Spatial Patterns of HWA Damage and Impacts on Tree Physiology and Water Use in the Black Rock Forest, Southern New York

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Abstract

This study was designed to document spatial patterns in HWA damage in three hemlock stands in the Black Rock Forest, southeastern New York, 4 to 8 years after adelgid infestation, and to quantify HWA impact on hemlock operating physiology and water use. In all three stands, damage was more severe along the stream courses and less severe away from the streams. A similar negative relationship was found between damage and distance from the forest/stand exterior. The data suggest that damage from HWA to large, native eastern hemlock stands progresses through stands in a linear manner over a course of several years, but these spatial differences in damage lessen over time. It is not known whether the pattern of lower damage away from stream channels is related to adelgid dispersal or to topoedaphic conditions. Managers can expect that mortality in hemlock stands will first occur at initial areas of contact on stand exteriors, potentially allowing more time to implement control strategies in interior locations. HWA damage reduces tree sap flow and transpiration but not simply as a linear function of defoliation damage class. During the summer, heavily damaged trees exhibited only 50% of the sap flow of other trees, but trees with lighter levels of damage showed no significant reduction. During the fall, however, sapflow drops precipitously in trees with moderate or high levels of damage compared to trees with lighter damage. Stand productivity and water use appear little impacted until an intermediate threshold of damage has occurred. Enhanced soil moisture availability may first be noticed toward the end of the growing season. Once trees reach heavily damaged status, water uptake and transpiration are severely reduced throughout the growing season, leaving substantially more water available for evaporation, runoff, and/or use by other plant species.

Keywords:

HWA damage, topography, sap flow, water use.

Introduction

Hemlock woolly adelgid (HWA) is having a devastating impact on eastern hemlock in many northeastern forests. Eastern hemlock, and land managers who wish to maintain its presence, are

disadvantaged by the lack of control by native predators and the lack of hemlock resistance to the detrimental impacts of HWA (McClure 1987, Orwig and Foster 1998). HWA continues to expand through the range of eastern hemlock, carried between stands by wind and animals. This study was designed to provide information for resource managers faced with the potential loss of hemlock stands. It addresses the questions:

- What spatial patterns are observed in HWA damage during the course of stand infestations?
- What impact does HWA damage have on hemlock operating physiology and water use?

The answers to these questions may assist managers in responding to new infestations in hemlock stands and enable them to predict responses in forest productivity and hydrology.

Methods

Spatial Analysis of HWA Damage. Three stands were selected for survey, ranging from 12 to 38 ha in size (Figure 1). HWA was first documented in the Black Rock Brook stand in 1992, in the Canterbury Brook stand in 1994, and in the Mineral Springs Brook stand circa 1996. Each of the stands is located along a stream course within the Black Rock Forest in southeastern New York. Transects were established every 100 meters along each stream, starting at the forest boundary and working toward the forest interior and stream headwaters. Each transect started from the streambed and extended away from the stream perpendicular to the direction of water flow. The point quarter method was used to gather stand composition data at survey points every 30 linear meters along these transects. Transects were terminated at the point where no more hemlocks were visible. At each point data were gathered on the closest tree to the plot center in each of four designated quadrants. In the Black Rock Brook stand more intensive sampling was used to examine the closest hemlock in each quadrant. Data collection included tree species, dbh, the distance of the tree from plot center, and canopy class. If the tree was a hemlock it was placed into a damage class depending on the degree of HWA-induced damage using a modified Braun-Blanquet scale (Mueller-Dombois and Ellenburg 1974):

(0) described trees with all their needles;

(1) described trees that had lost between 1 and 5% of their needles;

(2) described trees that had lost between 6 and 25% of their needles;

(3) described trees that had lost between 26 and 50% of their needles;

(4) described trees that had lost between 51 and 75% of their needles;

(5) described trees that had lost between 76 and 99% of their needles; and

(6) described trees that had lost all of their needles (considered dead).

Spearman rank-order correlation analyses were then performed between damage class and the various distance measures.

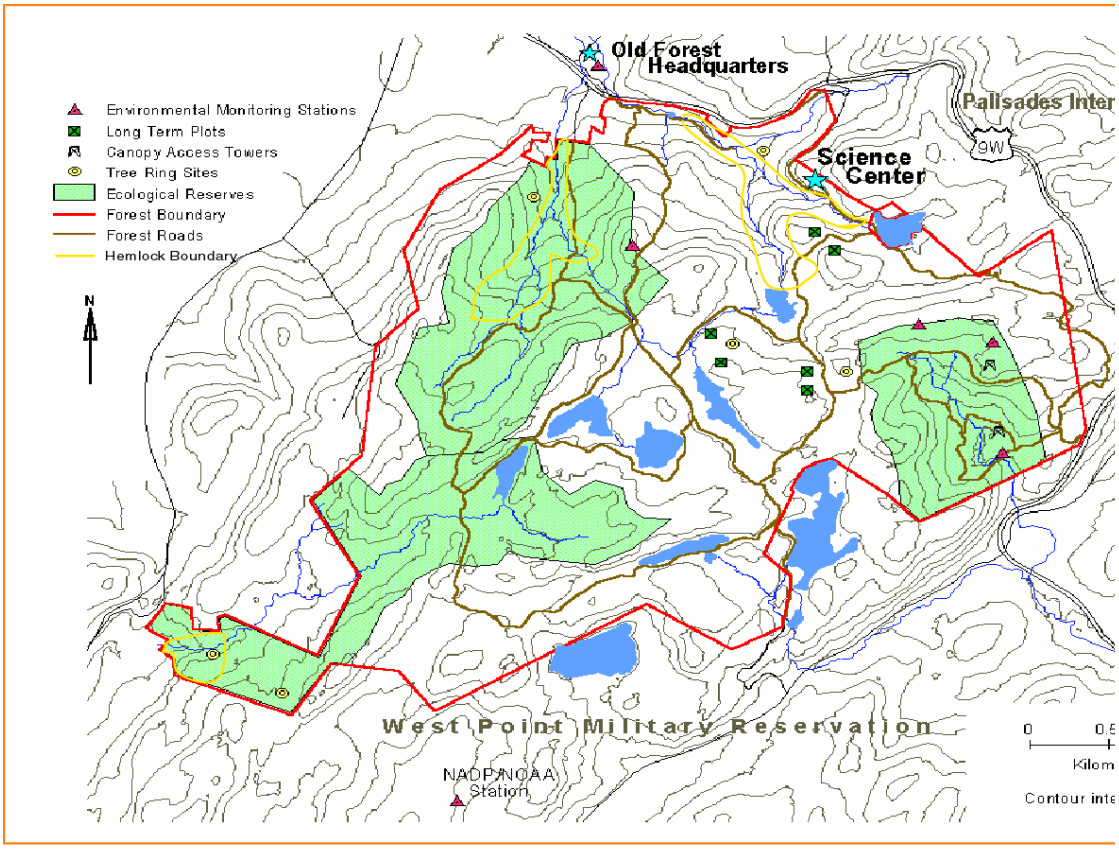

Figure 1. Map of the Black Rock Forest Field Station showing the limits of three hemlock stands in their study outlined in yellow.

Impact of HWA Damage on Operating Physiology and Water Use. Four plots were established for analysis of hemlock sap flow in the Black Rock Brook hemlock stand. All plots were located on the southern side of the stream on slopes less than five degrees. Three trees were selected for monitoring at each of the four sites. Two cylindrical probes, 1.5 mm in diameter, were encased in aluminum tubes (2 mm outside diameter) and inserted radially into the stem of the 12 trees to the depth of 20 mm, one located 100 mm below (upstream) of the other. The temperature difference between the two probes was measured with T-type thermocouple junctions. These temperature differences were used to calculate the sap flux density (kg $m^{-2}s^{-1}$) for each of the trees using the equation SFD = $0.116*(\text{max } dt/dt)^{1.2}$ (Granier 1987). For analysis trees were classified as high damage (class 5), moderately high damage (class 4), moderately low damage (class 3), or low damage (classes 1 and 2). The average maximum sap flux densities were compared for the four categories using one-way ANOVA for three 4-day periods. The first 4-day period started on August 2, 2000; the second started on September 9; and the last started on October 17.

Results

Spatial Analysis of HWA Damage. In all three stands, damage was worse along the stream course after 4 to 8 years of infestation, and became less severe away from the streams (Table 1).

Even the relatively conservative rank-order correlations were highly significant in two of the three stands. A similar negative relationship was found between damage and distance from the forest/ stand exterior, again significant in two of three cases. The lack of significance in the correlations in the Canterbury Brook stand may be due to its longer period of infestation (compared to Mineral Spring Brook) and its less intensive surveying (compared to Black Rock Brook). More detailed data from Mineral Springs Brook are shown in Figure 2. The data suggest that damage from HWA to large, native eastern hemlock stands progresses through stands in a linear manner over a course of several years.

Table 1. Spearman Rank Order Correlations (R) Between HWA Damage Class and Spatial Distance Measures

	Black Rock Brook	Canterbury Brook	Mineral Springs Brook
Distance From Stream Channel	R = -0.20***	R = -0.08	R = -0.28**
Distance From Forest Exterior	R = -0.16**	R = 0.01	R = -0.53***

**Correlations statistically significant at alpha = 0.01
*** Correlations statistically significant at alpha = 0.001

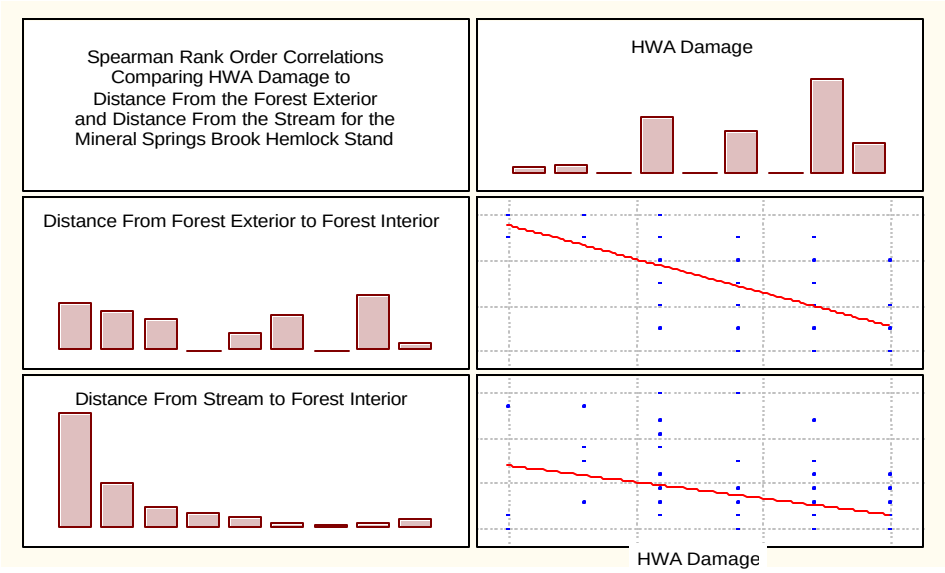

Figure 2. This figure shows a negative relationship between the damage class of hemlock trees and the distance of those trees from a) the forest exterior and b) the stream channel central to the Mineral Springs Brook Stand. Both correlations were statistically significant.

Impact of HWA Damage on Operating Physiology and Water Use. The results demonstrate that throughout the year heavily damaged hemlocks have a much lower transpiration rate than trees that are only lightly damaged or moderately damaged (Figure 3). Sap flow was reduced by approximately 50% in heavily damaged trees, during a wet summer (the summer of 2000). Trees with a moderately high degree of damage showed an initial sap flux density that was comparable to trees with lower damage. However, sap flux density for these trees decreased to levels comparable

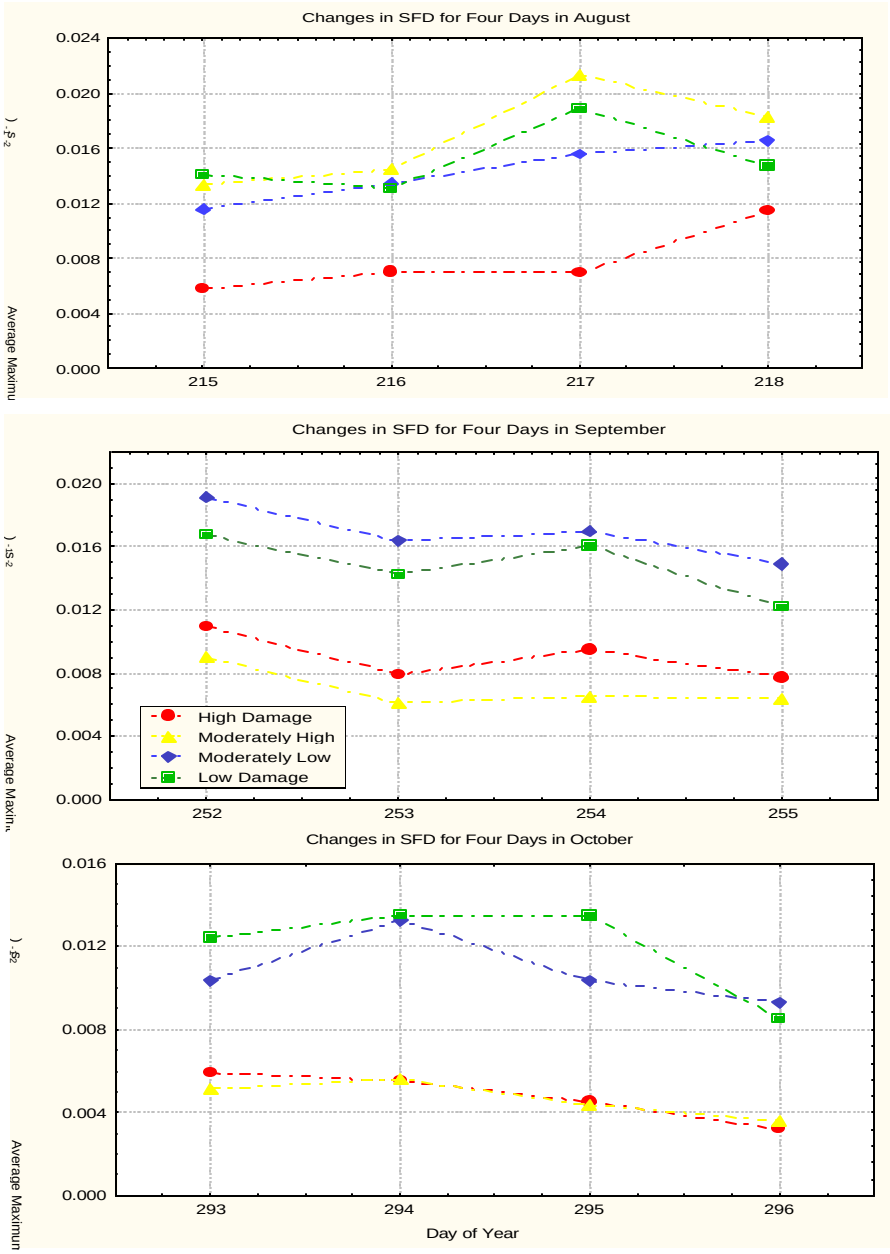

Figure 3. Maximum sap flux density for twelve HWA-impacted hemlock trees in three periods during the latter part of the 2000 growing season: a) August; b) September; and c) October.

to heavily damaged trees earlier in the season than trees with low and moderately low levels of damage. Trees with low or moderately low damage consistently showed higher sap flux density levels throughout the growing season ($p < 0.05$, ANOVA).

Conclusions

HWA exhibits clear spatial patterns of damage as it spreads through hemlock stands. Four to eight years after initial colonization, moderate to heavy damage is common. The greatest damage is found at presumed initial contact areas, but this pattern appears to fade over time. Managers can expect that mortality will first occur in these areas, and that they may have more time to implement control strategies in more interior locations. Trees also exhibited greater damage nearer to stream channels. It is not known, however, whether this also is related to adelgid dispersal or to topoedaphic conditions.

It is also clear that HWA damage reduces tree sap flow and transpiration but our results suggest this is not simply a linear function of damage, at least as estimated by defoliation damage class. During the summer, heavily damaged trees exhibited only 50% of the sap flow of other trees, but trees with lighter levels of damage showed no significant reduction. During the fall, however, as physiological operations decrease in all trees, sapflow drops more rapidly in trees with moderate and high levels of damage. Thus managers can expect that both productivity and water use may be little impacted until an intermediate threshold of damage has occurred. Enhanced soil moisture and streamflow may first be noticed toward the end of the growing season as transpiration in moderately and heavily damaged trees drops rapidly. Once trees reach heavily damaged status, water uptake and transpiration are severely reduced throughout the growing season, leaving substantially more water in the system for evaporation, runoff, and/or use by other plant species.

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