

# Mapping Susceptibility and Spread Associated with Hemlock Woolly Adelgid

Randall S. Morin<sup>1</sup>, Andrew M. Liebhold<sup>1</sup>, Andy Lister<sup>2</sup>, Kurt Gottschalk<sup>1</sup>, and Daniel Twardus<sup>3</sup>

<sup>1</sup>USDA Forest Service  
Northeastern Research Station

180 Canfield St., Morgantown, WV 26505 USA

<sup>2</sup>USDA Forest Service  
Northeastern Research Station

11 Campus Blvd., Suite 200, Newtown Square, PA 19073 USA

<sup>3</sup>USDA Forest Service  
Northeastern Area State & Private Forestry  
180 Canfield St., Morgantown, WV 26505 USA



## Abstract

The hemlock woolly adelgid, *Adelges tsugae*, is native to Asia and was first introduced to North America in British Columbia in the 1920's and was later discovered in the Shenandoah Mountains of Virginia in the 1950's. It has gradually been expanding its range, largely to the North. In the eastern US, the adelgid's principal host is eastern hemlock, *Tsuga canadensis*. Heavy infestations have killed trees in as little as four years, but some trees have survived infestations for more than 10 years (McClure et al. 2001). Thus, the hemlock woolly adelgid is likely to cause considerable damage in the future as it expands into areas with large quantities of hemlock. Invasions by exotic insects and diseases are one of the most important threats to the stability and productivity of forest ecosystems around the world. One of the most important steps in the development of effective strategies for management of alien species is to evaluate the risk of future impacts from specific exotic organisms. The generic activity, "risk assessment" is considered an important component to management of exotics both before and after their arrival in new habitats. Our research focuses on estimating the expected geographical extent of hemlock woolly adelgid through 2025 and which areas within that extent will be the most at risk. We used USDA Forest Service Forest Inventory and Analysis (FIA) data to create an estimated surface of eastern hemlock basal area.

## Introduction

The Hemlock Woolly Adelgid, *Adelges tsugae*, is native to Asia and was first introduced to North America in British Columbia in the 1920's and was later discovered in the Shenandoah Mountains of Virginia in the 1950's. It has gradually been expanding its range, largely to the North. Adelgids feed by sucking sap from hemlock twigs and when they reach very high densities they can cause dieback and mortality of their hosts. In the eastern US, the adelgid's principal host is eastern hemlock, *Tsuga canadensis*. Heavy infestations have killed trees in as little as four years, but some trees have survived infestations for more than 10 years (McClure et al. 2001). The range of this species is largely limited to moist, cool sites; it is most abundant in the New England states. The adelgid has only recently invaded southern New England and is now poised to expand its range into northern New England. Thus, the hemlock woolly adelgid is likely to cause considerable damage in the future as it expands into areas with large quantities of hemlock.



Figure 1. Hemlock branch infested with hemlock woolly adelgid.



Figure 2. Hemlock stand showing heavy hemlock woolly adelgid damage.

## Methods

### FOREST SUSCEPTIBILITY

The geographical distribution of the suitable habitat for hemlock woolly adelgid was mapped by interpolation of host species abundance estimated from 93,611 forest inventory plots located throughout the eastern US. These data represented the most recent available USDA Forest Service Forest Inventory and Analysis data sampled in each of the thirty-seven states in the Eastwide Database. Host abundance for hemlock woolly adelgid was measured as basal area/ha of eastern hemlock.

The ordinary indicator kriging procedure described by Deutsch and Journel (1998) was performed to interpolate a surface of basal area/ha of eastern hemlock. Kriging is a geostatistical method that provides unbiased estimates at unsampled locations as weighted averages of values from nearby locations (Issaks and Srivastava 1989; Liebhold et al. 1993). In this analysis we generated maps from the plot data by calculating kriged estimates on a grid of 1- by 1-km cells. Variography and kriging were performed using the GSLIB software library (Deutsch and Journel 1998). One percent of the plots were excluded to use in validating the estimated surfaces.

The forest susceptibility map was then adjusted for forest density. FIA plots are located randomly but restricted only to forest land area. Therefore, it was necessary to adjust estimates in each 1- by 1-km cell for forest density. This was accomplished using land cover data (National Land Cover Data) which was acquired from the Multi-Resolution Land Characteristics Consortium as a raster matrix of 30- by 30-m cells coded for land use. These data were aggregated to 1- by 1-km to estimate percent forest cover for each cell. Next, the forest susceptibility map was multiplied by the forest density map to generate a forest susceptibility map adjusted for percent forest cover.

### SPREAD PREDICTION

Future range expansion of hemlock was predicted by applying estimates of past spread derived from historical records (Figure 3). These records consisted of the year that each county first became infested. A GIS was used to calculate the minimum distance in the x and y direction of each county to the area initially infested. The rate of spread was estimated as the slope of the two linear models: the x and y distance of the county as a function of its time of first infestation. Least-squares regression was used to estimate linear models and the intercepts were forced through the origin. A predicted spread map representing years of expected presence (2001-2025) was generated on a 1- by 1-km grid using the estimated spread rate. Then the number of years of expected presence was divided by 25 (years of possible infestation) to produce a proportion of expected years of presence between 2001 and 2025. The proportion map was multiplied by the adjusted forest susceptibility map to create a map of hemlock woolly adelgid risk through 2025.

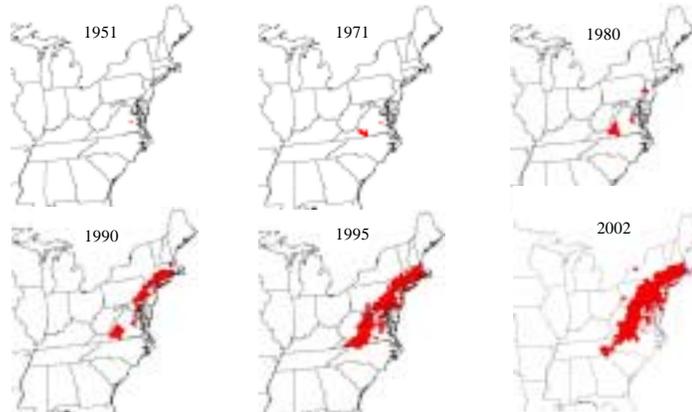


Figure 3. Maps of hemlock woolly adelgid spread (1951-2002).

## Results

Eastern hemlock basal area ( $m^2/ha$ ) was estimated using ordinary kriging (Figure 4) and then multiplied by the forest density map (Figure 5) to create a hemlock abundance map adjusted for forest density (Figure 6). A least-squares regression was run to validate the kriged estimates. The linear model explained 10% of the variation. Historical spread of hemlock woolly adelgid in the x direction was estimated at  $3.6 \text{ km/year} \pm \text{SEM}$  ( $r\text{-square}=0.9552$ ,  $\text{RMSE}=124.72$ ) (Figure 7) and in the y direction was estimated at  $5.8 \text{ km/year} \pm \text{SEM}$  ( $r\text{-square}=0.6575$ ,  $\text{RMSE}=176.49$ ) (Figure 8). A predicted hemlock woolly adelgid spread map was generated using this historical rate (Figure 9). Finally, the spread map and adjusted hemlock basal area map were multiplied to create a map of hemlock woolly adelgid risk for the next 25 years (Figure 10).



Figure 4. Estimated eastern hemlock basal area ( $m^2/ha$ ).

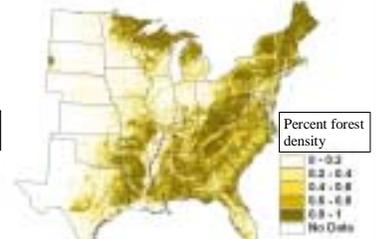


Figure 5. Percent forest density from NLCD data

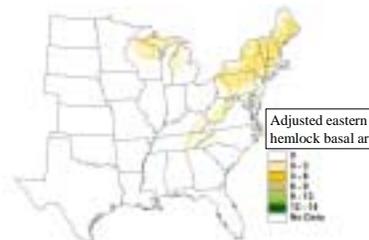


Figure 6. Eastern hemlock basal area ( $m^2/ha$ ) adjusted for forest density.

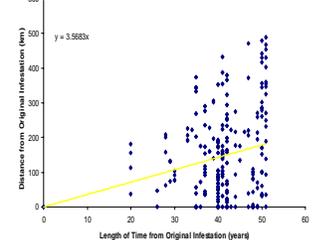


Figure 7. Linear model for hemlock woolly adelgid spread rate in the x-direction.

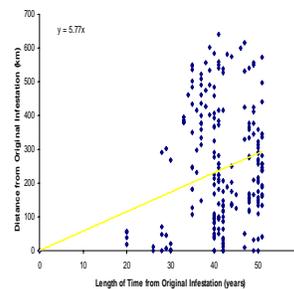


Figure 8. Linear model for hemlock woolly adelgid spread rate in the y-direction.

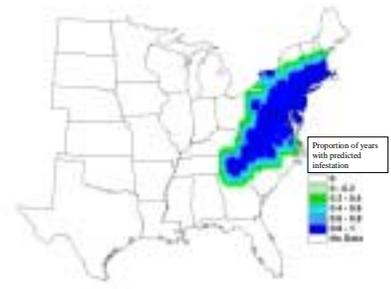


Figure 9. Proportion of years with predicted hemlock woolly adelgid infestation (2002-2025).

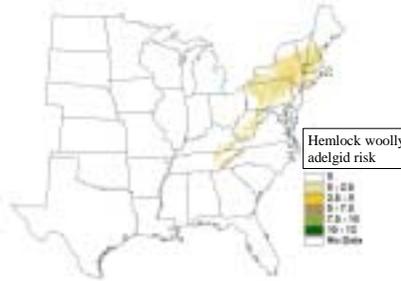


Figure 10. Hemlock woolly adelgid risk (2002-2025).

## Conclusions

- > Hemlock woolly adelgid has only recently begun to move into areas with a large eastern hemlock component.
- > The estimated risk of hemlock woolly adelgid disturbance was highest in a large portion of New England, as well as New York and northern Pennsylvania.
- > Vermont, New Hampshire, and New York are the highest risk areas that are currently uninfested.

## Literature Cited

Yon, J.E., S. Reichard, J.M. Randall, I.M. Parker, C.S. Smith, W.M. Lonsdale, I.A.E. Adkinson, T.R. Sasek, M. Williamson, E. Chornoky, D. Hayes. 2002. Directing research to reduce the impacts of nonindigenous species. *Conserv. Biol.* 16(3):630-777.

Smith, C.V., and A.C. Jaenke. 1998. GISLIB: Geostatistical software library and user's guide second edition. Oxford University Press, New York, New York. 369 p.

Issaks, E.H. and R.M. Srivastava. 1989. An introduction to applied geostatistics. Oxford University Press, New York, New York. 561 p.

Liebhold, A.M., R.E. Rossi, and W.P. Kemp. 1993. Geostatistics and geographic information systems in applied insect ecology. *Ann. Rev. Entomol.* 38:303-327.

Liebhold, A.M., W.L. Macdonald, D. Berglund, V.C. Masto. 1995. Invasion by exotic pests: a threat to forest ecosystems. *For. Sci. Mon.* 30, 49 p.

McClure, M.S., S.M. Salton, and K.S. Shields. 2001. Hemlock woolly adelgid. USDA For. Serv. FHEET-2001-01.