The Effects of Site Factors on the Rate of Hemlock Decline: A Case Study in New Jersey

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Abstract

The rate of decline of hemlock (*Tsuga canadensis*) trees infested with hemlock woolly adelgid (*Adelges tsugae*) appears to be highly variable and site dependent. Rates of hemlock forest decline have not been quantified at the landscape scale and reasons for observed variations in the rate of decline remain unknown. Others have suggested that site characteristics and/or landscape features, hemlock woolly adelgid (HWA) dispersal patterns, weather and climate, genetic variation, and a host of other factors may play a role in structuring this apparent variation in the rate of decline. In this paper, we: 1) report the results of a preliminary investigation in which we quantify the rate of change in hemlock forest canopy across the Highlands landscape of northern New Jersey using multiple dates of remotely sensed data and change detection techniques; 2) summarize patterns in the rate of change in hemlock forest canopy; and 3) explore the effects of site factors on the rate of change.

The study area consists of the New Jersey Highlands, a 2,340 km^2 (900 mi^2) area of rugged, forested terrain, containing about half of the state's estimated 10,690 ha (26,000 ac) of hemlock forest. The remotely sensed data consist of four scenes of leaf-off (November or December) Landsat TM imagery: 1984, 1992, 1996, and 1998, (30m pixel resolution). All scenes were terrain-corrected and georeferenced, converted to radiance values, and normalized to remove atmospheric differences.

Hemlock forest was delineated using a digital map produced by New Jersey Department of Environmental Protection forestry personnel from air photos. Although hemlocks do occur in wetlands such as cedar swamps, they comprise a small percentage of the canopy, and were thus excluded from analysis. Therefore, only upland hemlock forest pixels representing cloud- and snow-free sites in all image dates were retained for analysis, representing about 5,527 ha (13,657 ac) of hemlock-mixed hardwoods forest type The Normalized Difference Vegetation Index (NDVI), derived from near infrared and visible red reflectance values ((NIR - red)/(NIR + red)) was obtained for each hemlock pixel in each image. A neighborhood value was calculated for each hemlock pixel to diminish the effects of any minor, inherent misregistration of the images on the change detection. This neighborhood value represented the average NDVI for that pixel and its eight hemlock neighbors (four adjacent and four diagonal). An increase in the NDVI from Time 1 to Time 2 represents an increase in the amount of hemlock foliage present on a site (pixel), while a decrease in the NDVI represents a loss of hemlock foliage. By simply subtracting the Time 2 data from the Time 1 data, the change in the NDVI can be quantified.

We calculated the rate of change in NDVI for each time interval by subtracting the images in sequence: 1992-1984, 1996-1992, 1998-1996, and dividing the change in NDVI by the number of years in that time interval, e.g., (1992-1984)/8). During the first time interval before 1992, 90% of the NJ Highlands hemlock forests showed no change, but there were areas of severe defoliation comprising 8% of the hemlock forests. During the second time interval (1992 to 1996), the majority (52%) of the hemlock forests showed no change, while 21% showed a decline, and 27% increased in NDVI. During the third time interval (1996 to 1998), the majority (65%) of the Highlands hemlock forests decreased in NDVI, while 25% showed no change and 10% increased in NDVI.

Analysis focused on those site factors related to site moisture, directly or indirectly. The hypothesis is that hemlocks stressed by a moisture deficit decline at a faster rate. As part of the initial data exploration, we conducted a multiple regression analysis to determine the extent to which site variables correlated with the rate of change. We selected 5,000 hemlock sites at random for analysis. The dependent variable was the rate of change in NDVI, and the independent variables were: elevation in meters above mean sea level; slope in degrees; aspect represented as northness; a brightness index representing site illumination levels; a land form index representing convexity and concavity. All of these site variables were derived from a digital elevation model (DEM) of the area (30m resolution). The independent variables were standardized to prevent varying scales of measurement from influencing the analysis.

In general, all of the site variables except aspect were highly significant ($P < 0.0001$). However, site characteristics explained a relatively small amount of the overall variation in the rate of change in NDVI (R^2 varied per time period and ranged from 0.09 to 0.25). Slope was significant during the first two time intervals, but not during the last interval. Though weak, the results suggest that: 1) during the early years (before 1992), the rate of change was greatest at low elevation, concave sites; 2) during the second time interval, the rate of change was greatest at high elevation, bright, convex sites; and 3) during the third time interval, rate of change was again greatest at low elevation, concave sites. Only during the second time period does the decline appear to be related to site moisture deficit (i.e., exposed ridge tops). The results for the first and third periods run counter to our original hypothesis.

No simple, clear cut relationship is evident from this analysis, and explaining the rate of decline may require additional variables. To incorporate the observed coarse-scale pattern in HWA dispersal across the region over the entire time period, latitude and longitude will be included. Future work will explore the inclusion of weather records, alternative sampling schemes, and statistical techniques to further investigate the relationship between site and landscape factors and the rate of hemlock decline.

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