RESEARCH AND DEVELOPMENT PROGRAM ON HOST PLANT RESISTANCE TO HEMLOCK WOOLLY ADELGID

Michael E. Montgomery[1] and Kurt W. Gottschalk[2]

[1]U.S. Forest Service, Northern Research Station
51 Mill Pond Rd., Hamden, CT 06514

[2]U.S. Forest Service, Northern Research Station
180 Canfield St., Morgantown, WV 26505

ABSTRACT

Adelges tsugae Annand, the hemlock woolly adelgid (HWA), is a serious pest of hemlocks in the eastern United States. Hemlocks native to western North America and Asia are not damaged by this sucking insect. Recent phylogenetic research (Havill et al. 2006) determined that HWA is native to western North America and Asia and that the population in the eastern U.S. is non-native and came from Japan. It is hypothesized that in the areas where HWA is native, a combination of host resistance and natural enemies maintains HWA populations below damaging levels.

For more than a decade, the Forest Service has aggressively supported a program to obtain natural enemies from areas where HWA is endemic for establishment as biological controls for HWA in the eastern U. S. This initial emphasis on establishing biological controls was based on the premise that biological control could be achieved more rapidly than increasing host resistance or tolerance to HWA. Recently, the quest for management options has been more balanced and the availability of special funding in 2005-2007 permitted acceleration of research on biological controls, chemical insecticides, and host resistance. Requests for proposals (RFP) issued these 3 years funded 11 proposals on host resistance research totaling $624,493.

These extramurally funded proposals cover a wide range of topics, including host chemistry and physiology, feeding behavior, tree breeding, tree ring analysis, and field evaluation of tree resistance, and illustrate the need for a multidisciplinary approach to development of host resistance. Projects funded were (1) Evaluating phytochemicals (terpenoids) in hemlock species and cultivars in relation to host resistance (Villanova University), (2) Single cell EST sequencing to define molecular responses associated with resistance (FS Southern Research Station), (3) Feeding behavior of HWA in relation to host suitability (North Carolina State University), (4) Field evaluations of non-indigenous and local hemlock species (Cornell University), (5) Evaluating hemlock species for resistance, hardiness, and cultural suitability (Pennsylvania State University), (6) Role of twig morphology in resistance (Oregon State University), (7) Production and evaluation of eastern hemlocks with putative resistance (University of Rhode Island), (8) Evaluation of inter-specific hybrids and development of new hybrids (ARS National Arboretum), (9) Dendrochronological analyses for resistance and changes in soil and foliar nutrients in relation to HWA attack (West Virginia University). Most of these studies are still in progress, but below are brief accounts of some research on HWA initiated before 2006.

The volatile chemistry of hemlocks has been examined by Anthony Lagalante of Villanova University, who developed a sampling method to determine the relative content of volatile terpenoids in the needles of seven hemlock species. For all species, 51 terpenoids were identified, with 2 of these—isobornyl acetate and α-pinene, the most abundant terpenoids—accounting for 90 percent of the total variance in a principal component analysis on untransformed data. Except for *T. metensiana*, which is in a separate phylogenic group from the other species, the grouping of the hemlocks along both axes of the PCA corresponded to their east-to-west geographic locations. When PCA is run on log-transformed data to minimize the influence of the mean size of the variable, *T. caroliniana* is grouped with the Asian species and *T. canadensis* is considerably distant from the other species.

This grouping corresponds to the phylogeny of *Tsuga* species. It is suggested that the high level of isobornyl acetate in the eastern North American hemlocks reflects evolutionary pressure from defoliators in the absence of pressure from sucking insects.

Controlled pollinations by Susan Bentz of the National Arboretum, USDA ARS, resulted in authentic hybrids between *T. caroliniana* and *T. chinensis*. These hybrids are now of sufficient size in a field nursery that their resistance can be evaluated using artificial inoculations of HWA. Preliminary results indicate that the hybrids have resistance to HWA that is intermediate to that of their parents.

Recent understanding of the genetics of worldwide HWA populations and observations on the biology of these populations has made it clear that populations of HWA in the eastern U.S. cannot be assumed to have the same relationships with hemlock species as populations in other regions. *Tsuga chinensis* generally has light—but sometimes dense—populations of HWA in China but is virtually immune to HWA when grown in the eastern U.S. Similarly, *T. heterophylla*, in western North America, often has dense HWA, but this species seldom is observed with dense populations of the adelgid when growing in eastern U.S. Conversely, *T. canadensis* growing in arboreta in western North America seems to be more resistant than the native, western hemlock growing beside it. Greater abundance of natural enemies of HWA in Asia and Western North America has been a suggested explanation for both native and exotic hemlocks being less damaged in these areas; however, the different genotypes of HWA in these areas may cause less damage to hosts on which they have coevolved. Although the relative resistance of the hemlock species remains unclear, care should be taken to avoid additional introductions of HWA from Asia or western North America because these may differ in biology from the genotype now present in the eastern U.S.

Other researchers are looking for putative heritable resistance among eastern and Carolina hemlocks that have escaped damage from HWA. Another tactic is to identify the role of environment on susceptibility of hemlock to HWA, including silvicultural prescriptions to increase tolerance to HWA.

Literature Cited

Bentz, S.E.; Riedel, L. G. H.; Pooler, M.R.; Townsend, A.M. 2002. **Hybridization and self compatibility in controlled pollinations of eastern North American and Asian hemlock *(Tsuga)* species.** Journal of Arboriculture. 28: 200-205.

Havill, N.P.; Foottit, R.G. 2007. **Biology and evolution of Adelgidae.** Annual Review of Entomology. 52: 325-349.

Havill, N.P.; Montgomery, M.E.; Yu, G.; Shiyake, S.; Caccone, A. 2006. **Mitochondrial DNA from hemlock woolly adelgid (Hemiptera: Adelgidae) suggests cryptic speciation and pinpoints the source of the introduction to Eastern North America.** Annals of the Entomological Society of America. 99: 195-203.

Havill, N.P.; Campbell, C.S.; Vining, T.F.; LePage, B.; Bayer, R.J.; Donoghue, M.J. [In press.] **Phylogeny and biogeography of *Tsuga* (Pinaceae) inferred from nuclear ribosomal ITS and chloroplast DNA sequence data.** Systematic Botany.

Havill, N.P.; Montgomery, M.E. 2008. **The role of arboreta in studying the evolution of host resistance to the hemlock woolly adelgid.** Arnoldia. 65: 2-9.

Lagalante, A.F.; Lewis, N.; Montgomery, M.E.; Shields, K.S. 2006. **Temporal and spatial variation of terpenoids in eastern hemlock (*Tsuga canadensis*) in relation to feeding by *Adelges tsugae*.** Journal of Chemical Ecology. 32: 2389-2403.

Lagalante, A.F.; Montgomery, M.E. 2003. **Analysis of terpenoids from hemlock (*Tsuga*) species by solid-phase microextraction/gas chromatography/ion-trap mass spectrometry.** Journal of Agriculture and Food Chemistry. 51: 2115-2120.

Lagalante, A.F.; Montgomery, M.E.; Calvosa, F.C.; Mirzabeigi, M.N. 2007. **Characterization of terpenoid volatiles from cultivars of eastern hemlock (*Tsuga canadensis)*.** Journal of Agriculture and Food Chemistry. 55: 1085-1056.