Eastern Hemlock (*Tsuga canadensis*) Mortality in Shenandoah National Park

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Abstract

Heavy infestations of hemlock woolly adelgid (*Adelges tsugae*) on eastern hemlock trees have progressively led to crown health decline and tree mortality. Long-Term Ecological Monitoring System (LTEMS) and Hemlock Crown Health (HCH) sites within the hemlock forest cover type were established in Shenandoah National Park (SNP), Virginia. During this time, the number of dead trees within monitored stands significantly increased. Hemlock crown health decline and mortality was significantly higher at lower elevations.

Keywords:

Hemlock, hemlock woolly adelgid.

Introduction

The hemlock woolly adelgid (HWA) is a serious pest in Shenandoah National Park (SNP). It threatens to eliminate all eastern hemlock stands. Hemlock woolly adelgid was first reported in Virginia during the 1950s, yet adelgid-caused decline remained almost unreported until the mid-1980s (McClure 1987). First observed in the SNP in the fall of 1988, it has since been found in all districts, elevations, and aspects of surveyed hemlock stands. Although LTEMS site installation in various covertypes began in 1988, elevated concern about the potential impacts this insect might exert on the unique forest ecosystem prompted SNP ecologists to make the eastern hemlock covertype a priority. This decision was made in spite of initial estimates of less than one percent forest coverage within the SNP. These LTEMS sites were established during 1990 to 91 and have been monitored annually.

Terrestrial LTEMS is a permanent plot system designed to provide data for evaluating changes in the forest vegetation of SNP. The objectives of permanent plots are to evaluate changes in forest composition, structure, regeneration, and growth as they may be influenced by factors over time. The periodic measurement of permanent sample plots is statistically superior to independent inventories for evaluating changes in forest conditions (Avery and Burkhart 1983). Data collected by measuring these plots at periodic intervals provides information needed to identify changes that occur within the various ecological land units as a result of natural succession or disturbances, both

natural- and human-caused. LTEMS was designed to provide a general framework and baseline data to enable future researchers to utilize the plots for various study purposes.

LTEMS is an excellent data collection tool that provides information used to identify changes within an ecological land unit. However, the sample size was too small to draw accurate conclusions about SNP-wide hemlock health. Also, LTEMS sites were located in areas where there was no doubt of the forest type, i.e., areas with a high population of hemlocks. This led to the annual random HCH monitoring of 94 hemlock stands from 1991 to 1998. This initial hemlock site monitoring did not use specific locations and surveyed trees varied from year to year. In 1999, 101 sites were randomly located within known hemlock areas mapped by USGS Leetown in an attempt to minimize bias by facilitating the return to the same trees. This larger sample size was composed of unstratified random points within known hemlock areas and was determined to be adequate to yield statistically viable information. Stratification by elevation was avoided since it could introduce the possibility of inaccurately weighting elevation classes rather than providing an unbiased park-wide assessment of hemlocks.

The purpose of these studies was to measure hemlock decline and determine if elevation influenced tree vulnerability for mortality.

Methods

LTEMS. Six sites with three 24 x 24 meter plots each were installed and baseline data were collected in 1990 to 91. Locations for LTEMS sites were selected to encompass all representative combinations of forest covertype, elevation, aspect, and three administrative districts in the SNP. Two sites (one in each district) are located in the north and south ends of the SNP. Four sites are located within the central district since it contains the majority of the SNP's hemlock areas. Three sites were located at low and high elevations with 2,000 feet as the break point. Trees were initially measured for diameter breast height (dbh), crown health, canopy class or position, and their locations documented in sixteen 6 m by 6 m quadrats using an "xy" grid system. In 1998, individual tags were attached to each tree. Crown health categories were based on the percent of intact foliage as follows: Class 1: 90 to 100% (excellent), Class 2: 50 to 89% (moderate), Class 3: 1 to 49% (poor), and Class 5: dead (Initially there were two classes for dead trees, Classes 4 and 5. These were combined into one category because speculation about the time of death was subjective). Plot installation and data collection was made by SNP staff following protocols outlined in the *Shenandoah National Park LTEMS Component User Manual* (Smith 1990).

HCH. One hundred and one sites with a 15 m fixed-point radius plot were located by using a military PLGR with $\pm$ 4 m accuracy and baseline data collected in 1999. Site landmarks were initially mapped and later photographed. Data collection was accomplished during the winter months. This allowed less variation between sites during a time of slow tree growth and more accurate assessment of crown health after deciduous leaf drop. Trees were measured for dbh, crown health, and canopy class or position. Data collection followed LTEMS protocols with the exception of tree location and crown health categories. The plot was divided into four sections using north/south and east/west lines. This general location was documented instead of specific

coordinates for each tree. Crown health categories were based on visual assessment of intact foliage but were recorded in 10% increments beginning with Class 0: 1 to 9%, Class 1: 10 to 19%, respectively to Class 10: 90 to 100%. Data was also collected for 2000 and 2001.

Results

LTEMS. Stem counts for each crown class category were taken in 1990, 1991, 1999, and 2000 from the six hemlock sites. Comparisons between tree crown health data show a dramatic shift of trees exhibiting excellent crown health (90 to 100% foliage intact) to poor crown health (1 to 49% foliage intact) or dead (Figure 1). Mortality significantly increased during the past ten years from an initial 8% to 48.7 percent.

HCH. Crown health classes within elevation classes were compared by 500 foot increments. The

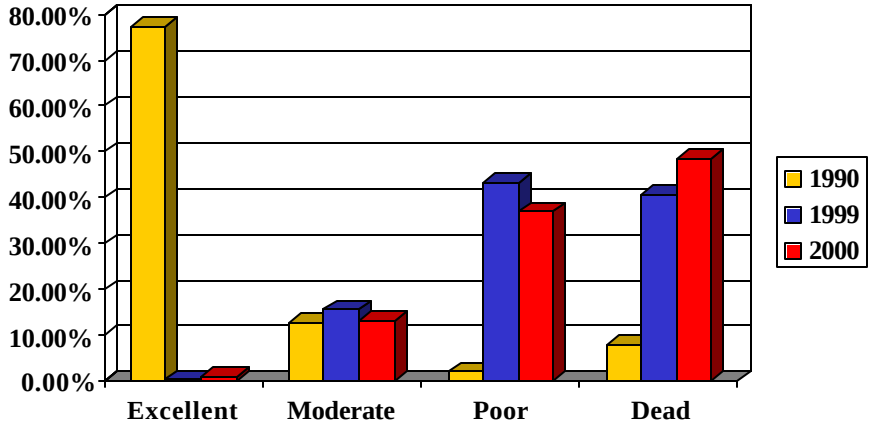

Figure 1. Percentage of trees in each crown class for 1999, 2000, and 2001.

mean crown health declined proportionally with drop in elevation (Figure 2). This agreed with LTEMS results (Willeford Bair unpublished data, 2000) where trees in both the higher and lower canopy groups exhibited significant decline in crown health at higher elevations (29%) as compared to lower elevations (68%).

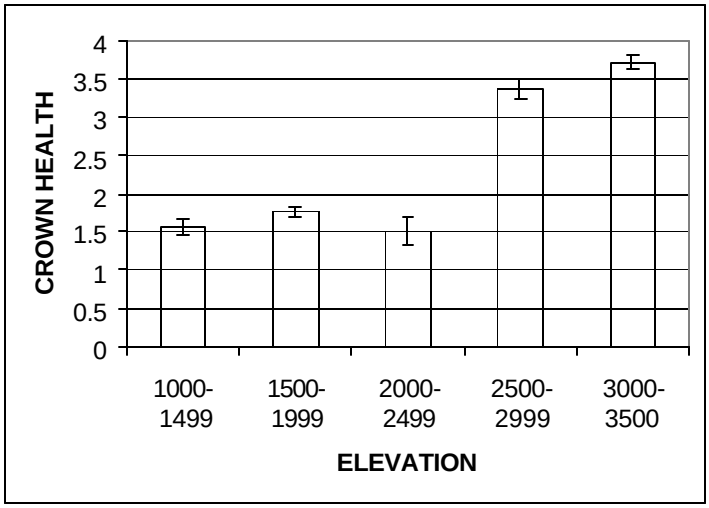

Figure 2. Mean crown health by elevation for 1999.

The Shenandoah Complex Fire impacted 24,222 acres in October to November 2000, and burned more than 26 of the

101 HCH sites. This unexpected event provided the opportunity to study the effect of fire on HWA-impacted hemlock stands. Mortality was more than twice as high in the burned sites than in the unburned sites (Figure 3).

Although the Hemlock Springs site was spared from fire damage, crown health decreased dramatically. This was not expected for a 3,200 foot elevation site (Figure 4).

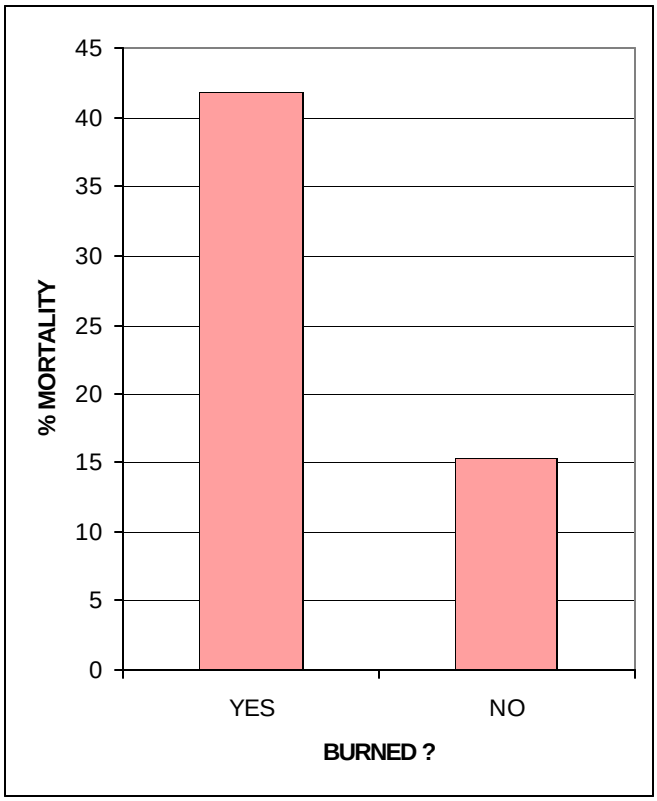

Figure 3. Percent mortality for burned sites was 41.8% as compared to 15.3% in unburned sites.

Discussion

HWA has caused significant decline in hemlock crown health over the past decade. Decline and mortality was especially evident at lower elevations. Fire was probably the strongest factor in the determination of tree mortality in burned sites for the 2001 field season. Unfortunately, burn areas were not selected at random; therefore, none of the burn sites were located in the highest elevation category. Closer examination of site factors must be made to determine if other influences, such as elevation, inflated this figure.

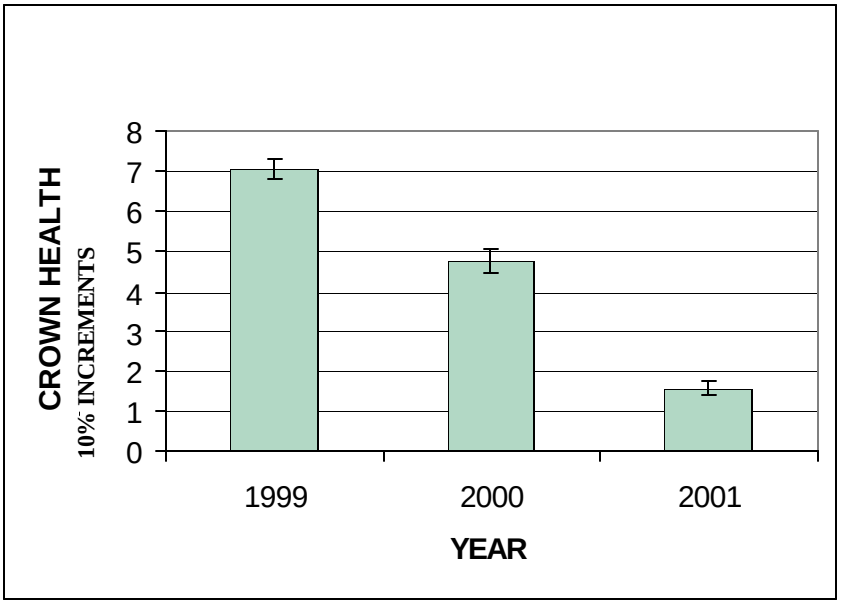

Figure 4. Dramatic drop in crown health from 70.6 to 15.6% at Hemlock Springs.

Elevation and aspect are the two most important site factors that directly and indirectly affect forest cover. Both of these site factors affect temperature and water on a site-specific basis. As elevation increases, temperature decreases and precipitation increases, both of which will affect site quality by increasing

available soil moisture and affecting such site factors as rock weathering and soil formation. Aspect affects forest cover primarily as a result of changes in site quality directly related to temperature-induced available soil moisture changes. Hemlocks have a shallow root system; therefore, they prefer moist conditions found on north- and east- facing slopes or hollows (Benzinger 1994). Although hemlock is adaptable, the roots are close to the surface making them more susceptible to extremes in soil moisture. Mortality often occurs after drought or flooding (Graham 1943).

A downward trend in crown health in hemlock areas virtually devoid of adelgid from 1993 to 1995 has been documented (Onken 1996). Drought conditions were cited as the likely cause of failing crown health. Reduced rainfall may be a contributing factor to increased hemlock woolly adelgid-induced tree decline. Preliminary results of a study by the USGS Biological Resource Division (BRD) in SNP addressing possible landscape correlates strongly suggest that site factors (elevation, aspect, slope, slope shape, slope position) and canopy class may influence decline and mortality rates (Young et al. 1999).

Summary and Conclusion

Hemlock stands with HWA infestations located at lower elevations tend to cause more crown health decline and subsequent mortality than those found at higher elevations; therefore, this should be taken into consideration when planning management actions. Further study of factors relating to site moisture is recommended. Although HWA infestations have led to extensive hemlock crown health decline, these insects may be only one of several contributing factors leading to mortality. Presence of secondary agents, such as hemlock borer, should also be considered since they can speed the demise of a tree. Additional stressors, especially forest fires, should be avoided whenever possible. Relationships between site conditions and canopy position in relation to hemlock crown health need to be explored further. A joint effort by the USGS BRD, and NPS to analyze 1999 to 2001 HCH site data using landscape correlates of hemlock decline is slated for early 2002 and should yield insight into these relationships.

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