Stand, Landscape, and Ecosystem Analyses of Hemlock Woolly Adelgid Outbreaks in Southern New England: An Overview

David A. Orwig and David R. Foster[1]

Abstract

Hemlock woolly adelgid (HWA) (*Adelges tsugae*), an introduced aphid-like insect from Asia, is expanding across the northeastern United States through the range of eastern hemlock (*Tsuga canadensis* (L.) Carr.) and has the potential to severely reduce or eliminate this important late-successional species. While infestation and unimpeded migration of HWA presents a tremendous management problem, it also has provided an unusual opportunity to examine the impacts of an introduced pest as it spreads. In order to develop insights into these management issues, we have developed a multi-faceted research effort that examines various forest responses to HWA outbreaks in Connecticut including stand and community reorganization dynamics, landscape patterns of HWA infestation, damage, and hemlock mortality, microenvironmental changes and their impact on ecosystem processes, and the effect of cutting infested forests on successional and ecosystem dynamics. This paper presents an overview of this research, conducted by Harvard Forest scientists.

Introduction

Hemlock woolly adelgid (HWA; *Adelges tsugae* Annand), an introduced aphid-like insect from Asia, is expanding across the northeastern United States through the range of eastern hemlock and has the potential to severely reduce or eliminate this important late-successional species (McClure 1995a; Orwig and Foster 1998). Despite the growing knowledge about the biology of HWA (McClure 1987, 1989,1990,1991, 1995a; Salom et al. 1996; Young et al. 1995) and increasing efforts to find, raise and release natural or exotic biological controls (Gouli et al. 1997; McClure 1995b; McClure and Cheah 1998; Sasaji and McClure 1997; Others, this volume), we still know very little about how HWA infestation will affect forest and ecosystem processes. Therefore, this paper will present results from past and current research by Harvard Forest scientists on the various forest responses to HWA outbreaks in southern New England.

Research Approaches

Stand-level Dynamics

As part of a large study investigating stand to landscape level forest dynamics resulting from HWA infestation, we examined the initial community response of hemlock stands varying in mortality levels in south-central Connecticut (Orwig and Foster 1998). Since 1995, mortality of overstory and understory hemlock has risen to over 60% in half of the stands and continues to increase 5 to 15% per year. The health and vigor of remaining trees has deteriorated in all stands, with the majority of trees containing less than 25% of their foliage. We have observed no sign of tree recovery on these sites over the last 4 years and predict that all sampled trees will die within the next few years. A rapid recolonization of these forests with seedlings of black birch (*Betula lenta* L.), red maple (*Acer rubrum* L.), and oak (*Quercus*) as well as opportunistic herbaceous species has continued to occur following additional hemlock mortality. Seedling densities have increased in moderately damaged sites and have thinned but increased in cover in heavily damaged areas. We will continue to examine the ongoing dynamics in these forests to gain detailed information on the mechanisms and rate of vegetation recovery.

Landscape-level dynamics

Data and observations from these original eight stands were limited to southern Connecticut and we were interested in how representative the results were compared to a much broader study region. To meet this objective we established a 5900 km^2 transect surrounding the Connecticut River Valley extending from Long Island Sound north to the Massachusetts border (Orwig et al. unpublished data). Within the transect we mapped hemlock stands from aerial photographs and then visited and compiled information on stand composition and structure, presence of HWA, degree of overstory and understory mortality, seedling densities, and site characteristics from 114 stands. HWA presence was observed in nearly 90% of all stands visited and hemlock sapling and overstory trees have experienced much higher rates of mortality (20 to 100%) in the southern part of the state compared to rates in the northern part of the state (0 to 15%). Hemlock mortality exceeded 20% on most topographic aspects, not just the drier southwest or west facing slopes. The health of remaining trees exhibits a pattern similar to mortality, with healthier trees located in the northern part of the transect. These data suggest that except latitude, site factors play little, if any role in the susceptibility of forests to adelgid, and that most stands will suffer heavy or complete mortality following infestation.

Forest composition data from infested stands is useful in predicting the species that will eventually replace hemlock. Currently, black birch, red oak (*Quercus rubra* L.), and red maple are present in the overstory of most stands and are starting to become established in the understory. We have found that most forests contained few hemlock seedlings but modest to high densities of hemlock saplings (200 to 800 ha^{-1}). However, saplings are currently experiencing high levels of adelgid infestation and mortality and seeds do not remain viable for more than a year or two. Therefore, we predict a complete change in cover type from hemlock to hardwood-dominated forests across broad geographical areas.

[1]Harvard Forest, Harvard University, Petersham, MA 01366

Ecosystem-level Impacts

Results from prior ecosystem-level research conducted on sites we have been following for several years (Jenkins et al. 1999; Yorks et al. this volume) suggest that HWA infestation can lead to dramatic changes in nitrogen cycling. Jenkins et al. (1999) found large increases in N mineralization and nitrification rates in infested versus healthy hemlock forests. However, we still do not know how rapidly these changes occur, how long they persist, or to what degree changes in soil temperature or biotic uptake affect nutrient cycling. In order to answer these questions, we have initiated a study examining N availability, mineralization, and nitrification rates in a subset of Connecticut sites that are infested with HWA but have experienced little to no hemlock mortality (Orwig et al. unpublished data). These measurements will continue for at least 3 years to investigate the temporal dynamics and potential mechanisms driving the changes. Additional soil analyses including pH, moisture, carbon to nitrogen ratios, texture, and total soil organic matter have been completed on these 8 sites and we will be quantifying macronutrients such as Ca, Mg, P, and K.

To complement the ongoing ecosystem study, R. Cobb et al. (unpublished data) have initiated a 2-year project examining the effect of HWA infestation on hemlock foliar decomposition rates. We predict that rates will increase with thinning hemlock canopies, although the magnitude of increase may, in turn, be mediated by foliar quality, which may be affected by HWA infestation. To elucidate these potentially interacting factors, hemlock foliage from eight infested stands in Connecticut and from uninfested forests at Harvard Forest in Petersham, MA will be examined for total C, N and C:N ratios and then analyzed *in situ* over time for relative decomposition rates. To investigate what role microenvironmental changes have on nutrient cycling and decomposition rates, organic-layer and mineral-layer soil temperatures are being recorded and hemispherical photographs are being examined to quantify increases in light reaching the forest floor.

Logging impacts

While sampling forests for the landscape-level study, we observed hemlock being cut on over 20% of the stands visited. These observations and others throughout Connecticut, Rhode Island and Massachusetts suggest that hemlock logging is increasing in frequency as a management option in infested stands. However, we do not know how cutting infested hemlock stands will affect regeneration composition or ecosystem processes. Newly initiated research by M. Kizlinski (unpublished data) is examining the effect of hemlock logging on revegetation and ecosystem processes that will complement ongoing research efforts in uncut stands and will shed insight on whether continued cutting will have any adverse impact on hemlock ecosystems.

Conclusions

The future of hemlock forests in New England is bleak. HWA continues to migrate northward apparently unimpeded by any site or meteorological characteristics except extremely cold winter temperatures (Parker et al. 1998). In currently infested stands, trees continue to deteriorate over time and observations from hundreds of stands suggest there is little chance of recovery. Unless an effective biological or chemical control is found that can be released or used on a massive scale that coincides with the range of HWA, hemlock may be eliminated across broad portions of its range in a few decades. By investigating the various forest and ecosystem responses to adelgid infestation as it progresses, however, we can be armed with predictions and pertinent information on how best to manage these lands in the future.

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Literature Cited

Gouli, S.; Parker, B. L.; Skinner, M. 1997. **Isolation of fungi associated with hemlock woolly adelgid (Homoptera: Adelgidae).** Journal of Invertebrate Pathology. 70: 76-77.

Jenkins, J. C.; Aber, J. D.; Canham, C. D. 1999. **Hemlock woolly adelgid impacts on community structure and N cycling rates in eastern hemlock forests.** Canadian Journal of Forest Research. 29: 630-645.

McClure, M. S. 1987. **Biology and control of hemlock woolly adelgid.** Bulletin of the Connecticut Agricultural Experiment Station. 851.

McClure, M. S. 1989. **Evidence of a polymorphic life cycle in the hemlock woolly adelgid, *Adelges tsugae* Annand (Homoptera: Adelgidae)**. Annals of the Entomological Society of America. 82: 52-54.

McClure, M. S. 1990. **Role of wind, birds, deer, and humans in the dispersal of hemlock woolly adelgid (Homoptera: Adelgidae).** Environmental Entomology. 19: 36-43.

McClure, M. S. 1991. **Density-dependent feedback and population cycles in *Adelges tsugae* (Homoptera: Adelgidae) on *Tsuga canadensis*.** Environmental Entomology. 20: 258-264.

McClure, M. S. 1995a. **Managing hemlock woolly adelgid in ornamental landscapes.** Bulletin of the Connecticut Agricultural Experiment Station. 925.

McClure, M. S. 1995b. **Using natural enemies from Japan to control hemlock woolly adelgid.** Frontiers of Plant Science. 47: 5-7.

McClure, M. S.; Cheah, C. A. S.-J. 1998. **Released Japanese ladybugs are multiplying and killing hemlock woolly adelgids.** Frontiers of Plant Science. 50: 6-8.

Orwig, D. A.; Foster, D. R. 1998. **Forest response to the introduced hemlock woolly adelgid in southern New England, USA.** Journal of the Torrey Botanical Society. 125: 60-73.

Parker, B. L.; Skinner, M.; Gouli, S.; Ashikaga, T.; Teillon, H. B. 1998. **Survival of hemlock woolly adelgid (Homoptera: Adelgidae) at low temperatures.** Forest Science. 44: 414-420.

Salom, S. M.; Tigner, T.; Reardon, R., eds. 1996. **Proceedings of the First Hemlock Woolly Adelgid Review.** FHTET 96-10. U.S. Department of Agriculture, Forest Service.

Sasaji, H.; McClure, M. S. 1997. **Description and distribution of *Psuedoscymnus tsugae* sp. nov. (Coleoptera:Coccinellidae), an important predator of hemlock woolly adelgid in Japan.** Annals of the Entomological Society of America. 90: 563-568.

Young, R. F.; Shields, K. S.; Berlyn, G.P. 1995. **Hemlock woolly adelgid (Homoptera: Adelgidae): stylet bundle insertion and feeding sites.** Annals of the Entomological Society of America. 88: 827-835.