LONG-TERM WEATHER VARIABILITY AND SHIFTING DISTRIBUTION LIMITS OF THE INVASIVE HEMLOCK WOOLLY ADELGID (*ADELGES TSUGAE* ANNAND)

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ABSTRACT

The hemlock woolly adelgid (HWA) is a small, aphid-like piercing-sucking insect native to Asia and northwestern North America (Havill et al. 2006, 2007). First documented in 1951 in the eastern United States near Richmond, VA, the HWA has spread to infest at least 17 states along the Appalachian Mountains from Georgia to southern Maine, where infestations have been limited to coastal regions with more moderate temperatures. Currently, the northern regions of Vermont, New Hampshire, and Maine remain uninfested.

Although hemlock species native to Asia and northwestern North America are either resistant to, or tolerant of, infestation by the adelgid, the two species native to eastern North America (*Tsuga canadensis* and *T. caroliniana*) are highly susceptible and can be killed within a few years following infestation. To date, native predators have failed to control populations of the adelgid, and no parasites are known in either the native or introduced ranges. Without these biotic regulators, the hemlock woolly adelgid in eastern North America may be free to infest the range delimited by host availability and the abiotic tolerances of the adelgids. Past work has shown that the adelgid is vulnerable to low temperatures, and winter temperatures can reduce adelgid population densities at the landscape scale (Parker et al. 1998, 1999; Trotter III and Shields 2009). However, little is known about how the geographic distribution of temperature-dependent population boundaries vary through time (although see Paradis et al. [2008] for estimates of boundaries based on global circulation model based projections of climate change). To fill this knowledge gap, weather records were extracted from the NOAA (National Oceanic and Atmospheric Administration) NCDC (National Climate Data Center) CDO (Climate Data Online) database for ~1,700 weather stations in the eastern United States. Minimum monthly temperatures for these stations were loaded into a GIS (ArcGIS) and interpolated (kriged) to produce temperature surfaces estimating the annual minimum temperature from 1960 through 2008. These annual temperature maps were then converted to estimates of adelgid survival using equation 4-E in Trotter and Shields (2009) and were in turn used to produce contour maps of adelgid survival. The 2-percent adelgid survival isocline was selected as the functional population boundary, and the boundaries from each of the 49 included years were combined into a single map. This composite map of annual, temperature-driven adelgid population boundaries provides a spatial probability distribution of the conditions suitable for adelgid population survival. From this output, several patterns emerge. First, the map indicates that approximately 2.2 percent of the eastern hemlock population range in the continental United States occurs in regions in which none of the included 49 years were well suited for adelgid survival; these regions are found in northern Maine, New Hampshire, and Wisconsin. Second, the data suggest large inter-annual variation in the geographic location of the boundary, which is found as far south as the Georgia/North Carolina border, and as far north as upper New England and Michigan. Third, when evaluated by decade, the weather data suggest a northward-trending shift in the conditions suitable for adelgid survival, in agreement with the findings of Huntington et al. (2009). These shifts could pose a threat to the climatic refugia for hemlock found in Maine, New Hampshire, and Wisconsin. Finally, these

data suggest the spatial distribution of adelgid survival probabilities, which, in combination with an improved understanding of population dynamics and processes (such as Allee effects) that drive them, can facilitate a probabilistic approach to evaluating the spatial risk of this invasive species.

Literature Cited

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