Factors Contributing to Sugar Maple Decline Along Topographic Gradients on the Glaciated and Unglaciated Allegheny Plateau

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Popular Summary

In the early to mid 1980s, foresters began to notice a reduced level of sugar maple health characterized by unusual mortality of large trees, decreased crown vigor and crown dieback. Affected trees most often were located on the upper slopes of unglaciated sites; sugar maple on the lower slopes of unglaciated sites and in any landscape position on glaciated sites seemed less affected or unaffected. These observations were made against a background of unusual levels of insect defoliation and untimely climatic events (Drohan and Stout this volume).

During the past 30 years, declines of sugar maple have been reported in Massachusetts, Ontario, Quebec, Vermont, New York and Pennsylvania (Kolb and McCormick 1993). While defoliation and other stress factors also seem to be involved in each of these situations, nutrient deficiencies, particularly of base cations including Ca, Mg and K, seem to be a common thread in all of these declines. Recently, Long et al. (1997; this volume) reported that addition of dolomitic limestone at four high elevation unglaciated sites in north central Pennsylvania resulted in significantly increased sugar maple survival, crown vigor, diameter and basal area increment, flower and seed crop production. Black cherry and American beech were unaffected by lime addition. Lime significantly increased foliar concentrations of Ca, Mg, the Ca:Al and Mg:Mn molar ratios and decreased foliar concentrations of potentially toxic Al and Mn. On unlimed plots, trees with high crown vigors had higher foliar concentrations of Ca and Mg than trees with moderate crown vigor. And for all trees, mean BAI was positively correlated with foliar concentrations of Ca and Mg and negatively correlated with foliar concentrations of Al and Mn. Overall, the study showed that Ca and Mg supplies and perhaps those of potentially toxic ions like Al and Mn were important for health and growth of sugar maple.

Northwestern and north central Pennsylvania and southwestern New York lie at the boundary of the Wisconsin and earlier glacial advances. Areas to the north were glaciated as recently as 12,000 to 21,000 years ago; those south of the terminal moraine are older and have not been glaciated. Soils on glaciated portions of the Allegheny Plateau are Inceptisols and generally have higher supplies of base cations than the Ultisols found on unglaciated areas, but the distribution of Ca, Mg, Al and Mn with topographic position was not known.

In the present study, we investigated the relationship between sugar maple health and 1) glacial history, 2) topographic or physiographic position, 3) site (elevation, aspect) and stand characteristics (species composition, structure, density), 4) disturbance history (management, defoliation), and 5) foliar nutrition.

Methods

A series of plots was established in stands along topographic gradients at 19 sites across the glaciated and unglaciated portions of the Allegheny Plateau in northwestern and north central Pennsylvania and southwestern New York. In 1995, plots were established on upper, mid- and lower topographic positions at 5 sites; these were supplemented in 1996 with plots on upper and lower topographic positions at 14 additional sites. In all there are 43 stands; 18 on glaciated soils and 25 on unglaciated soils. In each stand, we identified 5 dominant or co-dominant sugar maple trees that were judged to be healthy by lack of crown dieback. These trees were used for mid-crown foliage collection during the last 2 weeks in August. Foliar levels of N, P, K, Ca, Mg, Al and Mn were determined for each tree, then averaged for each stand. The foliage sample trees became the locus for plots to evaluate other site and stand characteristics.

Health of all trees including sugar maple was measured in mid- to late July on three 400 m^2 plots in each stand using North American Maple Project protocols (Cooke et al. 1996). Four parameters were calculated for sugar maple which gave an estimate of sugar maple health over different time scales: % Dead sugar maple basal area (PDEADSM), crown vigor index (SMVIG), crown dieback (SMDIE) and crown transparency (PTRANS). Cluster analysis was used to determine which health variable best discriminated healthy from unhealthy stands. PDEADSM, the best health measure, separated the 43 stands into a healthy group of 37 stands with 0 - 11% dead sugar maple basal area and an unhealthy group of 6 stands with 21 - 56% dead sugar maple basal area.

Stand species composition, structure and density were calculated from data obtained on the three 400 m^2 plots. Species composition was evaluated as the percent of the total basal area that was sugar maple and the percent of the total basal area that was black cherry. Relative sugar maple diameter was the measure of stand structure and expresses the relative position of sugar maple in the diameter distribution of the stand. Relative density was used as the measure of stand density.

At each site, aspect was estimated with a compass and elevation was determined from 7.5 minute topographic maps after geolocating the sites with a GPS unit.

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Information on disturbance histories was determined from two sources: 1) annual layers of digitized defoliation sketch maps were queried to determine the timing, severity and agent of defoliation, and 2) land managers who were responsible for each stand were contacted and queried concerning stand management history and additional information on stand defoliation history.

Results

Thirty-three of the 43 stands were on north and east facing slopes; 4 (12%) were unhealthy. The remaining 10 stands were on south and west facing slopes; 2 (20%) were unhealthy. All of the unhealthy stands were at elevations >500 m, but there was not a precise relationship between sugar maple health and elevation.

Health of sugar maple varied with glacial history and topographic position. Sugar maple were uniformly healthy and there were no trends with topographic position on glaciated sites. But on unglaciated sites, PDEADSM was higher on upper than lower topographic positions. Health on the lower slopes of unglaciated sites was indistinguishable from that on glaciated sites. Each stand was categorized according to its physiographic position. Summits, shoulders and upper backslopes represent the positions in the landscape where the soils are most leached and the driest; mid- and lower backslopes have moderate leaching potential and higher moisture. Foot and toe slopes and enriched sites such as those with concave microtopography, benches or seeps have the least potential for leaching; soil moisture is variable depending upon position in the landscape and the nature of enrichment. On unglaciated sites, stands with unhealthy sugar maple were located on summits, shoulders and upper backslopes. But, all stands in these physiographic positions were not unhealthy. Stands on mid- and lower backslopes, on foot or toe slopes or on enriched sites remained healthy.

Among the stand variables, competitive effects of black cherry, which forced sugar maple into a lower crown position and a lower relative diameter, seem to be the most important. The proportion of sugar maple in the stand and the stand relative density had little relationship with sugar maple health. Overall, the effects of stand parameters on sugar maple health were relatively small.

Disturbances caused by stand management activities also had little effect on sugar maple health. Thinning was the only management activity at the study sites over the past 20 years. Eleven of the 43 stands were thinned from 4 - 20 years previously. The remaining 32 stands had no management activity in the past 20 years. Thinning did not predispose or protect sugar maple from decline in the long term. Two thinned and four unthinned stands were among the six stands with unhealthy sugar maple.

Defoliation disturbance played a key role in determining which stands were unhealthy. We evaluated the number of defoliation events and defoliation severity for the 10 and 20 year period prior to overstory health evaluation. A defoliation severity index was constructed by assigning a value of 3 to a heavy defoliation where >60% of the foliage was lost, a 2 to moderate defoliations where 30 - 60% of the foliage was lost and a 1 to a light defoliation where <30% of the foliage was lost. These values were summed over the 10 or 20 year period prior to health evaluation. The most recent 10 year period proved to be the most important. The upper slopes of unglaciated sites were defoliated more often and more severely than the lower slopes of unglaciated sites or any topographic position on glaciated sites. Both the number and severity of defoliation events had an effect on sugar maple health. Stands with unhealthy sugar maple were those defoliated 2 or more times during the past 10 years with a defoliation severity index of 4 or more, representing two moderate defoliations. However, all stands with these defoliation history characteristics did not have unhealthy sugar maple, suggesting that there must be something which makes trees in some stands more resilient to repeated defoliation.

There were important relationships between foliar levels of Ca, Mg, Al and Mn and glacial history, topographic position, physiographic position and sugar maple health. Foliar chemistry data were expressed on concentration, content and leaf area bases. There were no differences in interpretation of the results among these expressions. There also were no relationships between foliar N, P and K and sugar maple health.

Comparison of the foliage chemistry of healthy sugar maple on glaciated and unglaciated sites showed that trees on glaciated sites had more Ca and Mg and higher molar ratios of Ca:Al, Ca:Mn and Mg:Mn, similar amounts of Al and less Mn than trees on unglaciated sites. There were few differences in foliar values between upper and lower slopes of glaciated sites; trees in upper slope stands had similar levels of Ca, Mg, and Al and molar ratios of Ca:Al, Ca:Mn, and Mg:Mn and more Mn than trees in lower slope stands. On unglaciated sites, there were important differences. Foliage from trees in upper slope stands had less Ca and Mg, lower molar ratios of Ca:Al, Ca:Mn, and Mg:Mn and more Al and Mn than foliage from trees in lower slope stands. Similar trends in foliar nutrition were found when each stand was assigned to a physiographic position.

Foliar nutrition was correlated with sugar maple health and with defoliation disturbance history. Foliar Mg, Mn and the Mg:Mn molar ratio were significantly correlated with PDEADSM and the Ca:Al molar ratio was marginally correlated with PDEADSM. Foliar Mg content showed a strong relationship with PDEADSM. Stands with less than threshold amounts of foliar Mg became unhealthy, if the stands had had ³2 moderate or severe defoliations (defoliation severity index ³4) during the past 10 years. Stands with greater than threshold levels of foliar Mg could withstand greater numbers and severity of defoliation and still remain healthy. Foliar Mn alone could not be used to distinguish healthy from unhealthy sites. All stands which became unhealthy had relatively high foliar Mn content, but in some stands, trees with foliar Mn as high or higher than those which became unhealthy remained healthy; these trees had greater than threshold amounts of Mg. The molar ratio of Mg:Mn did not distinguish healthy from unhealthy stands as well as foliar Mg alone.

Discussion

Our work confirms the observations of practicing foresters that sugar maple is healthy on glaciated sites and the lower slopes of unglaciated sites. Unhealthy sugar maple was found on unglaciated upper slopes in the summit, shoulder and upper backslope physiographic positions. These sites had the lowest foliar Ca and Mg, the highest Al and Mn, and were defoliated more often and more severely than any other landscape position. Poor base cation status of upper slope sites probably is the result of long-term weathering of initially base-poor substrates, which may be aggravated by acid deposition. Flowpaths of water which is in contact with Ca and Mg-containing bedrock may explain the higher base cation status of lower slope unglaciated sites (Bailey et al. this volume).

Foliar Mg was the key ion associated with sugar maple health. Healthy trees had greater than threshold amounts of foliar Mg. Mg interacted with defoliation stress. Unhealthy trees were those with low Mg AND two or more moderate or severe defoliations in 10 years. Sugar maple remained healthy on low Mg sites if defoliation stress was low. This is corroborated by the fact that sugar maple with low foliar Ca and Mg and low stress in New England remained healthy (Hallett et al. this volume). Furthermore, trees with greater than threshold foliar levels of Mg were more resilient to stress, withstanding greater numbers and severity of defoliation. Foliar levels of Mn seem to be important only when there is inadequate Mg; at present, the role of Mn in sugar maple decline is unclear.

The decline of sugar maple fits the definition of a decline-disease: a syndrome of canopy-dominant trees characterized by gradual deterioration in health and vigor which leads to death (Manion 1991; Houston 1992). Decline-diseases seem to result from complex interactions of factors that predispose or weaken trees, followed by inciting or triggering events that result in dieback and mortality. Our study suggests that sugar maple decline occurs as a result of an interaction between imbalanced Mg nutrition and excessive defoliation stress. Sugar maple with low foliar levels of Mg (and Ca) photosynthesize at a lower rate than those with higher levels of these cations (Liu et al. 1997). The level of storage carbohydrates accumulated by trees growing on base cation-poor sites likely is less than those growing on base cation-rich sites. Thus, trees growing on base cation-poor sites are predisposed to be less resilient to stress because they have less carbohydrate reserves to maintain living tissue and repair damaged tissue. Stresses such as defoliation, particularly those that are severe enough to cause refoliation, and to a lessor extent drought, trigger or incite decline because they result in a substantial drain on storage carbohydrates (Wargo this volume). Under these circumstances, trees first dieback, reducing the amount of living tissue that is supported by storage carbohydrates. If stress continues trees often die, either as a result of carbohydrate starvation or from the action of secondary organisms such as *Armillaria*, which invade the weakened trees (Wargo and Harrington 1991).

For land managers, the implication of our study is that unglaciated upper slope sites in northwestern and north central Pennsylvania are sensitive sites where sugar maple and other high base cation-demanding species may be at risk during stress events such as insect defoliations. They are areas where land managers should focus insect monitoring and suppression activities and consider management activities that favor species with lower base cation requirements.

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