Hemlock woolly adelgid and the disintegration of eastern hemlock ecosystems

By Richard A. Evans

An alien insect is causing decline in eastern hemlock forests, leading to the loss of native biodiversity, and opening the way for invasions of alien plants

Hemlock woolly adelgid *(Adelges tsugae)* is an aphid-like insect native to Asia that feeds exclusively on hemlock (*Tsuga* spp.) trees. First documented in Richmond, Virginia, in 1951, hemlock woolly adelgid (HWA) now occurs in 13 states, from Georgia to New Hampshire. During the past decade, HWA has been associated with widespread, severe decline and mortality of eastern hemlock *(T. canadensis)* trees. The insect also debilitates Carolina hemlock *(T. caroliniana)*, the other hemlock species native to the eastern United States. The geographic range of Carolina hemlock is limited to the southernmost Appalachian Mountains, which has just recently been infested by HWA. Examples of National Park System areas affected by HWA include Great Smoky Mountains and Shenandoah National Parks, New River Gorge National River, Catoctin Mountain Park, and Delaware Water Gap National Recreation Area.

Eastern hemlock is an ecologically important and influential conifer that for thousands of years was a major component of forests over much of the eastern United States. It is an extremely shade-tolerant species, and with appropriate climatic and site conditions forms nearly pure stands that can persist for hundreds of years. Hemlock-dominated forests create characteristically dark, acidic soil conditions that control and limit fundamental ecosystem characteristics such as plant and animal species composition, productivity, nutrient cycling, decomposition, and succession dynamics. During the past 400 years, the distribution and abundance of eastern hemlock was dramatically reduced by land clearing and logging, especially for the tanning industry, which utilized the tannic acid contained in the bark.

The decline and loss of our remaining eastern hemlock stands could be more ecologically significant in some respects than the loss of American chestnut *(Castanea dentata)* in the early 1900s because of chestnut blight. Following the demise of American chestnut, an array of native oak and hickory species naturally expanded, and have functioned as "ecological surrogates" for chestnut, providing habitat and mast (fruits and nuts) critical to many species of wildlife. In contrast, the species most likely to expand in declining hemlock stands include deciduous trees, white pine *(Pinus strobus)*, and invasive alien plants like "tree-of-heaven" *(Ailanthus altissima)*, Japanese barberry *(Berberis thunbergii)*, and Japanese stiltgrass *(Microstegium vimineum)* (Orwig and Foster 1996, Battles et al. 1999). These species will not provide habitat or ecological functions resembling those of eastern hemlock (fig. 1).

Figure 1. Openings in the canopy of hemlock forests killed by hemlock woolly adelgid at Delaware Water Gap National Recreation Area mean lost habitat for songbirds and other native wildlife. The disturbance also increases light and temperature in the forest understory, opening the way for invasive alien plants like Japanese barberry, Japanese stiltgrass, and "tree-of-heaven." NPS PHOTO BY RICHARD A. EVANS

HWA and hemlock forests at Delaware Water Gap

Eastern hemlock forests contribute much to the ecological, aesthetic, and recreational values of Delaware Water Gap National Recreation Area (Pennsylvania and New Jersey). Eastern hemlock is an important component of the forest canopy of 141 forest stands covering approximately 2,800 acres (1,134 ha) (about 5%) of the recreation area (Myers and Irish 1981, Young et al. 2002).

Many of these hemlock stands were designated in the recreation area's general management plan as "outstanding natural features" having "high intrinsic or unique values" (National Park Service 1987). Scenic waterfalls are associated with hemlock stands in the recreation area, and very popular activities like hiking, trout fishing, bird watching, and picnicking are concentrated in these areas.

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Hemlock woolly adelgid was first detected within the national recreation area in 1989. In the fall of 1992, recreation area staff initiated a program to address the threat that HWA posed to valued park resources (Evans 1995, Evans et al. 1996). Three main goals of this program have been to (1) generate information about the distribution and abundance of HWA and hemlock tree health in the recreation area; (2) identify and document the distinctive characteristics of hemlock ecosystems in the recreation area, especially their contribution to park biodiversity; and (3) manage HWA and maintain hemlock ecosystems to the extent possible.

Monitoring

To monitor and relate HWA infestation levels to the health of individual hemlock trees, we established a system of 81 permanent hemlock plots at seven areas around the recreation area. Each plot includes 10 hemlock trees (810 trees total) permanently marked with individually numbered tags, so we can track the HWA populations and the health of each tree over the years. We have found a very strong relationship between HWA infestation level and the amount of new twig growth on branches (Evans 1996). As the HWA infestation level increases, the amount of new growth decreases sharply; branches having 45% or more of their twigs infested with HWA are unlikely to produce much new growth (fig. 2).

Ecological studies

We have used two complementary approaches to generate information about hemlock ecosystems and biodiversity in the recreation area. One approach has been to conduct detailed, "intensive" ecological studies at two sites (Battles et al 1999, Sciascia and Pehek 1995, Schrot 1998). The other approach has been to conduct less detailed, "extensive" studies at many sites, and compare hemlock forests to hardwood forests. In 1996, the Biological Resources Division (BRD) of the U.S. Geological Survey used a digital elevation model and data on park forest cover types and streams in a geographic information system to select 14 representative hemlock stands in the recreation area, and pair each of these hemlock stands with a hardwood stand having similar terrain characteristics (Young et al. 2002). Since then, studies of tree species composition (Sullivan et al. 1998), stream water temperatures and macroinvertebrates (Snyder et al. 2002), fish (Ross et al. 2003), salamanders (Brotherton et al. 2001), and forest breeding birds (Ross 2000) have been conducted at these 14 paired sites. Following are highlights from some of these studies at the paired hemlock and hardwood sites.

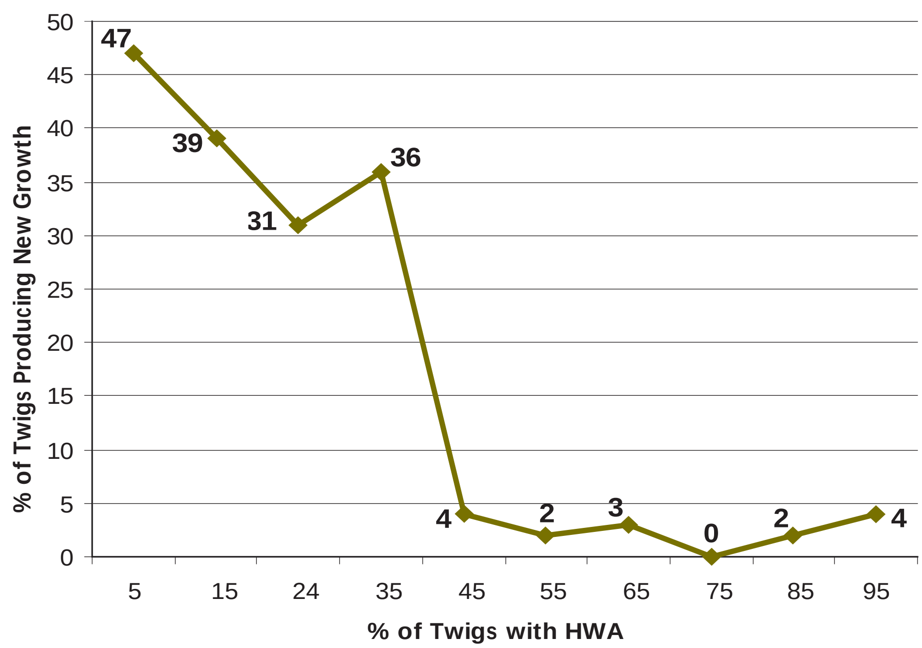

Figure 2. Relationship of HWA infestation level and new twig growth on hemlock branches at Delaware Water Gap National Recreation Area during summer 2000. Branches with 45% or more twigs infested with HWA produced almost no new growth. A total of 318 branches and 16,154 twigs were evaluated.

Results highlights

Small streams in hemlock forests support more macroinvertebrate species than similar small streams in hardwood forests in the recreation area. The average number of aquatic macroinvertebrate taxa found in hemlock streams was 37% greater than that found in hardwood streams (55 versus 40 taxa). Fifteen macroinvertebrate taxa were strongly associated with hemlock streams, and three taxa were found only in hemlock streams. No macroinvertebrate taxa were strongly associated with the hardwood streams (Snyder et al. 2002). Brook trout *(Salvelinus fontinalis)* are three times more likely to occur in small hemlock streams than in similar hardwood streams (Ross et al. 2003) in the recreation area.

Data from electronic temperature recorders showed that hemlock streams were consistently cooler in summer (May through September), and warmer in winter (December through February), than their paired hardwood streams in the recreation area. During June, July, and August, median daily temperatures in hemlock streams were typically 1° C to 2° C (1.8° F to 3.6° F) cooler than their hardwood stream counterparts. These stream temperature differences are potentially important to brook trout condition and survival. Temperatures above 20° C (68° F) are very stressful for brook trout. Whereas the maximum daily temperature in hemlock streams exceeded 20° C only 3% of the time, the maximum daily temperature in hardwood streams exceeded 20° C 18% of the time (Snyder et al. 2002).

Small streams draining hardwood forests are much more likely to dry up during summer droughts than similar small streams draining hemlock forests in the recreation area (table 1). The extent and frequency of stream channel drying is very likely a major factor controlling the aquatic macroinvertebrate assemblages, in addition to the occurrence of brook trout, in these small streams. The higher species richness in hemlock streams compared to hardwood streams is probably related to the frequency of hardwood streams drying up.

Table 1. Comparison of streams in hemlock and hardwood forests that dried up in summer 1997 and 1999

Forest Type	1997—% and (#)	1999—% and (#)
Hemlock	0 (0)	7 (1)
Hardwood	29 (4)	43 (6)
χ^2 p-value	0.013	0.023

Several species of breeding birds common in hemlock forests are rare or absent in hardwood forests in the recreation area (Ross 2000). These include the blackburnian warbler *(Dendroica fusca)*, black-throated green warbler *(Dendroica virens)*, and blue-headed vireo *(Vireo solitaris)*. Populations of these species will probably decline in the recreation area as hemlock forests decline. These conclusions are very similar to those drawn from studies in New Jersey (Benzinger 1994a and 1994b) and in the western Great Lakes region (Howe and Mossman 1995).

Hemlock forest management: maintain, mitigate, and restore

Biological control agents provide the only hope of limiting the damaging effects of HWA in large or remote hemlock forests. Several biocontrol agents for HWA are in the research and development phase (see papers in Onken et al. 2002). However, only one, the predatory "Pt" beetle *(Pseudoscymnus tsugae)*, has been available for use. Since completing an environmental assessment (Evans 2000) and a "Finding of No Significant Impact," we have released 65,000 Pt beetles in the recreation area (fig. 3).

Dead and dying hemlock trees in certain situations present threats to human safety and property that must be addressed. At Delaware Water Gap National Recreation Area, more than 250 dead or dying hemlock trees were cut down at a popular visitor use area in October 2002 (fig. 4).

Figure 3. Former national recreation area superintendent Bill Laitner releases HWA biocontrol beetles ("Pt" beetles) in Delaware Water Gap National Recreation Area, June 2000. NPS PHOTO BY RICHARD A. EVANS

Figure 4. Dead and dying hemlock trees in certain situations present threats to human safety and property that must be addressed. At Delaware Water Gap National Recreation Area, more than 250 dead or dying hemlock trees were cut down at a popular visitor use area in October 2002. NPS PHOTO BY RICHARD A. EVANS

We are currently working to develop a hemlock management plan for the park. We intend to develop strategies and techniques to foster regeneration of native tree species, curtail invasions by alien plant species in affected areas, and minimize impacts to park visitors.

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References

Battles, J. J., N. Cleavitt, T. J. Fahey, and R. A. Evans. 1999. Vegetation composition and structure in two hemlock stands threatened by hemlock woolly adelgid. Pages 55–61 in K. A. McManus, K. S. Shields, and D. R. Souto, editors. Proceedings of the Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America. USDA Forest Service GTR-NE-267. Durham, New Hampshire.

Benzinger, J. 1994a. Hemlock decline and breeding birds I: Hemlock ecology. Records of New Jersey Birds 20(1):1–12.

Benzinger, J. 1994b Hemlock decline and breeding birds II: Effects of habitat change. Records of New Jersey Birds 20(2): 34–51.

Brotherton, D., R. M. Bonett, J. L. Behler, and R. Cook. 2001. Paired hemlock-hardwood stream salamander survey, Delaware Water Gap National Recreation Area. Draft final report. National Park Service, Philadelphia, Pennsylvania.

Evans, R. A. 1995. Hemlock ravines at Delaware Water Gap National Recreation Area: highly valued, distinctive, and threatened ecosystems. Proceedings of the 35th Anniversary of Delaware Water Gap National Recreation Area. National Park Service, Milford, Pennsylvania.

Evans, R. A., E. Johnson, J. Shreiner, A. Ambler, J. Battles, N. Cleavitt, T. Fayhey, J. Sciascia, and E. Pehek. 1996. Potential impacts of hemlock woolly adelgid on eastern hemlock ecosystems. Proceedings of the First Hemlock Woolly Adelgid Review. FHTET 96—10:42–57. USDA Forest Service, Roanoke, Virginia.

Evans, R. 1996. Revised protocols for new growth and HWA data. Unpublished protocol guidelines. Delaware Water Gap National Recreation Area. National Park Service, Bushkill, Pennsylvania.

Evans, R. A. 2000. Environmental assessment for the release and establishment of *Pseudoscymnus tsugae* (Coleoptera: Coccinellidae) as a biological control agent for hemlock woolly adelgid *(Adelges tsugae)* at Delaware Water Gap National Recreation Area. National Park Service, Bushkill, Pennsylvania.

Howe, R. W., and M. Mossman. 1995. The significance of hemlock for breeding birds in the western Great Lakes region. Pages 125–139 in G. Mroz and J. Martin, editors. Proceedings of a conference on the ecology and management of eastern hemlock, 27–28 September 1995, Iron Mountain, Michigan. Department of Forestry, University of Wisconsin, Madison.

Myers, W. L., and R. R. Irish. 1981. Vegetation survey of Delaware Water Gap National Recreation Area. Final report. USDI National Park Service, Philadelphia, Pennsylvania.

National Park Service. 1987. General Management Plan for Delaware Water Gap National Recreation Area. Bushkill, Pennsylvania.

Onken, B., R. Reardon, and J. Lashomb. 2002. Proceedings: Hemlock Woolly Adelgid in the Eastern United States Symposium, 5–7 February 2002, East Brunswick, New Jersey.

Orwig, D. A., and D. R. Foster. 1996. Forest ecosystem response to hemlock wooly adelgid outbreak in southern New England. Bulletin of the Ecological Society of America 77:365.

Ross, R. 2000. Mesohabitat use of threatened hemlock forests by breeding birds at Delaware Water Gap National Recreation Area. Hemlock Woolly Adelgid Newsletter, Issue #5, USDA Forest Service. Available at http://www.fs.fed.us/na/morgantown/fhp/hwa/news5/hwa5.htm (accessed 8 July 2004).

Ross, R. M., R. M. Bennett, C. D. Snyder, J. A. Young, D. R. Smith, and D. P. Lemarie. 2003. Influence of eastern hemlock *(Tsuga canadensis)* on fish community structure and function in headwater streams of the Delaware River basin. Ecology of Freshwater Fish 12:60–65.

Schrot, A. 1998. Assessment of arthropod diversity associated with eastern hemlock forests at Delaware Water Gap National Recreation Area. Pennsylvania State University, University Park, Pennsylvania.

Sciascia, J. C., and E. Pehek. 1995. Small mammal and amphibian populations and their microhabitat preferences within selected hemlock ecosystems in the Delaware Water Gap National Recreation Area. Report to the National Park Service. New Jersey Department of Fish and Wildlife, Nongame Division; Trenton, New Jersey.

Snyder, C., J. Young, D. Lemarie, and D. Smith. 2002. Influence of eastern hemlock *(Tsuga canadensis)* forests on aquatic invertebrate assemblages in headwater streams. Canadian Journal of Fisheries and Aquatic Sciences 59(2):262–275.

Sullivan, K., B. Black, C. Mahan, M. Abrams, K. C. Kim, and R. Yahner. 1998. Overstory tree composition of paired hemlock and hardwood forest stands at Delaware Water Gap National Recreation Area. Final report. National Park Service, Philadelphia, Pennsylvania.

Young, J., C. Snyder, D. Smith, and D. Lemarie. 2002. A terrain-based, paired-site sampling design to assess biodiversity losses from eastern hemlock decline. Environmental Monitoring and Assessment 76:167–183.

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