Investigating Decreasing Growth Rates of Sugar Maple in the Adirondacks

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Recent research in the northeastern United States and eastern Canada suggests that sugar maple faces an uncertain future. Branch loss, discoloration in leaves, decreased nutrition, a reduction in sapling counts, and large die-off events in some regions have researchers concerned over the health and viability of maple populations.[1-4] The term coined for this phenomenon is 'maple decline',[5] and evidence of this decline has been observed across sugar maple's range. Researchers have been on alert to identify the causes of these decline episodes, proposing long-term effects from acid rain, insect outbreaks, disease, competition, and climate as possible inciting factors.[1,4,6] Up to this point, relatively little work had been conducted investigating trends and influences of the annual growth of sugar maple trees, utilizing the widths of tree rings to estimate growth rates for each year. Using this tree-ring approach, recent research suggests that growth rates have been decreasing in the Adirondack Mountains of New York State.

Growth rates are an important indicator of forest productivity, especially when observed over a large area. For foresters and ecologists, forest productivity is a strong proxy of the health, nutrition, and viability of a stand. When trees are not experiencing heavy stress – e.g. from climate-, nutrient-, or forest density-based sources – they should be growing at a steady rate over time. However, when essential nutrient pools are depleted or an unusually dry summer suddenly reduces the available water supply in soils, the tree's growth rate will decrease. The severity and duration of these stressors can have varying effects on the annual growth rates of trees.

Two major mechanisms of stress over the last 50-60 years to sugar maple populations have come from acid rain and climate change. The first, acid rain, is a well-documented stressor in the northeastern United States, especially in the Adirondacks. Sugar maple is 'calciphillic', in that its productivity is very dependent on calcium availability in soils. In effect, the species is highly vulnerable to soil acidification from acid rain, which leads to depleted soil calcium availability and the mobilization of inorganic aluminum. The increased aluminum concentrations intensify the negative effects of acid rain on sugar maple productivity by blocking root uptake of calcium and other essential nutrients.[7] Intuitively, a reduction in essential nutrient uptake can disrupt the production of different plant functions, such as reducing growth rates. Thankfully, since the federal Clean Air Act was enacted in 1963, large-scale reductions in acid deposition have been observed,[8] indicating that sugar maple productivity should be improving. Whether it is an immediate or delayed response, enough time has passed to facilitate some recovery of the slowest-growing trees.

The second major mechanism of stress, climate change, is also a well-documented stressor for all tree species, both regionally and globally. Niche models - models that predict suitable habitats for different tree species under different climate change scenarios - predict that sugar maple will experience a large reduction in range and prominence in eastern North American forests by the turn of the century.[9] However, very little work has been conducted to evaluate historical growth response of sugar maple to past climate conditions. A shift in the sensitivity of growth to climate or a strong correlation to seasonal or monthly temperature and precipitation would present a novel understanding of the susceptibility of the species under different climate change scenarios.

Given this prior knowledge of sugar maple and its changing environment, we were compelled to ask two questions: (1) How have the growth rates of sugar maple changed over recent years; and (2) How has sugar maple productivity responded to recent changes in climate and acid deposition? To answer these questions, my co-authors, Colin Beier and John Stella of the SUNY College of Environmental Science and Forestry, Neil Pederson of Harvard Forest, Greg Lawrence of the US Geological Survey, and Tim Sullivan of E&S Environmental Chemistry, Inc., and I assessed the growth rates of range-centered sugar maple populations across 18 stands in the Adirondack Mountains and published our findings in the peer-reviewed journal *Ecosphere*. Through sampling efforts conducted in 2009 and 2011, we collected and processed 450 increment cores from 242 trees over a

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wide gradient of soil chemistry composition. To calculate growth rates, we measured raw annual ring-widths for each increment core, and then scaled to basal area increment (BAI) to remove the effects of tree size on growth rates. Using BAI, we were able to evaluate long-term trends in annual growth rates for individual trees, identifying the total number of trees experiencing reductions in growth rates along with the timing (years) of these growth reductions. We then compared the average BAI during the periods of declining growth rates to site-level soil chemistry variables, with the expectation that growth rates would be lowest on acid-impaired sites (low calcium, high aluminum availability). We also took the ring-widths and removed long-term geometric trends and ecological disturbance using a statistical detrending technique to isolate interannual variability in growth. Finally, we compared these ring-width indices to climate variables to evaluate the climatic sensitivity of sugar maple growth, with the expectation that the growth sensitivity to climate would be weakest on the most acid-impaired sites.

We were surprised to find that the majority (57%) of sugar maple trees exhibited negative growth trends over recent years (Figure 1). Across the entire population, we observed declining growth rates in a large number of trees after 1970 with an intensification after 1990 (Figure 2). These decreasing growth rates were not anticipated by any of us at the onset of our study, as we sampled across a wide range of age classes in both healthy and unhealthy stands. In addition, recent warming[10] and increases in summer precipitation totals and rainfall frequency[10-12] in the region combined with reductions in acid deposition8 should have led to stabilized or increased growth rates.

Our results also yielded mixed results to the direct causes of this growth decline. We found weaker than anticipated growth sensitivity to climate. Specifically, sugar maple growth had positive correlations with summer precipitation and late winter precipitation, and negative correlations with summer minimum (overnight) temperatures. Growth sensitivity to climate did change over time, but we will need to engage in further research to resolve the mechanisms

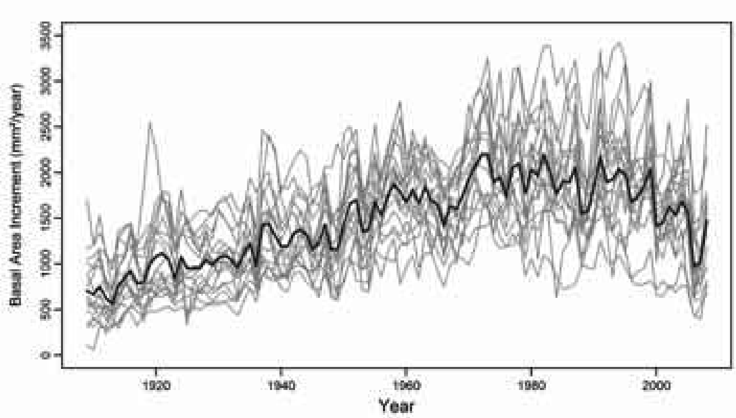

Figure 1. Growth patterns of canopy-dominant sugar maple across a network of upland forests (n = 18) in the Adirondack Mountains, New York (USA). Basal area increments (BAI) are averaged by site (grey lines) and region (black line).

of these changes. As hypothesized, we found that growth was lower for trees growing in acid-impaired soils (low calcium, high aluminum), but the trends in growth rates and timing of the declines were not related to soil chemistry. This led us to conclude that growth rates were decreasing regardless of soil chemistry, in that both base-rich and acid-impaired soils both were supporting sugar maple trees with decreasing growth rates.

Changes in long-term growth rates are quite informative for forest management decision-making and act as a useful proxy for many different ecosystem services. For example, if these observed growth declines continue over a large area, we may experience reductions in carbon sequestration in these maple-dominated forests, as well as major disruptions in nutrient cycling and reductions in habitats of other forest species. Under this scenario, foresters would need to consider adapting future management plans of maple-dominated forests.

Of course, one of the major services of maple-dominated forests is sugar maple sap production. It certainly is too early to tell whether our findings will lead to reductions in sap yield. Our study did not directly test for changes in sugar content in sap or overall sap production in the region. Further, it is important to note that these trees were all sampled in state forests. These forests had experienced little management over recent years and sugar maple trees had not been tapped. However, a decline in growth rates could signal a reduction in energy and resources in an individual. Depending on a species' plasticity, resources can be allocated to

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varying degrees among many different functional and structural components of a plant, and a reduction in one function could signal a change in another function. Further research will be needed to evaluate whether these changes have greater implications for the maple syrup industry.

In conclusion, our study raises concern over the future of sugar maple in the Adirondack Mountains. We have discovered new evidence of decreasing growth and productivity in the region. Although decreased growth rates do not necessarily indicate that a tree's death is forthcoming or that recovery is unattainable, this observed trend over such a large area could indicate a significant problem for the species. Other studies have raised concerns that similar patterns may be observed across the northeastern United States and eastern Canada, warranting further study over a larger area. Despite our study's findings, there is no immediate need for panic among maple syrup producers; however we suggest scientists and stakeholders monitor productivity of this extremely important species over the coming years to establish whether growth declines are occurring more widely across sugar maple's range. If we do continue to observe these trends, the sustainability of this iconic and highly valued species will need to be addressed.

Notes

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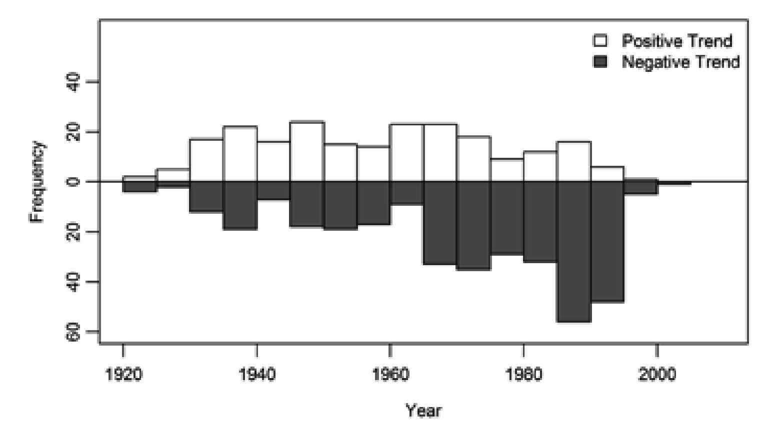

Figure 2. Frequency of individual tree growth trends through time (bin = 5 years). Positive trends in growth are shown in white and negative trends are in grey. Only significant trends are displayed ($p < 0.05$).

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