Hemlock Woolly Adelgid (*Adelges tsugae* Annand) on DWSP Lands: Problem extent and proposed management approach

Introduction

The hemlock woolly adelgid (HWA) is a small aphid-like insect native to Japan. It arrived in North America in the 1920s, and was first recognized on the east coast of the US in 1951 and in Connecticut in 1985. It is spreading in all directions across the range of eastern hemlock (*Tsuga canadensis)*. It is a serious pest on both eastern hemlock and Carolina hemlock (*Tsuga caroliniana* Engelm), but does not seriously injure the western hemlocks (*Tsuga heterophylla* or *Tsuba mertensiana*). Chinese hemlock (*Tsuga chinensis*) planted at the Harvard University Arnold Arboretum resists HWA (Peter Del Tredici, Senior Research Scientist, Arnold Arboretum, personal communication).

Eastern hemlock grows throughout the watersheds under care and control of the DCR/Division of Water Supply Protection, but is concentrated in three forest types: relatively pure hemlock stands; in mixes where white pine dominates; and in mixes where hardwoods dominate. Forest typing completed in the past several years indicates that out of the approximately 58,000 acres of Quabbin watershed forest that DWSP controls, 1,642 acres (~3%) is in pure hemlock stands and an additional 5,434 acres (~9%) is in stands with a significant component of hemlock in mixes with other softwood and hardwood species. About 9% of the overall basal area on Quabbin permanent inventory plots was in hemlock in 2000, and hemlock sawlog volume based on those plots was approximately 30-35 MMBF. On DWSP properties on the Ware River watershed, about 7% of the overall stocking is in hemlock, the vast majority of which is in mixed white pine/hemlock stands, which total approximately 4,325 acres. A rough estimate puts the hemlock volume at Ware River in excess of 10 MMBF. Hemlock is <2% of the stocking, on just over 120 acres of hemlock/hardwood type on the Wachusett Reservoir watershed. A significant portion of the hemlock stocking overall is located on wet soils, on steep slopes, or in riparian zones, some of which are steep-sided ravines, while other stands are on drier and flatter terrain.

The hemlock woolly adelgid is a particularly troublesome pest on DWSP watersheds (and elsewhere) for several reasons:

1. The insect is without natural enemies in the northeastern US. Several potential biocontrols have been imported from Japan and China, reared in laboratories, and released at HWA sites, but to date these have had very limited impact for a variety of reasons. Successful chemical controls are mostly limited to systemics and dormant oil spraying. These can be effective in ornamental plantings, but are virtually impossible to apply in an extensive forest infestation.
2. The HWA is parthenogenic, which means that every adult is capable of reproduction. Each adult lays 50-300 eggs, typically about 100. Furthermore, the population successfully completes two generations within a year. The first eggs are laid in March and April. Crawlers hatch from these eggs and begin feeding at the base of needles, where they remain throughout development. This generation matures in mid-June, when adults lay eggs again. These hatch in July, move to new hemlock growth and then become dormant until October, when they begin feeding again. They continue feeding throughout the winter (the species evolved in high elevations in Asia and tolerates low temperatures), maturing by spring to begin the process again. Mortality rates observed during the winter of 2002-2003 were as high as 75% (Jen Pontius, USDA FS, personal communication), but the fecundity of this species will likely allow its rapid recovery.
3. While hemlocks that are under attack eventually become incapable of supporting the infestation, resulting in a population crash in the HWA on that tree, these trees are also incapable of recovering from this level of damage. Trees that are infected may die within 4-5 years, although some may persist for longer in a weakened condition. The insect attacks all ages of trees, and in fact prefers younger foliage. There is so far no clear evidence of resistance sufficient to allow any individual eastern hemlock tree to survive once infested with the hemlock woolly adelgid (Orwig et al. 2002).

4. Where hemlock dominates the riparian zone along streams leading to the reservoirs or the Ware River, it is of particular concern to DWPS. Loss of this overstory may present short-term threats to water quality by raising stream temperatures and through uncaptured nitrogen and other cation losses following increases in nitrogen mineralization and nitrification rates. Regeneration may prevent significant losses to stream water.

Principles from current literature

1. Hemlock of all ages and sizes is susceptible to HWA infection, and infection will eventually kill the infected tree. Trees on poorer, drier, ridge top sites may die more rapidly than those on well-watered sites, but trees located on the full range of sites have become infected and ultimately died.

> Orwig et al, 2002. "Mortality was weakly related to aspect and stand size. Average mortality was highest on western aspects but exceeded 20% on most slopes. Remaining trees averaged over 50% foliar loss, with no significant difference among aspects. …… Results suggest that as HWA becomes abundant, stands on xeric aspects succumb rapidly, but that stand and landscape variables such as overstory composition and structure, slope, and elevation, exert little control over susceptibility or eventual mortality."

2. ALL approaches to management, including simply allowing HWA mortality to occur without intervention, result in changes to the forest floor that include increased mineralization and nitrification rates that produce more mobile inorganic nitrogen. To the extent that regeneration occurs in pace with, or in advance of mortality, available inorganic nitrogen is recaptured and immobilized by biomass accumulation. Consequently, it should be expected that the highest accumulation of inorganic nitrogen will occur in soils where heavy cutting occurs with little or no regeneration on the ground, while the more gradual conversion associated with either partial, preparatory cutting designed to stimulate advance regeneration or letting the stand die and regenerate without intervention should reduce both the volume and the duration of soil accumulations of inorganic nitrogen. The significance of these differences in soil nutrient accumulations to quality changes in adjacent surface waters is uncertain.

> Kislinski, et al. 2002. "The total amount of N captured in recent harvests was about five times greater than HWA-damaged [unharvested] sites and nine times greater than undamaged sites….Compared with undamaged sites, inorganic N pools increased only slightly in HWA-damaged sites, but increased tremendously following logging.…Net nitrification rates were 41 times higher in HWA-damaged sites, 72 times higher in recent harvests, and over 200 times higher in old harvests when compared with the near-zero rates in undamaged hemlock sites.…Relatively large amounts of ammonium and nitrate captured in recent harvests indicate higher N availability, less vegetative uptake, and a greater potential for N leaching. Hemlock harvesting imposed more abrupt microenvironmental changes, and rapidly reduced vegetative cover while chronic HWA infestation led to gradually thinning canopies. Both disturbances led to black-birch dominated forests, although logging resulted in greater amounts of shade-intolerant regeneration, higher soil pH and nitrification rates, and reduced forest floor mass. Pre-emptive cutting of undamaged forests may lead to greater N losses than those associated with HWA infestation or logging of deteriorated hemlock forests, because of reduced vegetative uptake. Silvicultural methods that allow for vegetation establishment prior to harvesting will probably lessen the ecological impacts of hemlock removal.…We predict in sites infested with HWA, the slow and progressive hemlock decline and gradual development of a hardwood understory may result in the least amount of nitrogen loss. Pre-emptive cutting of undamaged sites appears to pose the greatest threat for nitrate leaching, followed by logging of declining sites."

> Yorks, et al. (2000). "There is clearly a strong potential for significant losses of N and nutrient cations to soil water in hemlock stands with high mortality. These losses reduce site nutrient

capital and may affect future productivity, especially on sites that were nutrient-poor prior to hemlock mortality. Nutrient losses to soil water may also lead to declines in surface water quality (i.e. increases in nutrient concentrations) in areas with significant proportions of hemlock and where hemlock is typically dominant in ravines and on steep slopes. Such effects on surface water quality will be particularly important to those managing forested watersheds that provide a domestic water supply."

3. As is true with any overstory removal of trees, the loss of hemlock due either to salvage logging or defoliation and mortality results in an increase in soil moisture and subsurface flow, which also increase the likelihood of transporting both organic and inorganic nutrients to streams.

Kimple and Schuster. 2002. "Stand productivity and water use appear little impacted until an intermediate threshold of damage has occurred. Enhanced soil moisture availability may first be noticed toward the end of the growing season. Once trees reach heavily damaged status, water uptake and transpiration are severely reduced throughout the growing season, leaving substantially more water available for evaporation, runoff, and/or use by other plant species."

4. There remains some uncertainty about the fate of individual hemlock stands. While trees eventually succumb once infected, the distribution of infection has been moderated at least by the variability in distribution vectors. Selected stands within large forests that have escaped infestation and remain healthy may be worth protecting, even at high cost. The possibility that they can persist beyond the infestation and provide landscape points from which hemlock might eventually recover, especially if natural and introduced controls eventually strengthen, should be considered.

5. Scientists throughout the range of *Tsuga canadensis* are working to find and release safe predators shown to be effective in controlling HWA, including a wide variety of predatory coccinelid beetles and fungi. To date, these efforts have not produced controls able to keep pace with the reproduction and spread of HWA. However, our experiences with *Lymantria dispar* (gypsy moth) and the dramatic reduction of its threat brought on by the growth of *Entomophaga maimaiga*, a population-controlling fungus, raise a glimmer of hope that science and natural systems might combine to moderate the demise of the hemlock population throughout its range.

Reid, et al (2002). " Management of forest pests such as HWA in natural areas relies on natural controls that are simple to use and of low cost. To date the major emphasis of research in this area has been on the rearing and release of exotic coccinelid predators. However, rarely will one biological control organism—a “silver bullet”—effectively suppress serious exotic pest populations below damaging levels. More realistic is a multifaceted approach using several compatible agents that together reduce pest populations. Entomopathogenic fungi comprise a group of naturally occurring organisms that penetrate, multiply within, and ultimately kill their insect hosts. These represent a group of promising, but as yet underutilized biological control agents for management of HWA and other exotic insect pests. Fungi are particularly promising for HWA management for several reasons. They have been found infecting HWA naturally in the eastern United States and in low-level adelgid populations in China. Many species of these fungi are relatively easy and inexpensive to mass-produce, and most have little or no negative impact on the environment, humans, or non-target organisms. Production is species and strain specific, and under ideal conditions, enough material for 1 ha. can be prepared for under $20.00 (Wraight et al. 2001). Naturally occurring epizootics caused by fungi have been observed in populations of scales and various aphids demonstrating the potential for their use. An additional benefit of entomopathogenic fungi is their potential to persist in an infected population, providing an ongoing chronic fungal infection. Such conditions may cause an overall reduction in health and fecundity of the pest species. This stress may sufficiently reduce the pest population to a more manageable level—a level perhaps that coccinelid predators could reduce even further."

DWSP Policy for Hemlock Management in Response to HWA

It is a primary objective of DWSP to make forest management choices that conservatively protect the drinking water supply. Secondary objectives include the protection of biological diversity and meeting the market demand for renewable resources, in part to offset the costs of protecting the water supply. The policy outlined below factors in background information as well as these objectives, in attempting to conservatively address the hemlock woolly adelgid problem.

1. Because of the uncertainty associated with hemlock mortality and the possibility of natural or introduced biological controls, DWSP will not conduct pre-emptive harvests of hemlock. Forest stands containing greater than 50% stocking of hemlock will be monitored for the presence of HWA. When the majority (>50%) of the hemlock trees in an operable stand are infected with HWA, the stand will be considered to be infested and will be considered for a harvest/salvage operation. Exceptions include operable, infested stands within areas such as the Pottapaug Natural Area on the Quabbin Reservoir, where harvesting is generally excluded unless managers determine that it is needed to prevent the spread of an insect or disease to other parts of the watershed.

2. Due to water quality protection concerns and the likelihood of increased inorganic nutrient availability, the hemlock management policy in uplands will differ from management in wetlands and riparian zones.

In upland areas, the Division will harvest operable, infested hemlock stands to salvage wood and to reduce potential fire and recreational hazards associated with large volumes of standing and falling dead wood, while working to meet management goals for diverse forest structure. Where possible, scattered healthy overstory hemlock trees will be retained. These salvage operations will be designed to provide enough light to stimulate a diversity of shade intolerant species to compete with the common black birch regeneration response. Enrichment planting may be used in these upland areas to strengthen the diversity of the regeneration response.

The Division will not cut infested hemlock stands located in seasonally flooded wetlands, and will avoid running equipment in hemlock stands growing on hydric soils, except when these soils are dry enough or frozen enough to carry logging equipment without damage. In riparian areas, cutting practices regulations limit cutting to 50% of the basal area, thus limiting the opportunity to stimulate shade intolerant regeneration except by increasing cutting adjacent to the filter strip. Harvesting stimulates mineralization and nitrification, leading to higher inorganic N pools. Black birch is competitively enhanced by high N levels and moderate light levels. Therefore, partial harvesting in riparian areas may favor black birch rather than diverse regeneration, the opposite of the desired effects. The Division has experimented with planting in conjunction with partial cutting in riparian zones, and is working to document examples in which these trees have successfully competed with natural black birch regeneration. Riparian areas will eventually lose their hemlock to HWA, but leaving them to gradually die may reduce the risk of nutrient transport to adjacent streams, although this has not yet been adequately documented. In light of all the above, the Division will not cut within the variable width filter strip defined by Chapter 132 regulations during salvage operations in hemlock stands infested with HWA, unless hemlock occupies less than 30% of this filter strip, in which case up to 20% of the filter strip stocking may be cut from the non-hemlock species, to add structural diversity. This policy will be in effect until evidence from stream and soil water sampling and/or regeneration research recommends modifications.

In summary, Division policy regarding management of hemlock includes:

1. Monitoring of stands with greater than 50% stocking in hemlock for presence of HWA.
2. Conducting salvage cuts only in infested stands, defined as stands in which the majority of the hemlock trees are infected.*

3. Designing salvage cuts to stimulate regeneration of both shade tolerant and shade intolerant species, while retaining scattered healthy hemlock individuals, and attempting to leave sufficient stocking of other species to meet forest structural goals.
4. Leaving the variable-width filter strip (as defined in Chapter 132) uncut in hemlock salvage operations**,** except when hemlock occupies less than 30% of that filter strip, in which case up to 20% of the filter strip stocking may be cut from the non-hemlock species.
5. Avoiding hemlock salvage in seasonally flooded wetlands and keeping equipment off of hydric soils in hemlock stands except when they are dry enough or frozen enough to support logging equipment.

*Note: because these are salvage operations that require more rapid response than typical silvicultural operations, the Division internal lot review process will be conducted within four weeks of the identification of a stand as sufficiently infested to warrant a salvage cut. This determination will be made by field consultation between Forestry and Natural Resources Staff using methods mutually agreed upon to determine the condition of the stand.

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