

# Spatial Relationships Between Sugar Maple (*Acer saccharum* Marsh), Sugar Maple Decline, Slope, Aspect, and Atmospheric Deposition in Northern Pennsylvania

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## Popular Summary

Sugar maple decline began to affect Allegheny Plateau forests in the early to mid-1980s. The forests of the region were exposed to several stresses in the period from 1985-1996, including droughts during 1988, 1991, and 1995. Additionally, both native and exotic insects reached epidemic levels during this period (see, for example, Rhoads, 1993). Other documented stresses in the region include past and present harvesting practices (Allen and others 1992), herbivory by deer (Tilghman 1989), and low soil nutrient availability (Long et al. 1997, DeWalle and Swistock 1997) possibly associated with soil acidification (Hendershot and Jones 1989).

Examination of sites experiencing sugar maple decline has yielded much valuable information about the potential causes of decline but has not provided estimates of the relative abundance of declining sugar maple sites or their spatial distribution within northern Pennsylvania. Nor did these studies provide an opportunity to contrast declining sugar maple stands with those that are not declining across a large geographic area. These estimates are desirable from both policy and scientific perspectives.

The long-term goal of our research is to characterize sites with sugar maple decline across northern Pennsylvania. In this preliminary work, our objectives were:

- to determine if the decline could be detected using data collected by the USDA Forest Service Forest Inventory and Analysis program (FIA) between 1978 and the late 1980s (Alerich 1993); and,
- to characterize the relative abundance of sugar maple decline and the sites on which declining and healthy sugar maple was found in the late 1980s across northern Pennsylvania.

This paper reports preliminary results from our study.

## Methods

We limited our study to the Pennsylvania portions of the Northern Unglaciaded Allegheny Plateau Section (212G) and the Northern Glaciaded Allegheny Plateau Section (212F) of Bailey's Ecoregions and Subregions of the United States (Bailey and others 1994). These regions are characterized by northern hardwood forests and encompass the range of reports documenting sugar maple decline within Pennsylvania (Laudermilch 1995; McWilliams et al. 1996).

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We excluded points in which overall basal area fell below the threshold of continuous forest cover ( $9.2 \text{ m}^2 \text{ ha}^{-1}$ ) and those in which sugar maple basal area was insufficient for analysis ( $2.3 \text{ m}^2 \text{ ha}^{-1}$ ). We found that 248 plots met these criteria (Figure 1); 140 plots were located in unglaciaded Section 212G and 108 in glaciaded Section 212F. Locations recorded at the center of each FIA plot were entered into a geographic information software program to create a map of stand locations and to provide points for later analysis.

FIA plot coordinates for this preliminary study consisted of actual longitudes and latitudes rounded to the nearest 100 seconds. The imprecision of FIA plot locations limited our preliminary analysis to variables (such as slope and aspect) measured directly at sample locations by FIA or to variables whose spatial resolution was compatible with plot location accuracy.

Several variables were chosen from the FIA database to determine the health status of the sugar maple population as measured in 1989. These variables were sugar maple basal area mortality in 1989 (SMBAM) and sugar maple basal area change 1978-1989 (SMBAC—we added any sugar maple basal area cut during the period to the 1989 value). We also calculated the percent dead sugar maple basal area (PDSMBA) (sugar maple basal area mortality as a percent of total living and dead sugar maple basal area), and percent sugar maple basal area change (PSMBAC) (sugar maple basal area change as a percent of basal area in 1979).

We used K Means Cluster Analysis (Minitab Inc. 1994) with these four variables to determine whether the data would cluster into healthy and declining subpopulations with sufficient separation for analysis. For slope and aspect, we tested for differences between clusters and between glacial regions as well as within region using the non-parametric Kruskal-Wallis test. Kruskal-Wallis contrasts use variable ranks rather than variable values in tests of significance. Therefore, we examined the differences in medians wherever rank difference suggested statistical significance to determine whether the differences were likely to be biologically meaningful (Minitab Inc 1994).

Wet deposition data, based on a spatially explicit model for Pennsylvania (Lynch et al. 1995), were obtained in digital format for 1987-1989 ( $\text{NO}_3$ ,  $\text{NH}_4$ ,  $\text{SO}_4$ , H, Ca, and Mg ( $\text{kg ha}^{-1} \text{ yr}^{-1}$ )). We used the mean deposition over the three-year period for each element for our tests. Again, the Kruskal-Wallis test was used to contrast the deposition rankings of healthy and declining clusters across the state and within each glacial region.

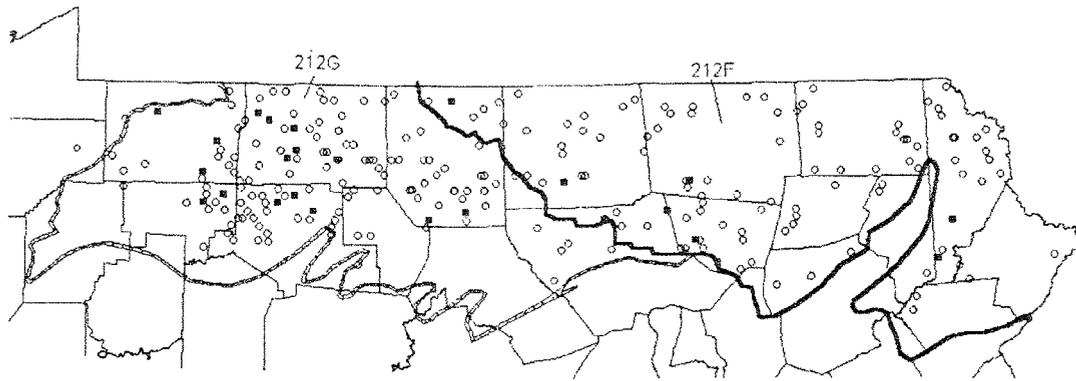


Figure 1.—Map showing the 248 FIA plot locations and the health status assigned by K-means cluster analysis (○healthy cluster, ■declining cluster). The map shows political boundaries and ecoregion boundaries (the solid line shows the boundary of glaciated Section 212F and the thin double line shows the boundary of unglaciated Section 212G).

## Results and Discussion

### Clustering for Health Status

Our best separation using cluster analysis resulted in the two populations seen in Figure 1 (223 healthy stands and 25 declining stands). This was achieved with all four standardized health variables (SMBAM,  $F=298$ ; SMBAC,  $F=111$ ; PDSMBA,  $F=458$ ; PSMBAC,  $F=31$ ) in the cluster analysis. Percent dead sugar maple basal area (PDSMBA) was the strongest variable contributing to the clustering. There were 123 members of the healthy cluster and 17 members of the declining cluster (about 12% in Ecoregion 212G, the unglaciated section, and 100 members of the healthy cluster and 8 (about 7%) members of the declining cluster in Ecoregion 212 F, the glaciated area. While this difference suggests that there is a tendency towards a higher proportion of declining cluster members in the unglaciated section, the difference is not significant ( $p=0.22$ ).

The declining cluster included stands with 1989 measurement period basal areas ranging from 9.2  $m^2 ha^{-1}$  to 38.9  $m^2 ha^{-1}$ , with a median of 25.9  $m^2 ha^{-1}$  (Table 1). Percent dead sugar maple basal area ranged from 20 to 80 percent, with a median of 33 percent. In the healthy cluster, 1989 measurement period basal area ranged from 9.2  $m^2 ha^{-1}$  to 41.7  $m^2 ha^{-1}$ , with a median of 25.9  $m^2 ha^{-1}$ . In this cluster, percent dead sugar maple basal area ranged from 0 to 26 percent, with a median of 0 percent. Figure 2 shows percent dead sugar maple basal area in the two clusters plotted against their case number in the file.

Both the proportion of the stands with decline and the characteristics of the declining cluster are comparable to results found by Horsley et al. (this volume) in their study of topographic gradients in northern Pennsylvania and

## SUGAR MAPLE MORTALITY BY CLUSTER

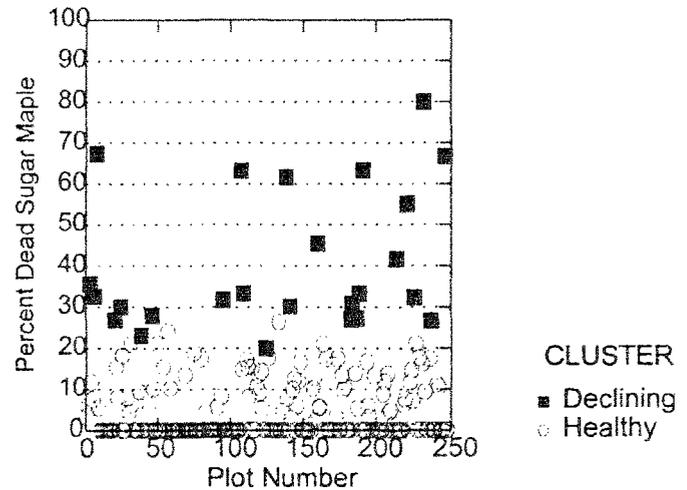


Figure 2.—Percent dead sugar maple basal area in the healthy and declining clusters (○healthy cluster, ■declining cluster).

southwestern New York. Six of the 43 plots that they examined (14%) were declining; all of these plots had a percent dead sugar maple basal area in excess of 20 percent, and all the plots in their healthy cluster had percent dead sugar maple basal area less than 20 percent. All of the plots in the Horsley et al. declining cluster occurred within the unglaciated region, but our analysis detected no difference in the rate of decline between regions. Our study area extends further east and west than the Horsley et al. study, specifically including a larger portion of the glaciated region.

**Table 1.—Medians, means ( $\pm$  standard deviation) of selected characteristics as measured or calculated from data collected during the 1978 and 1989 measurement cycle from plots in the healthy and declining clusters used for this analysis. SMBA = Sugar maple basal area.**

Cluster	Basal area (m <sup>2</sup> ha <sup>-1</sup> )	SM BA (m <sup>2</sup> ha <sup>-1</sup> )	Change in SM BA (m <sup>2</sup> ha <sup>-1</sup> )	SM BA mortality (m <sup>2</sup> ha <sup>-1</sup> )	% change, SM BA	% Dead SM BA
All stands	25.9	6.9	1.2	0.0	14	0
medians						
means ( $\pm$ SD)	25.6( $\pm$ 7.3)	8.0( $\pm$ 5.2)	1.4( $\pm$ 2.2)	0.7( $\pm$ 1.2)	24( $\pm$ 46)	8( $\pm$ 14)
1 – healthy	25.9	7.0	1.4	0.0	17	0
medians						
means ( $\pm$ SD)	25.6( $\pm$ 7.2)	8.3( $\pm$ 5.3)	1.7( $\pm$ 1.8)	0.4( $\pm$ 0.6)	30( $\pm$ 46)	4( $\pm$ 6)
2 – declining	25.9	4.4	2.1	2.8	-21	33
medians						
means ( $\pm$ SD)	25.2( $\pm$ 8.2)	5.2( $\pm$ 3.3)	-2.3( $\pm$ 1.9)	3.3( $\pm$ 1.9)	-22( $\pm$ 16)	41( $\pm$ 17)
212F-glaciated	24.5	6.3	1.7	0.0	18	0
medians						
means ( $\pm$ SD)	24.7( $\pm$ 7.6)	8.3( $\pm$ 5.8)	1.7( $\pm$ 2.1)	0.5( $\pm$ 1.0)	33( $\pm$ 56)	6( $\pm$ 12)
212G-unglaciated	26.7	7.0	0.9	0.2	10	3
medians						
means( $\pm$ SD)	26.4( $\pm$ 7.0)	7.8( $\pm$ 4.8)	1.1( $\pm$ 2.2)	0.8( $\pm$ 1.3)	18( $\pm$ 36)	10( $\pm$ 15)

**Table 2.—Percent of sugar maple plots on each aspect by ecological subsection.**

Region	Aspect			
	North	South	East	West
Entire State	39	14	31	16
Glaciated 212F	38	12	29	21
Unglaciated 212G	39	16	33	11

**Table 3.—Median deposition for several ions for healthy and declining clusters, and the p value for the Kruskal Wallis test of differences between clusters. For the Kruskal-Wallis test, the values of a variable are transformed to ranks (ignoring group membership) to test that there is no shift in the center of the groups (that is, the centers do not differ). Thus, a low p value indicates that the groups differ in rank for a particular deposition variable.**

Ion deposited	Median deposition, healthy cluster (kg ha <sup>-1</sup> yr <sup>-1</sup> )	Median deposition, declining cluster (kg ha <sup>-1</sup> yr <sup>-1</sup> )	Kruskal Wallis p
Ammonium	2.6	2.9	0.02
Calcium	1.1	1.3	0.04
Hydrogen	0.66	0.74	0.02
Magnesium	0.21	0.22	0.23
Nitrate	18.7	20.5	0.02
Sulfate	29.4	33.7	0.02

## Slope and Aspect

Sugar maple distribution across four main aspects (N, S, E, and W) was similar for all three areas studied: the entire state, the glaciated region, and the unglaciated region (Table 2). North and east aspects contained 70 percent of the sugar maple plots across the two regions.

Plots in this study occurred on slopes ranging from 0 to 62 percent (median = 16). In the glaciated region, percent slope ranged from 0 to 52 percent (median = 15) and in the unglaciated region, 0 to 62 percent (median = 17). No differences were detected between the distributions of slope steepness (percent) ( $p=0.645$ ) or aspects ( $p=0.291$ ) by glacial region. Nor were there significant differences across the state (slope  $p=0.283$ , aspect  $p=0.291$ ), within the glaciated region (slope  $p=0.958$ , aspect  $p=0.863$ ), or within the unglaciated region (slope  $p=0.214$ , aspect  $p=0.313$ ) in the distributions of slope or aspect between healthy and declining populations of sugar maple. These results are consistent with the observations of Whitney (1990) and Abrams and Ruffner (1995) who found increases in sugar maple abundance from presettlement times to the present. Comparisons are difficult because of slight differences in data form and organization. Using data from the early settlement period in a study area that spanned the glacial, ecoregional border, Abrams and Ruffner (1995) found that sugar maple preferred stream valleys and north-facing coves. Whitney (1990), working with presettlement data from the Allegheny National Forest (ANF), within the unglaciated ecoregion, found that sugar maple had a marked preference for plateau top landscape positions with slopes  $\leq 8$  percent. In an old-growth area on the ANF, Hough and Forbes (1943) found that sugar maple was more abundant on north-facing slopes.

## Deposition Variables

Nitrate, ammonium, sulfate, and calcium deposition falls on a distinct gradient from high levels in northwestern Pennsylvania to lower levels in northeastern Pennsylvania (Lynch et al. 1995). The spatial pattern of magnesium deposition is different from that of other elements, with a secondary peak deposition level near the eastern end of the Northern Tier.

Significant differences were found across the state between healthy and declining stands for all deposition variables ( $p=0.02$  through  $0.04$ ) except magnesium ( $p=0.23$ ). Median differences in deposition values were small in all cases (Table 3). The same pattern was found within the unglaciated region. Within the glaciated region, differences between plots in the healthy cluster and those in the

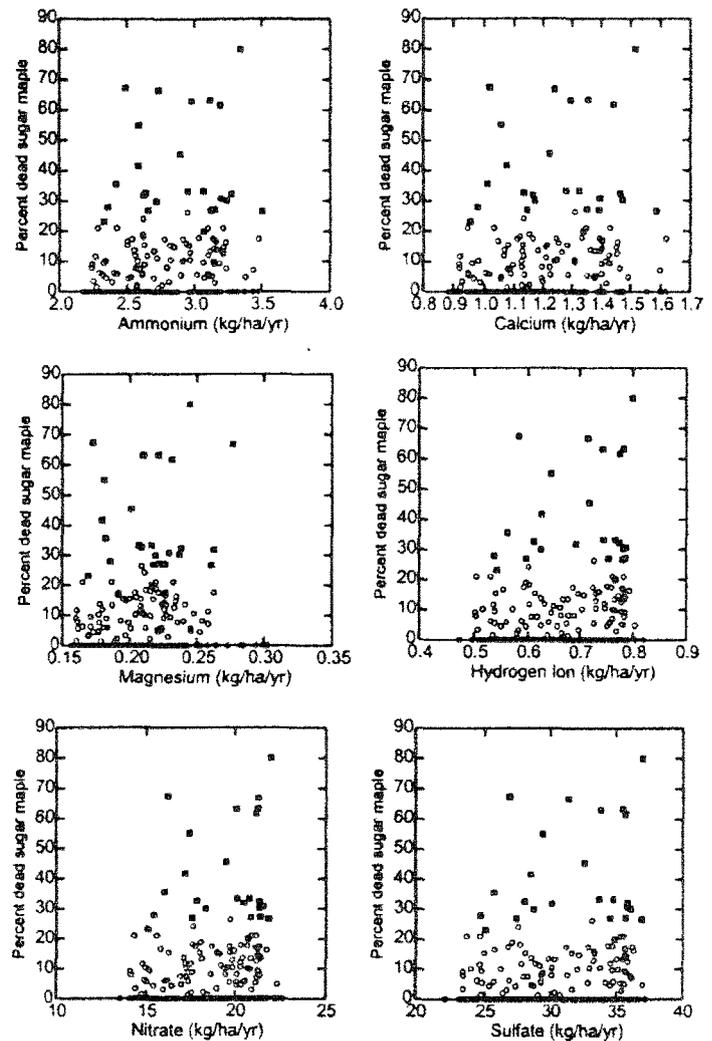


Figure 3.—Percent dead sugar maple basal area vs. each of the deposition variables examined in this study ( $\circ$  healthy cluster,  $\blacksquare$  declining cluster). Deposition values are mean annual  $\text{kg ha}^{-1}$  for the period 1967-1989.

declining cluster were not significant ( $p=0.296$ ). Figure 3 shows the relationship between dead sugar maple basal area and each of the deposition variables for both ecoregions, including healthy and declining cluster plots.

This exploratory analysis of the correlation between deposition levels and sugar maple decline showed relationships that achieved statistical significance, but are associated with differences in actual deposition values that are unlikely to have biological meaning.

## Future Work

Future work on this project will include both additional analysis at the large geographic scale reported here and analysis of intensive field-sampled data from a subset of these plots. At the large scale, we plan to test for differences between declining and healthy plots with respect to historical defoliations, elevation, and topographic position with the 248 plots. We also plan to develop much more intensive site characterizations for a sub-sample of these plots. During the summer of 1998, a crew from the Pennsylvania State University collected data at thirty of the 248 plots used in this study. They sampled soil and vegetation at 15 plots with various levels of percent dead sugar maple basal area and 15 plots with no dead sugar maple.

At each plot, the crew remeasured basal area following the methods set by the FIA program during the previous survey in 1989, collected foliage for chemical analysis, and collected cores from three trees. Other data included: slope and aspect (8-pt. scale), topographic position, tree vigor, dieback and transparency, forest floor and soil characteristics, and ground vegetation. Analysis of soil and rock physical and chemical properties and foliar chemistry will allow us to detect much more specific characteristics that distinguish plots in the healthy cluster from those in the declining cluster.

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