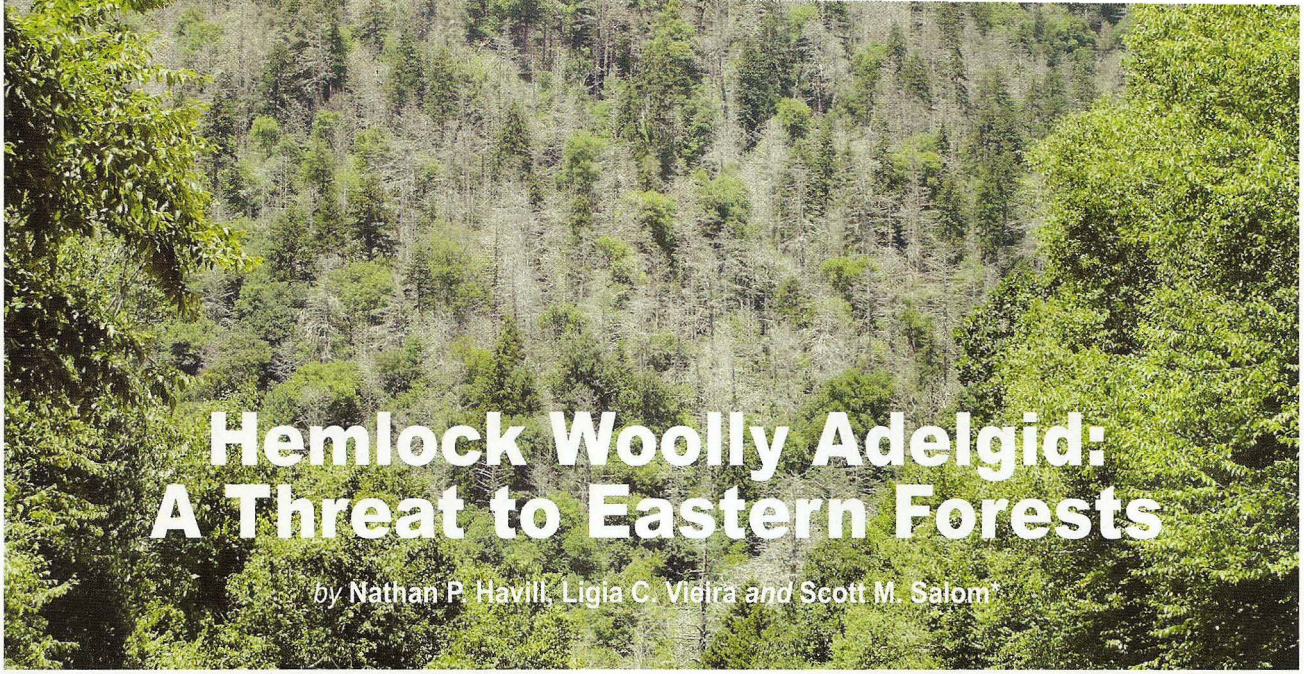


Hemlock Woolly Adelgid: A Threat to Eastern Forests

by Nathan P. Havill, Ligia C. Vieira and Scott M. Salom*

(Photo: Scott M. Salom, Virginia Tech)

Introduction

The hemlock woolly adelgid (HWA) *(Adelges tsugae Annand)* is a destructive, non-native pest of forest and ornamental hemlock trees in eastern North America. It was first collected in the eastern United States in 1951 in Richmond, Virginia, arriving sometime earlier directly from southern Japan, probably on live plant material. Other than its new association with eastern and Carolina hemlock, HWA has been historically associated with hemlock species in western North America and Asia.

The geographic range of eastern hemlock extends from the Canadian Maritime Provinces, west to the Great Lakes region, and as far south as northern Georgia and Alabama, with many separated populations to the south and west of its main range. Carolina hemlock has a much smaller range with isolated pockets in Virginia, North Carolina, South Carolina, Tennessee, and Georgia. Currently, HWA occupies approximately half of eastern hemlock's natural range and all of Carolina hemlock's range. Its spread north has slowed by the colder climate. It continues to move west.

Damage to Trees

HWA inserts its long, piercing-sucking mouth parts into the base of hemlock needles and feeds on nutrients stored in the xylem ray cells. In addition to removing the tree's nutrients, the adelgid is thought to cause a hypersensitive response that restricts water transport in the tree. Other stress factors can intensify these effects, causing decline and death of trees of all age classes. HWA can be fatal to hemlocks of all ages over a period of 4-15 years. In some areas, mortality due to HWA infestation has been as high as 95 percent. In other areas, especially in the North, some hemlock trees are still surviving in a weakened state after more than 15 years of infestation.

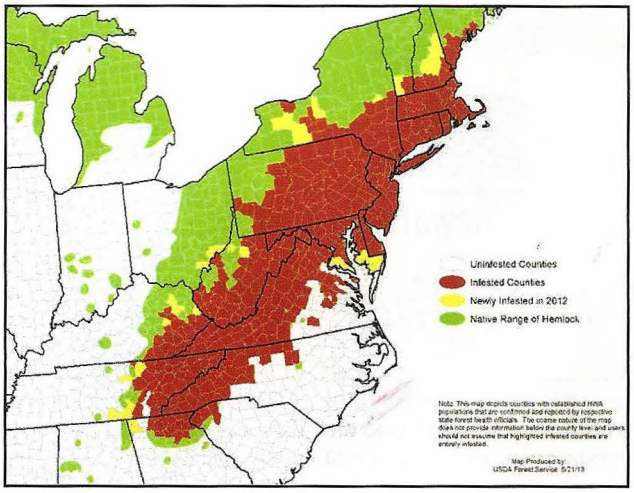
What HWA Looks Like

These small insects display several different forms during their life cycle, including winged and wingless forms. Generally, they are brownish-reddish in color, oval in shape, and about 0.8 mm in length. Upon egg hatch, crawlers disperse and settle on the plant tissue. The developing nymphs produce white cottony/waxy tufts which cover their bodies and remain in place throughout their lifetime. The white masses are three millimeters or larger in diameter and are typically found on the underside of needles attached to the twig right below the needle abscision layer. The presence of these white masses is a sure sign of hemlock woolly adelgid. The woolly mass is largest at the adult stage and contains 25-100 amber colored eggs.

HWA Life Cycle

Adelgids typically live part of their life cycle on spruce as a primary host and another conifer species as a secondary host. In North America, HWA lives only on its secondary host, hemlock. There are two generations per year that remain on hemlock. These "sistens" settle on the new shoots of trees in July, go dormant in the summer, awaken in October, and then develop during the winter. Adults lay eggs in late February-March. The next stage, "progrediens" develop similarly but much more quickly from April through June, and have no dormant period. The crawler stage follows egg hatch for both generations and is the only mobile life stage of both sistens

Map of eastern hemlock distribution and range of HWA.



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and progrediens. Crawlers of both wingless life stages can disperse by falling to lower branches, or often move to other trees with help of birds or other animals they hitch a ride with. It only takes one successfully settled nymph to start a new population on a tree, since all adults are female and reproduce asexually. Winged forms, "sexuparae" occasionally develop alongside progrediens and as adults will fly off in search of spruce. Since no suitable spruce species is known to exist in North America, this population is lost to the system.

Chemical Control

Foliar insecticides were initially used with good efficacy, but the need for frequent re-application and to completely drench the foliage has diminished their use. In the early 1990s a new class of systemic insecticides, the neonicotinoids, became available. Several active ingredients (imidacloprid, dinotefuran, acetamiprid, and thiamethoxam) can successfully control HWA. Due to their systemic activity, neonicotinoids can be applied by soil drench, soil injection, and several methods of trunk injection.

Since xylem sap flow is essential for transporting and distributing the insecticide from the soil to the canopy of the tree, treatment should be applied prior to severe damage to the trees. In healthy trees, it can take weeks to several months for the insecticide to be transported to where HWA feeds. In damaged trees, it can take longer because they have more difficulty transporting the insecticide. Treatment should be timed for spring or fall when water uptake by the trees is greatest.

Biological Control

With no specialist natural enemies present in eastern North America, HWA is able to flourish and spread unchecked. Searching for and studying natural enemies in western North America and parts of Asia with native lineages of HWA is considered critical. The primary objective of biological control is to introduce a group of natural enemies considered important in the native habitat and deemed safe for introduction into the eastern United States. Since no known parasitoids are associated with *Adelgidae*, the classical biological control program for HWA has focused on prey-specific predator species and entomopathogens.

Predators

The first efforts toward the application of biological control of HWA in eastern North America started in 1992. Of the predators first collected from Japan, the most promising at the time, *Sasajiscymnus tsugae* (Sasaji and McClure) *Coleoptera* (Cocinellidae) was imported, evaluated, mass reared, and cleared for release.

Field releases started in 1995 in Connecticut and more than two million *S. tsugae* have been released throughout the introduced range of HWA. Post-release evaluations indicated successful overwintering, reproduction, and dispersal of *S. tsugae,* but establishment of the predator and impact on HWA populations has been inconsistent. In the South where establishment has been closely monitored, the predator population takes five to seven years to reach a detectable level at only some of the locations where releases were made. Large-scale rearing of this insect for release is being phased out, yet monitoring its presence and impacts will continue.

Laricobius beetles in the family *Derodontidae* are specialist predators of adelgids. In 1997, a predator native to western

An eastern hemlock branch heavily infested by HWA. *(Photo: Scott M. Salom, Virginia Tech)*

North America, *Laricobius nigrinus* (Fender), was found to consistently feed only on HWA in the lab, and its life cycle was shown to be synchronous with HWA. Following host-range testing studies in quarantine, the predator was cleared for release in 2000. Rearing procedures were developed and releases began in 2003. To date, more than 200,000 beetles have been released at over 200 sites.

Evaluations after release showed that establishment is positively correlated with minimum winter temperature and with the number of beetles released. *Laricobius nigrinus* collected from coastal sites in the West (coastal strain) appear to establish better in warmer climates (plant hardiness zones 6a and higher).

Because the strain of HWA that was introduced to eastern North America is from southern Japan, an additional effort was made to look for natural enemies in this location. A new species, *Laricobius osakensis* (Montgomery and Shiyake), was discovered in 2005 and imported to quarantine to study its biology and host-range. Permission to remove *L. osakensis* from quarantine was received in 2010 and the first open releases began in 2012. Continued efforts toward large-scale operational releases and monitoring of this predator are underway.

Fungal Pathogens

Twenty fungal genera and 79 entomopathogenic fungus isolates were found in association with HWA in the eastern United States and southern China. Of all the isolates, no putative specialists were found. A combination of generalist fungi that included two strains of *Beauveria bassiana* (Balasamo), one of *Lecanicillium lecanii* (Zimmermann), and one of *Metarhizium anisopliae* (Metchnikoff), demonstrated high efficacy against HWA. A commercially available *Lecanicillium lecanii* formulated with a whey carrier has been tested in small-scale forest trials and has been shown to be effective, especially against early instar HWA before they produce wool. This augmentative approach is still in the early developmental stages.

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