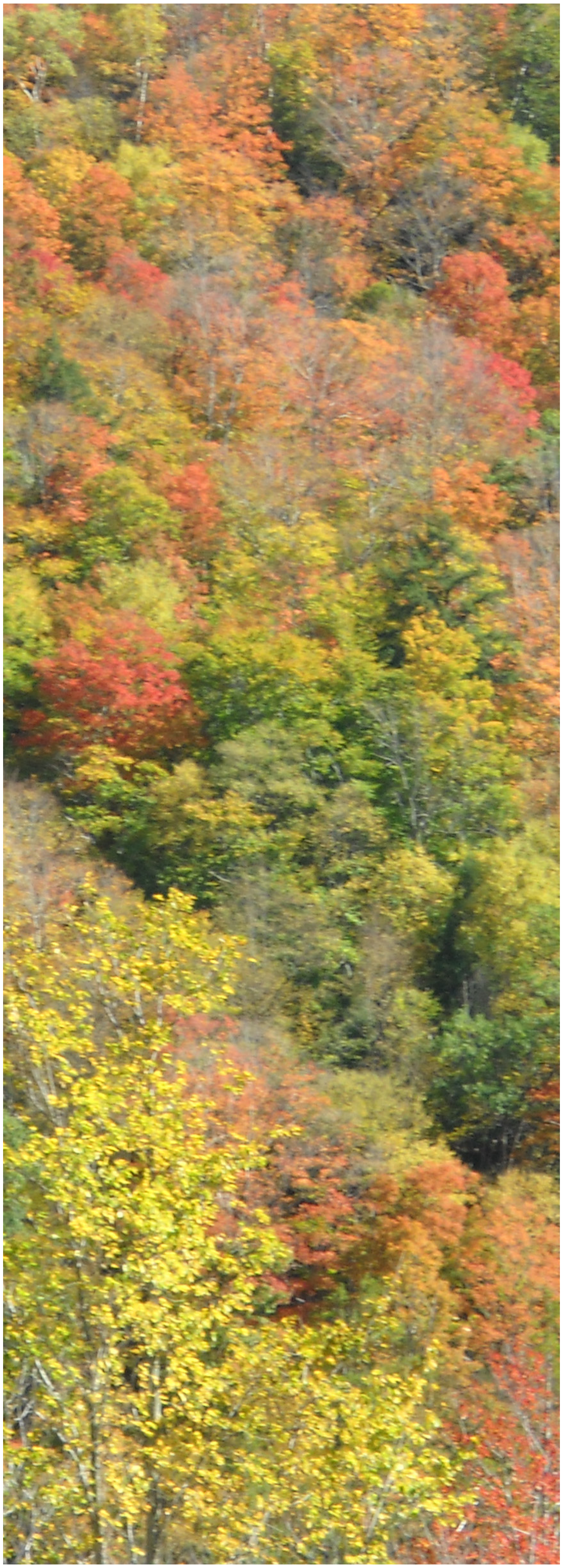
NYSERDA
Report 13-04b

NYSERDA Contract 10660

February 2013



Cover photo and photo above courtesy of Greg Lawrence, U.S. Geological Survey.

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Project Focus

This project measured the health, growth, and reproduction of sugar maple trees, an important and sensitive biological resource, in association with acidic deposition and chemical characteristics of watershed soils in the Oswegatchie and Black River Basins in the western Adirondack Mountains. This region receives relatively high levels of atmospheric sulfur and nitrogen deposition that have lowered the acid-buffering capacity of soils by depleting calcium reserves at some locations. The research team determined where in the project area and under what conditions the relative abundance and/or health of sugar maple was associated with the base cation supply in soils.

Context

Acidic deposition, sometimes referred to as acid rain, occurs when emissions from fossil fuel combustion and other industrial sources undergo chemical processes in the atmosphere and then fall to earth in wet or dry form, acidifying surface waters and soils. The adverse impacts of acidic deposition on resources in New York State have been well documented for Adirondack lake waters, and for stream waters in both the Catskill and Adirondack Mountains. Adverse effects on vegetation in New York State have also been demonstrated, but the extent and severity of damage has not previously been quantified. This project builds upon the results of recent research conducted on sugar maple health in Pennsylvania, New England, and Quebec, as well as recent NYSERDA-sponsored research in the Adirondack Mountains on soil and stream chemistry. Sugar maple makes a good index species for assessment of acidic deposition effects on the Adirondack forest because it has a high demand for calcium, which is becoming less available in the soils due to leaching caused by acidic deposition. Furthermore, sugar maple is a major component of northern hardwood ecosystems, and is highly valued for commercial, cultural, and aesthetic reasons (Figure 1).

Goal and Objectives

The goal of this project was to identify relationships among sugar maple health, soil chemistry, and stream chemistry, and to develop an integrated ecosystem assessment of acidic deposition effects on this important tree species for this region. The major objectives of this research were to:

- Assess the visible health of dominant and codominant sugar maple trees through systematic evaluation of tree canopy condition,
- Analyze historical tree growth trends through analysis of tree cores (dendrochronology),
- Assess sugar maple regeneration as reflected in seedling and sapling density,
- Identify relationships among sugar maple health and regeneration and soil chemistry, and
- Develop an integrated ecosystem assessment of soil and sugar maple conditions in the Oswegatchie and Black River basins.

Figure 1. Sugar maple provides substantial aesthetic, cultural, and monetary value. It is used for maple syrup production, provides lumber for furniture and flooring, and adds to autumn color in the northern hardwood forest. (Source: Scott Bailey)

Study Methodology

A field study was conducted in 2009 in which 50 study plots within 20 small Adirondack watersheds were sampled and evaluated for soil acid-base chemistry and sugar maple growth, canopy condition, and regeneration. Atmospheric sulfur and nitrogen deposition were estimated for each plot. This research built upon the sampling design and data collected during the NYSERDA-sponsored Western Adirondack Stream Survey (WASS) conducted by the U.S. Geological Survey (USGS). The WASS provided an assessment of stream acidification for small watersheds through the sampling of 200 streams randomly selected from the regional population of 565 streams. In the sugar maple assessment project, a subset of WASS watersheds was randomly selected for soil and vegetation sampling. Low-order stream watersheds were used as the integrating unit. This provided the foundation for statistically based regional extrapolation of research findings and included the possibility of using seasonal streamwater chemistry as an integrator of aspects of forest soil chemistry that are associated with adverse impacts on sugar maple.

To select the 50 study plots for this project, the 200 WASS watersheds were ranked by the stream water base cation surplus value (an indication of acid-base status of water), and divided into 20 groups that maintained their ranking. One watershed was randomly selected for sampling (one to three plots were established per watershed) from each group. Landscape characteristics were evaluated through the use of geographic information system (GIS) databases, aerial photography and field reconnaissance to select locations that were generally representative of each watershed and that included sugar maple trees. At these locations, sugar maple seedlings and saplings were counted, identified, and measured, and wood cores were collected from mature trees for dendrochronological analysis. In each plot, all standing living and dead trees of greater than 10 cm diameter at breast height (dbh) were evaluated by species, dbh, and crown class (dominant, codominant, intermediate, suppressed; Figure 2). Crown vigor index, percent branch dieback, and percent crown transparency were estimated for each tree (Figure 3). Percent dead sugar maple basal area, mean sugar maple crown vigor, and mean percent sugar maple dieback were determined for each stand.

Soil samples were collected from discrete horizons (Figure 4) to represent the upper organic (O and A horizons) and lower mineral (upper and lower B and C horizons) soil (Figure 5). These samples were dried and analyzed at the laboratory for a suite of chemical variables that reflect the acid-base chemistry of the soil. Analyses focused in particular on the concentration in the soil of exchangeable calcium and the soil base saturation. Exchangeable calcium is important for sugar maple condition because this species is a calcicole (performs best in soils with relatively large amounts of calcium) and because calcium has been depleted from the soil in the Adirondacks by acidic deposition. Soil base saturation expresses the percent of the soil cation exchange sites that are occupied by base cations (including calcium and several others) as opposed to acid cations (including aluminum, which is toxic to tree roots). Base saturation is the master chemical variable often used to represent soil acid-base chemistry.

Figure 2. A large sugar maple tree in the western Adirondack region being measured by a project scientist. (Source: Scott Bailey)

Figure 3. Field researchers collecting forest stand data and tree cores. (Source: E&S)

Figure 4. Soil pits were excavated at each study plot to collect samples from each horizon. (Source: E&S)

Figure 5. Soil pit excavation. (Source: E&S)

Project Findings

Trees growing on soils with poor acid-base chemistry (low exchangeable calcium and base saturation) that receive relatively high levels of atmospheric sulfur and nitrogen deposition exhibited little to no sugar maple seedling regeneration, relatively poor canopy condition, and short- to long-term growth declines compared with study plots having better soil condition and lower levels of acidic deposition.

Sugar maple, followed by American beech, was the dominant tree species in all study plots (Figure 6). Nevertheless, sugar maple sapling abundance was low, with nearly half of the study plots having no sugar maple saplings. Sugar maple seedling abundance was also low on most plots, compared with American beech (Figure 6). More than half of the cored sugar maple trees showed declining diameter growth since about 1950. Canopy condition varied across the study region (Figure 7). Ten of the plots showed canopy symptoms of severe decline for sugar maple, mostly in the southwestern Adirondacks. None of the plots showed American beech in severe decline.

Plots that contained sugar maple seedlings had significantly higher ($p < 0.01$) soil base saturation and exchangeable calcium compared with plots that lacked sugar maple seedlings (Figure 8). Sugar maple seedling abundance was lowest on plots with upper B horizon soil base saturation less than 12 percent and highest on plots with base saturation greater than 20 percent (Figure 9). The soil base saturation was typically low on plots having low seedling abundance regardless of the abundance of sugar maple trees. Similar results were found for soil exchangeable calcium (Figure 10). For upper B horizon data, the sugar maple seedling proportion increased with increasing exchangeable calcium up to a threshold of 1.3 cmol$_c$kg^{-1}. Plots that did not contain sugar maple seedlings or saplings were associated with base-depleted soils (Figure 11) that were low in pH and received relatively high levels of acidic deposition. There was a general absence of sugar maple saplings throughout the study region (Figure 6).

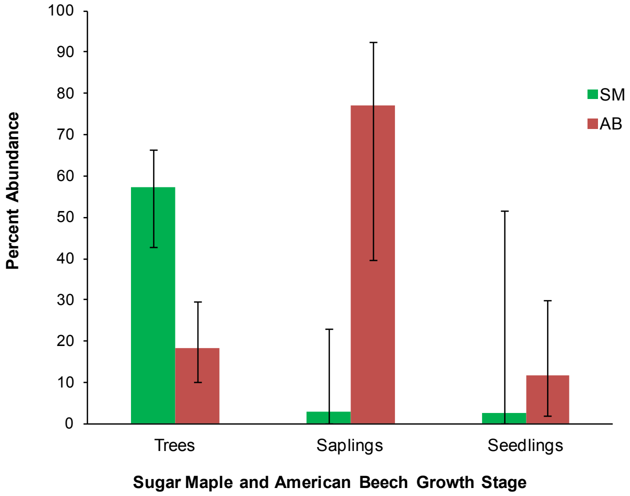

Figure 6. Growth stage abundance of sugar maple (SM) and American beech (AB), the two dominant canopy tree species in Adirondack northern hardwood forests. Abundance is represented as a percent of the total plot basal area for trees and saplings, and as a percentage of the total plot count for seedlings.

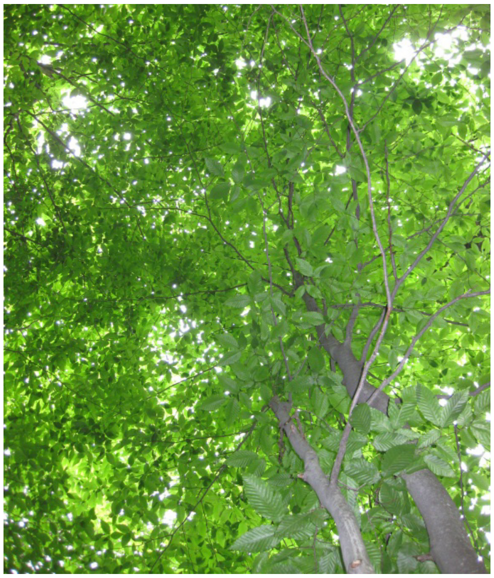

Figure 7a. Example of northern hardwood forest showing a healthy canopy. (Source: E&S)

Figure 7b. Example of northern hardwood forest showing poor canopy condition. (Source: E&S)

Figure 8. Project scientist surveying plot containing abundant sugar maple seedlings. (Source: Greg Lawrence)

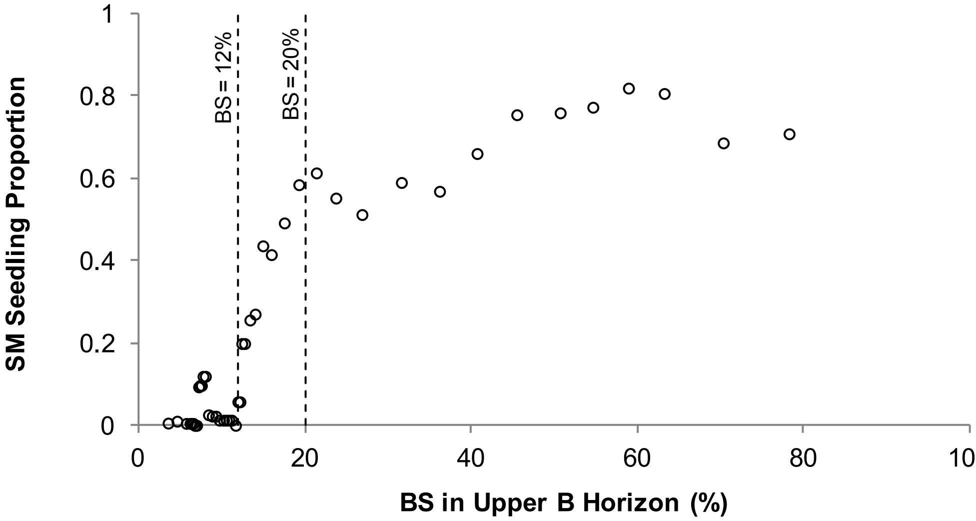

Figure 9. Relationship between the proportion of seedlings that were sugar maple and soil base saturation (BS) in the upper B horizon. Plots were rank ordered for this analysis based on soil BS and a five-plot rolling average was applied to both the soil BS and the seedling proportion data. These results suggest a near complete absence of sugar maple regeneration at sites where upper B soil horizon base saturation is less than about 12%. Earlier modeling results suggest that there are more than 1,000 acid-sensitive lake watersheds in the Adirondacks that have upper B horizon soil base saturation this low.

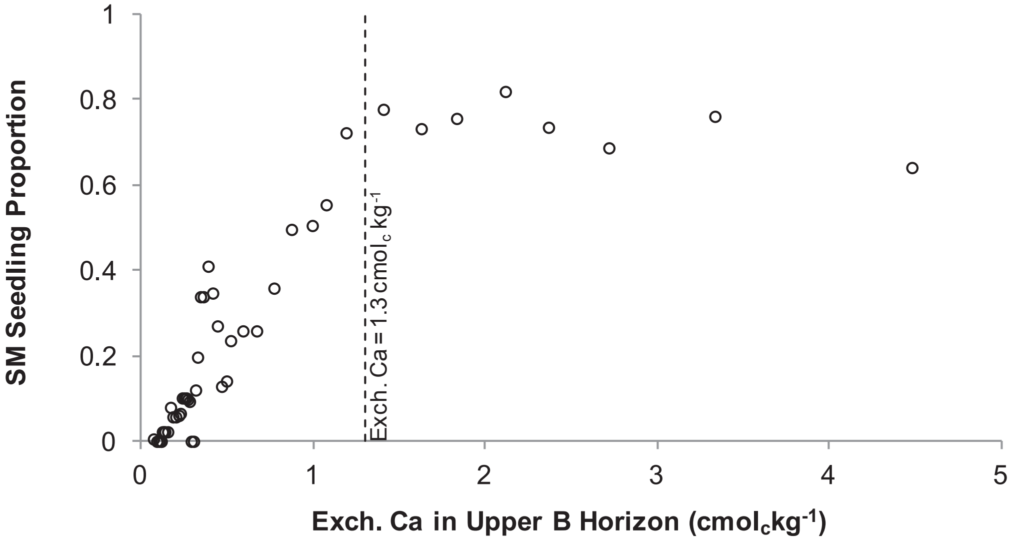

Figure 10. Relationship between the proportion of tree seedlings that were sugar maple and exchangeable calcium (Ca) in upper B horizon. Plots were rank ordered for this analysis based on soil exchangeable Ca and a five-plot rolling average was applied to both the soil exchangeable Ca and the seedling proportion data.

An overall response score was generated for each of the 50 study plots based on aspects of sugar maple regeneration, growth response, and canopy condition. A plot was given a point for each favorable condition for sugar maple that was observed. Favorable conditions included presence of sugar maple seedlings, absence of significant decline in growth between 1950 and 2005, and moderate or high vigor. Points were summed to generate overall response scores that ranged between 0 and 3. Estimated levels of acidic deposition, upper B soil horizon acid-base chemistry (as represented by base saturation) and the overall sugar maple response score all showed consistent spatial patterns, ranging from high impacts in the southwestern Adirondack region to low impacts in the northeastern Adirondacks (Figure 12). Soil base saturation in the upper B horizon was generally lower on plots with low overall response scores.

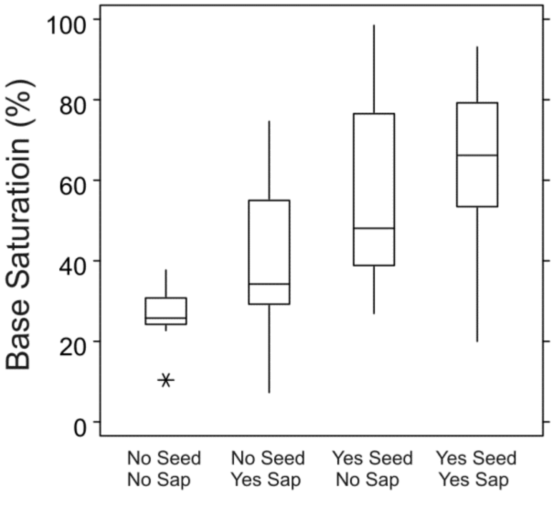

Figure 11. Box and whisker plot of soil base saturation in the A horizon for four groups of plots: those not containing either sugar maple seedlings or sugar maple saplings (No Seed, No Sap), those containing sugar maple saplings but not containing sugar maple seedlings (No Seed, Yes Sap), those not containing sugar maple saplings but containing sugar maple seedlings (Yes Seed, No Sap), and those containing both sugar maple saplings and sugar maple seedlings (Yes Seed, Yes Sap). Lowest base saturation was associated with an absence of sugar maple seedlings and saplings.

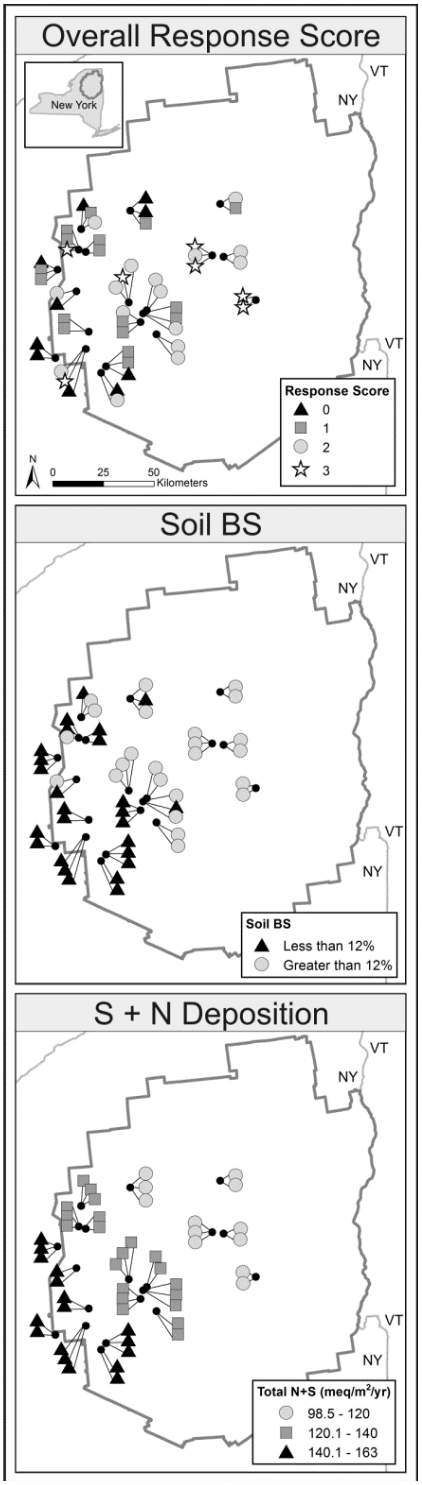

Figure 12. Maps showing the spatial distribution of sugar maple overall response score (upper panel), soil base saturation (BS) of the upper B soil horizon (middle panel), and estimated total wet plus dry atmospheric sulfur (S) plus nitrogen (N) deposition (bottom panel) at each of 50 study plots. One plot did not contain sufficient data with which to characterize tree decline; therefore, this plot was scored on a scale from 0 – 2 for the overall response score.

Project Implications

This research provides a foundation for determining the extent to which sugar maple trees and their watershed soils in the western Adirondack Mountains have been impacted by acidic deposition. It also helps in estimating the degree to which impacted forests can recover, both chemically (soils) and biologically (vegetation), following reductions in acidic deposition. This information will help policymakers better understand and evaluate the impact of current and future efforts to reduce acidic deposition in New York State and to determine locations where sugar maple recovery is not likely to occur in the absence of restoration activities.

Earlier modeling estimated that there are more than 1,000 acid-sensitive lake watersheds in the Adirondacks with soil conditions that this research found to be associated with a near complete absence of sugar maple regeneration. This suggests that the ecosystem services provided by sugar maple in the western and central Adirondack Mountain region, including aesthetic, cultural, and monetary values, are at risk from ongoing soil acidification caused in large part by acidic deposition.

Next Steps

The data collected in this project provide the technical foundation for calculating the critical loads of acidic deposition that will 1) protect sensitive Adirondack terrestrial resources, including sugar maple, from adverse impacts caused by acidic deposition, and 2) allow previously damaged resources to recover from acidification impacts. Project results also provide the basis for identifying Adirondack watersheds that are not likely to support sugar maple regeneration and sustain healthy growth without liming to restore calcium availability. These are locations where calcium availability has been depleted and natural processes are likely to be insufficient to restore calcium availability despite further reductions in atmospheric sulfur and nitrogen emissions and deposition.

Acknowledgments

This research was funded by a grant from NYSERDA Environmental Monitoring, Evaluation, and Protection Program, under the direction of Greg Lampman, to E&S Environmental Chemistry, Inc. Field sampling assistance was provided by M. Brand and M. Leopold. Data analysis and graphics assistance was provided by A. Herlihy, D. Moore, and S. Mackey.

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