

THE EFFECTS OF CLIMATE, GEOGRAPHY, AND TIME ON HEMLOCK WOOLLY ADELGID AND ITS NATURAL ENEMIES

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ABSTRACT

Although the hemlock woolly adelgid (HWA) has been documented in the western United States since the 1920s, it has not expressed outbreak dynamics, and has not behaved as a pest species. In the eastern United States however, the spatial and temporal dynamics of the HWA have been quite different. First observed in the east in 1951 in Richmond, VA, the HWA has rapidly expanded its range, and is now found from southern Maine to northern Georgia. This rapid range expansion threatens the health and sustainability of the eastern and Carolina hemlock (*Tsuga canadensis*, and *T. caroliniana*, respectively) in the east. Effective management of this species through biocontrol programs demands a solid understanding of the spatial and temporal factors influencing the dynamics of both the HWA, and the natural enemies used for biocontrol.

County records providing the first year in which HWA infestations were documented provide an opportunity to describe the coarse, large-scale movement of HWA through the distribution of hemlock. Spatial projections of these records as a time series show that early reports of HWA appear spatially disjunct, with new reported populations appearing in noncontiguous locations at significant distances from those previously infested. These early records suggest a number of scenarios including: 1) inadvertent anthropogenic movement of HWA populations; 2) early lack of experience with, and knowledge of, HWA by land managers and the general public resulted in failure to detect populations at the time of their arrival, which produced a lag between arrival and detection; 3) incomplete

records; and 4) some combination of these (and/or other) factors. Yet, despite the apparent spatial discontinuity of early populations, more recent records (1991-2004) of HWA, collected with improved detection and documentation, suggest a more continuous and regular expansion of HWA populations through hemlock forests.

Although this more recent expansion has been more contiguous, variation in the rates and directions of expansion suggest the interaction between landscape features and climate have produced "barriers" and "windows" which may inhibit or facilitate the spread of this species. The most apparent of these barriers is that produced by the cold temperatures in the high elevations along the Appalachian Mountain Range. Prior to 1998, populations of HWA were predominantly restricted to the eastern edge of this range. Previous work (Parker et al. 1997, 1999) has shown that HWA may be limited by cold tolerance. However, during 1998, populations of HWA became established along the western edge of the Appalachians, and have rapidly expanded through previously uninfested regions. Compilation of climate data throughout the eastern United States shows that the winter of 1998 and the following two winters were anomalously warm. The interaction between the landscape (via altitude driven cold temperatures), climate, and timing of HWA spread suggest the climate, specifically a warm period, opened a temporal window in a landscape driven temperature barrier. By exploiting these landscape patterns, we can begin to define the potential biogeographic limits to HWA populations, based on current and potential climate conditions.