An Overview of Hemlock Woolly Adelgid IPM in Pennsylvania: 1999-2004

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ABSTRACT

Since being introduced into the state in 1969, 42 of Pennsylvania's 67 counties have been infested with the hemlock woolly adelgid. In 2004, Pennsylvania's Department of Conservation and Natural Resources (DCNR) has been using a variety of integrated pest management techniques to manage this destructive insect. We implemented a monitoring program in 2004 that provides township level, georeferenced data on hemlock condition in Pennsylvania. We have had an active biocontrol program for hemlock woolly adelgid since 1999. To date we have released over 186,985 predatory *Sasajiscymnus tsugae* beetles and 600 *Laricobius nigrinus* beetles for use against hemlock woolly adelgid. We have confirmed overwintering and reproduction success of *S. tsugae* in the field. We have identified 86 high value hemlock areas on state forest and state park land that will be chemically treated with imidacloprid in spring 2005. Pre-treatment data was collected on treatment and control trees at eight of the sites in fall 2004. These sites will be used to evaluate the efficacy of chemical treatments in 2005 and 2006. Pennsylvania DCNR is also attempting to manage the introduced elongate hemlock scale. We have released 82,000 predatory *Cybocephalus nipponicus* beetles against this insect since 2003. Our future plans include expanding biocontrol efforts, using remote sensing in uninfested areas, and collaborating with others on hemlock resistance.

KEYWORDS:

Adelges tsugae, Sasajiscymnus tsugae, Laricobius nigrinus, imidacloprid, *Cybocephalus nipponicus.*

INTRODUCTION

Hemlock forest, as classified by Forest Inventory and Analysis (FIA), covers approximately 293,000 acres in Pennsylvania. Hemlock woolly adelgid (HWA) currently occurs in 42 of Pennsylvania's 67 counties, with the current leading edge cutting through the Ridge and Valley Province in the central part of the state (Figure 1). In 2004, Pennsylvania's DCNR developed an integrated pest management plan that outlines our strategies to manage this destructive insect (Appendix 1). Some of the IPM techniques we use to combat the hemlock woolly adelgid include host monitoring using the General Hemlock Survey, biological control, and chemical control of high value hemlocks on state land using imidacloprid.

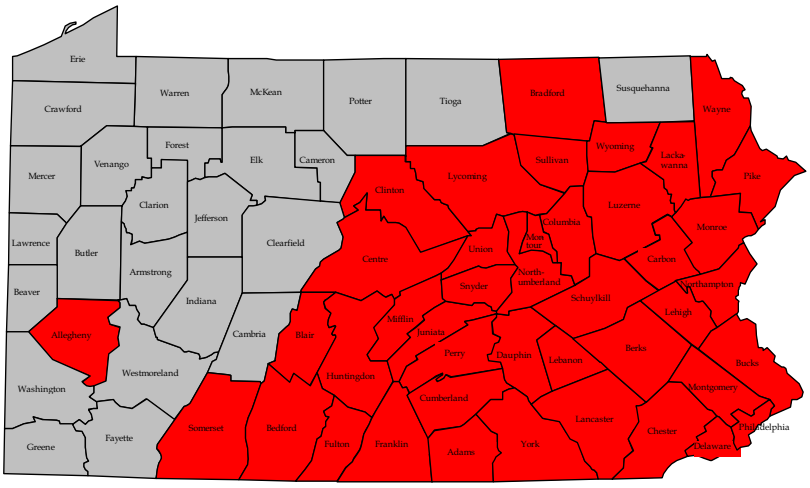

Figure 1. 2004 hemlock woolly adelgid distribution in Pennsylvania.

We currently use *Sasajiscymnus tsugae* (Coleoptera: Coccinellidae) and *Laricobius nigrinus* (Coleoptera: Derodontidae) for biocontrol. *Sasajiscymnus tsugae* is a tiny black predator native to Japan that feeds on the spring and summer generations of HWA. *Laricobius nigrinus* is a tiny black beetle that is native to western North America that feeds on HWA; it has one generation per year, and adult *L. nigrinus* feed on HWA from November–March.

The Pennsylvania DCNR's objectives in managing hemlock woolly adelgid are to:

- Identify eastern hemlock sites in Pennsylvania impacted by hemlock woolly adelgid, elongate hemlock scale, *Fabrella tsugae* (Helotiales: Hemiphacidiaceae) needle blight, and other stressors.
- Provide a general overview of hemlock condition in Pennsylvania.
- Release predatory Coleopteran biocontrol agents *Sasajiscymnus tsugae* and *Laricobius nigrinus* in forests infested with hemlock woolly adelgid.
- Assess establishment (overwintering and reproduction) of biocontrol agents at previous release sites.
- Chemically treat hemlock woolly adelgid on selected high-value hemlocks on state forest and state park sites.
- Evaluate chemical efficacy in a subset of treatment sites.

MATERIALS AND METHODS

Pennsylvania's DCNR recently implemented the General Hemlock Survey to provide township-level, georeferenced data of hemlock woolly adelgid infestation, to help focus our biocontrol efforts, and to monitor the statewide condition of hemlocks in Pennsylvania. Evaluators select areas that are a minimum of 1 acre and contain a minimum of 25% *Tsuga canadensis*. Ten branches (collected from three and 10 trees) are randomly selected and inspected for hemlock woolly adelgid, elongate hemlock scale, *Fabrella*, and other stressors, using a hand lens if needed.

Pennsylvania DCNR has been releasing *Sasajiscymnus tsugae* for biocontrol against hemlock woolly adelgid since 1999. Beetles are received from the Philip Alampi Beneficial Insect Laboratory in New Jersey in exchange for infested foliage we provide them. We also purchase beetles from EcoScientific Solutions in Scranton, Pennsylvania. Qualifying release sites are relatively healthy stands infested with hemlock woolly adelgid in central, southern, eastern, and northern areas in Pennsylvania. We usually try to focus releases along the leading edge of HWA infestation. Beating sheet evaluations are used to determine overwintering and reproductive success of these beetles in the field for at least three years post-release.

Pennsylvania DCNR participated in predator efficacy investigations of *Scymnus sinuanodulous* (Coleoptera: Coccinellidae) in 1999, in collaboration with the Connecticut Agricultural research Station (CAES). This involved providing weekly shipments of HWA to CAES in Hamden, Connecticut, and participating in branch bagging experiments.

Our *Laricobius nigrinus* release activities are part of a collaboration with Virginia Polytechnic Institute that began in 2003. The release site includes 15 release trees located in Huntingdon County, Pennsylvania, at N 40.6548, W 77.7371. There is also a nearby control site containing 10 similar trees at N 40.6707, W 77.7080. The release and control areas have healthy hemlocks with low-density infestations of hemlock woolly adelgid. Beating sheet evaluations and sticky panel traps in hemlock canopies have been used in an attempt to recover previously released beetles.

We have identified 86 high value hemlock areas on state forest and state park land that will be treated with imidacloprid in spring 2005. Most sites will be treated through a state-approved contractor, while DCNR personnel will treat a small subset of sites. Trees located on adequate soil that are more than 50 feet from a stream or lake will be treated using soil injections, while those that are closer to water will be treated using stem injections. We will evaluate hemlock condition before and after chemical treatment at eight of the treatment sites (four soil and four trunk injection sites) between 2004-2006.

Pennsylvania DCNR has been releasing *Cybocephalus nipponicus* (Coleoptera: Nitidulidae) for biocontrol against the elongate hemlock scale since 2003. We receive beetles from the Philip Alampi Beneficial Insect Laboratory in New Jersey. We compared scale densities at a control and release tree at one site in Lycoming County Pennsylvania to provide preliminary information on the effectiveness of *C. nipponicus*.

RESULTS

The DCNR surveyed 1,988 sites in 2004 as part of the General Hemlock Survey. Abundant new growth was observed on 80% of hemlocks surveyed, probably due to ample rainfall received during the past two years. 54% of hemlocks surveyed were in light decline, 33% were healthy, 10% were in moderate decline and 3% were in severe decline. HWA was found at 721 sites, while 258 sites contained elongate hemlock scale, 501 sites contained spider mites, and 78 sites contained spittlebugs. Townships with the highest populations of HWA were located in central and eastern Pennsylvania.

The DCNR released 43,890 *S. tsugae* on infested, vigorous hemlocks in central and southern areas of Pennsylvania between March and July 2004 (Figure 2). 186,985 *S. tsugae* have been released since 1999. To date 254 adults and 54 larvae have been recovered at 11 of the release sites using beating sheets in the year following release, including 11 adults recovered in 2004.

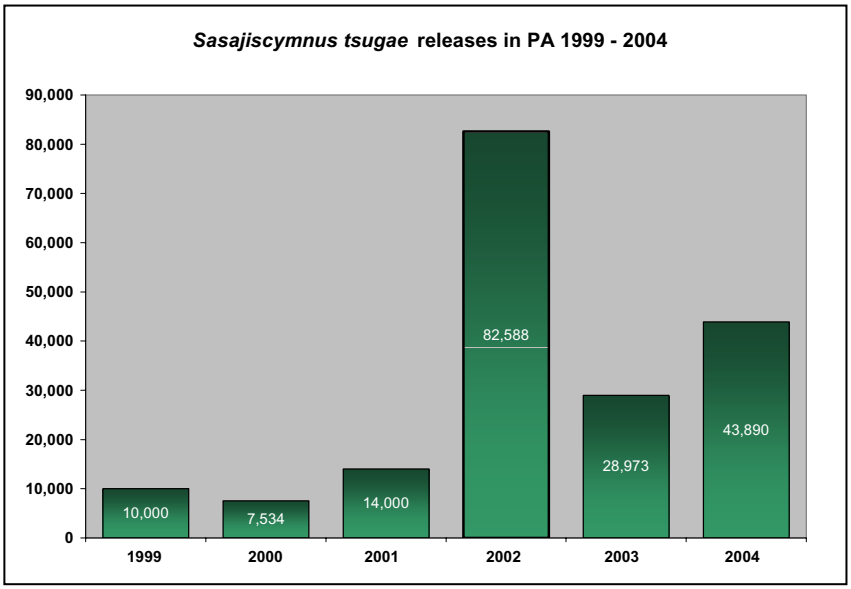

Figure 2. *Sasajiscymnus tsugae* beetles released in Pennsylvania since 1999.

The DCNR released 600 *L. nigrinus* in Huntingdon County, Pennsylvania, in fall 2003 and spring 2004. Evaluations of prior releases of *L. nigrinus* were conducted bimonthly from September to November 2004. No *L. nigrinus* were recovered.

The DCNR has released 82,000 *C. nipponicus* beetles in sites infested with the elongate hemlock scale since 2003. We recovered 40 adult beetles at two release sites in 2004.

This confirms that the beetles are able to successfully overwinter in the field in Pennsylvania. We also noticed decreased scale densities on our release as compared with our control tree at our evaluation site in Lycoming County. However, these results should be interpreted with caution, as our control tree had more new growth than the release tree, and most viable scales were located on new needles. Also, our sample site of one site and one tree are inadequate for the purposes of statistical analysis. However, these preliminary results are encouraging (Figure 3).

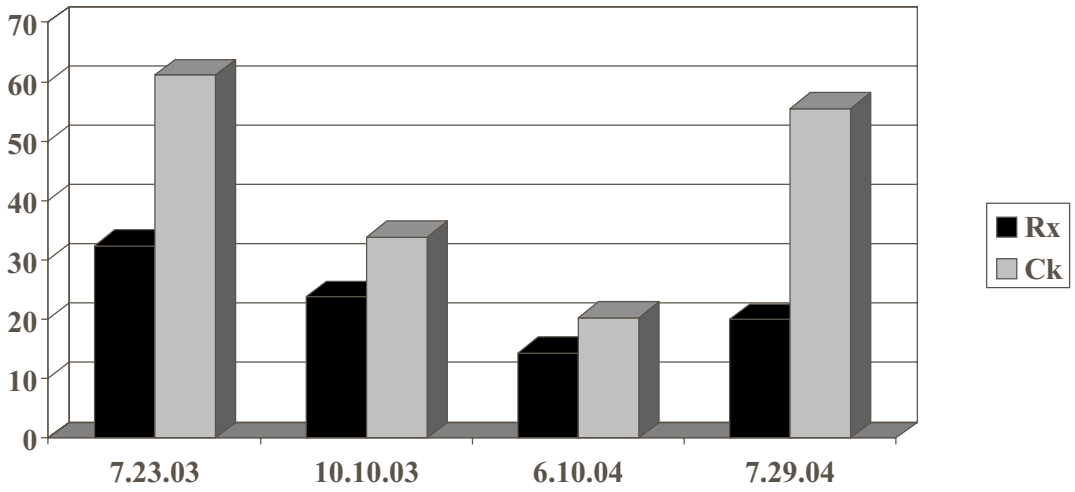

Figure 3. Relative elongate hemlock scale densities. Black bars represent scale density on a hemlock infested with elongate hemlock scale in Lycoming County, where 2,500 *C. nipponicus* were released against *Fiorinia externa* (elongate hemlock scale) in July of 2003. Gray bars represent scale density on a control tree that was located 100 meters away from the release tree.

FUTURE PLANS

Pennsylvania DCNR will continue to explore the use of remote sensing for detecting spot infestations of HWA in northwest Pennsylvania.

Pennsylvania DCNR plans to continue to release biocontrol agents against HWA in future years. We may add additional predators to our current natural enemy complex, including coccinellids in the genus *Scymnus*, as they become available.

Eight sites were established and pre-treatment data were taken in fall 2004. Chemical treatments will be conducted in spring 2005 on all evaluation and regular suppression sites.

We hope to collaborate or assist researchers who are trying to find potentially resistant hemlocks or who are working to develop hybrid species that are genetically resistant or tolerant to hemlock woolly adelgid.

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APPENDIX 1: HEMLOCK WOOLLY ADELGID, *ADELGES TSUGAE* ANNAND, (HOMOPTERA: ADELGIDAE) IPM PLAN

Pennsylvania Department of Conservation and Natural Resources,
Forest Pest Management

DESCRIPTION

The hemlock woolly adelgid, *Adelges tsugae* Annand, was introduced from Japan, where it does not damage *Tsuga diversifola* or *Tsuga seiboldii* due to host resistance and natural enemies. It was discovered in Pennsylvania in 1969. By 2004, 42 counties in the eastern two-thirds of Pennsylvania were infested with this insect (Figure A-1.).

A. tsugae damages *Tsuga canadensis* and *T. caroliniana* in eastern North America by feeding on xylem ray parenchyma. In addition, *A. tsugae* may inject salivary toxins into the hemlock while feeding, accelerating needle drop and branch dieback. Although some trees die within four years, many persist in a weakened state for several years (McClure et al. 2001). Jenkins et al. (1999) found annual nitrification rates to be 30 times higher in sites infested with *A. tsugae,* increasing the potential for nitrate leaching into water and limiting available soil nitrogen.

LIFE CYCLE

A. tsugae populations consist entirely of females that reproduce asexually and complete two generations per year in Pennsylvania. From March to April, sistens (the overwintering generation of adult females) lay 100-300 eggs on cottony masses on hemlock twigs (Figure A-2). In May, immature progrediens crawlers (the spring generation of emerging adelgids) hatch from these eggs and disperse or settle on needle bases to feed. Once settled, immature progrediens nymphs have three instars that mature into adult females by June. Adult females may be wingless or winged. The wingless adults remain on hemlocks, and lay up to 100 eggs in woolly masses on hemlock twigs (Figure A-3). The winged form (sexuparae) disperses to find an alternate spruce host upon which to feed. However, it will die because no suitable host is available in its introduced range. Wingless females are spread by the wind and carried incidentally by birds and other animals. By June-July, crawlers of the sistens generation settle on hemlock (preferring new growth) where they will remain dormant until October. Overwintering sistens nymphs feed and mature on hemlock from October to March (Figure A-4).

MONITORING/SAMPLING PROTOCOL

Look for hemlocks with discolored (grayish) needles and woolly masses on undersides of needle bases. Due to the high variability, high fecundity, and propensity for *A. tsugae* to have an aggregated distribution, Pennsylvania DCNR usually uses presence/absence methods to evaluate populations of hemlock woolly adelgid, rather than absolute population counts.

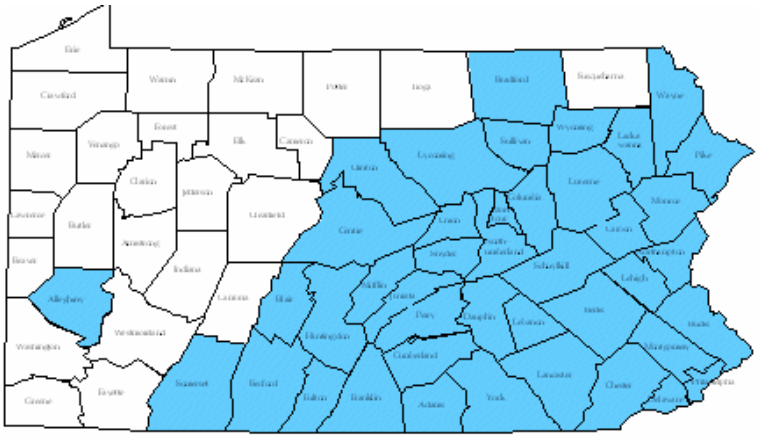

Figure A-1. Infested counties in Pennsylvania.

Figure A-2. *Adelges tsugae* eggs (T.R. Marasco)

Figure A-3. *Adelges tsugae progrediens* adults. Taken from Ravensburg State Park, May 2003 (S.M. Werner).

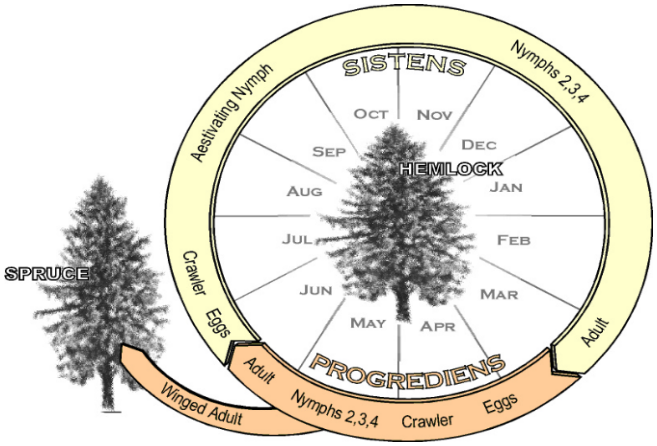

Figure A-4. Life cycle of hemlock woolly adelgid (Vic D'Amico and Mike Montgomery).

Pennsylvania DCNR uses the following method to compare control and treatment trees in our chemical suppression program. The distal 25 shoots of four vigorous branches are selected from the lower crown of a hemlock and tagged with cable ties on each control and treatment tree. All selected branches possess new growth and are infested with live adelgids, as confirmed by the presence of new wool on the branches. Samples targeting sistens on current year's growth will be taken in fall 2004. The same branches, if possible, will be re-evaluated in fall 2005 and fall 2006. On each branch, the number of shoots with new growth, the number of dead shoots, and the number of shoots infested with at least one live hemlock woolly adelgid will be assessed. The presence of other stressors, including *Fiorinia externa*, hemlock borer, and hemlock looper, will also be noted for each tree. The vigor, transparency, and live crown ratio will also be recorded for each tree, each time that *A. tsugae* evaluations are made.

In some cases, it may be necessary to obtain branch samples from tall trees using a shotgun or pole-pruning. Advantages of shotgun sampling are the ability to sample in higher in the canopy where new growth is present. However, it is not possible to count the number of terminals as fragments of branches rather than whole branches are often obtained using this method. Both methods have the disadvantage of being destructive sampling methods, which prevent the evaluator from repeatedly measuring the same branch over time.

Remote sensing technologies are also being evaluated for monitoring *A. tsugae*. Pennsylvania DCNR and Denise Royle, Rutgers University, are working on expanding the algorithm she developed for using Landsat imagery to detect changes in hemlock health in the area from New Jersey to Pennsylvania. Royle and Lathrop (1997) quantified impacts of *A. tsugae* on hemlock health in the New Jersey Highlands using Landsat Thematic Mapper data and a model to compare vegetative index differences in near infrared/red reflectance values. Royle found that, from 1984 to 1994, 47% of the hemlock remained healthy to lightly defoliated, 44% underwent moderate decline, and 9% died. Pennsylvania DCNR and the USDA Forest Service are exploring the use of remote sensing to detect new infestations of *A. tsugae* along the leading edge of infestations and in isolated patches.

MANAGEMENT/CONTROL

Biocontrol Recommended in forest situations, on smaller vigorous trees with moderate to heavy *Adelges tsugae* populations.

Sasajiscymnus tsugae (Coleoptera: Coccinellidae) A tiny, black beetle discovered by Mark McClure in Japan in 1992, *S. tsugae* larvae and adults are only known to prey upon hemlock woolly adelgid, balsam woolly adelgid, and pine bark adelgid. Each larva consumes about 500 eggs or 50-100 nymphs (Cheah and McClure 1998). Adults can live for over a year and consume 50 adelgids/week. *S. tsugae* females lay up to 300 eggs in March and April, during peak egg laying of adelgids. The beetles have a second generation in June around the same time as the second adelgid generation. Adult *S. tsugae* survive on dormant young adelgids during the summer. Pennsylvania DCNR obtains *S. tsugae* from EcoScientific Solutions (Scranton, Pennsylvania) and the New Jersey Department of Agriculture (NJDA), which rear *S. tsugae* on foliage sent to them from Pennsylvania. Releases of *S. tsugae* are focused on *Tsuga canadensis* along the leading edge of the *A .tsugae* infestation in Pennsylvania, on trees that are relatively healthy, and thus have some chance of recovery. At least 2,000 *S. tsugae* are released at sites on sunny days in

May through July. Beating sheet evaluations are used to confirm adult and larval establishment at release sites for at least three years following release. As of 2004, we have released 186,985 *S. tsugae* beetles in Pennsylvania.

Laricobius nigrinus (Coleoptera: Derodontidae) This beetle is found in western North America, where it preys on *Adelges tsugae* on western hemlock, *Tsuga heterophylla*. The genus *Laricobius* feeds only on woolly adelgids. *Laricobius nigrinus* has one generation per year, with adults feeding on HWA sistens in the fall and winter. Adults lay an average of 100 eggs around March 15 on *A. tsugae* sistens ovisacs. Each larva consumes up to 250 *A. tsugae* eggs until mature, when *L. nigrinus* enters the soil to pupate. Adults remain dormant in the soil until fall. Host specificity tests found that *L. nigrinus* preferred to feed on *A. tsugae* over most other woolly adelgids, and it was only able to complete its development on *A. tsugae* (Zilahi-Balogh 2002). Six hundred *L. nigrinus* were released in central Pennsylvania in 2003-2004.

Scymnus spp. Several species in this genus are being investigated for release.

Scymnus (Neopullus) sinuanodulus A univoltine coccinellid native to China, this beetle has a host range restricted to adelgids. Adults lay 130-200 eggs in early spring and feed on all stages of adelgid. Larval *S. sinuanodulus* grow faster and experience lower mortality on adelgid eggs than on nymphs (Lu and Montgomery 2001).

Scymnus ningshanensis Similar to *P. tsugae*, *S. ningshanensis* is found to have greater numerical response in terms of egg laying. Differentiating between males and females is problematic.

Scymnus campodromus Mike Montgomery is investigating this potential predator. It's eggs diapause.

Diapterobates humeralis An oribatid mite that regulates *A. tsugae* in Japan (McClure 1995a), *D. humeralis* doesn't eat eggs but dislodges them when feeding on their wool. But *D. humeralis* is not a good candidate for biocontrol due to low reproductive potential and long generations.

In general, our goal in biocontrol is to pick candidates for release that are effective and as specialized as possible. All organisms go through a testing and approval process with USDA. We may collaborate with that agency in the future to evaluate potential nontarget effects (i.e., on native prey or native competitors) of these biocontrol agents once released into the field.

Chemical Control Practical on an individual tree level for private landowners and public areas with specific high-value trees (e.g., state parks and high use recreational areas).

Imidacloprid For use on large trees after infestation has occurred. Fairly high cost (about 79 cents to $1 per inch of tree dbh) prohibits forest-wide use. Shown to be effective against *A. tsugae*, especially trees with little new growth and no dieback (Steward and Horner, 1994, Webb et al. 2003). Trees under drought stress and those with needle loss and dieback will have difficulty transporting and distributing this systemic insecticide to their canopies (McClure et al. 2001). The 75WP (wettable powder) formulation (Merit) may be applied at mid-concentration (1oz / inch tree dbh) using a Kioritz injector around the base of the tree in areas at least 50' away from waterways (which has advantage of not wounding the tree bark); the chemical is absorbed through the roots, affording at least six months of control. Direct tree bole injections of 5% concentration applied at the rate of ½-1 mL/inch tree dbh should be used for trees closer than 50' to waterways as part of a "best management practice." Preliminary research suggests that soil injection treatments made in the autumn and bole injections made in spring are optimally effective.

1% Horticultural oil More practical for single trees than large areas. May be used to drench trees often < 30' high in April or September and June. This option works by drying and suffocating adelgids and other soft-bodied insects, and is less toxic than conventional insecticides.

WARNING: avoid nitrogen fertilization of infested hemlock! McClure (1991) found five times as many *A. tsugae* on fertilized vs. unfertilized hemlocks, and the percentage of surviving nymphs and female egg production was more than twice as high. Results were similar whether fertilization occurred at infestation or 6 months later, indicating that no increased resistance was conferred from fertilization.

Silvicultural Maintain stand vigor by watering area beneath crown dripline during periods of drought to ensure that the tree receives 1 inch of water per week. Selectively remove large trees when heavily infested that act as "reservoirs" for adelgid spread. Replant decimated areas with natives, such as eastern white pine or resistant species, such as the western hemlock (*T. heterophylla)*, which resembles *T. canadensis* in growth form, appearance, and utility (McClure 1995b). Hemlock is known to inhibit its own regeneration through allelopathy. Hemlock litter extracts reduced seed germination by 74% and caused 100% mortality in 6 day old seedlings, but no mortality in seedlings 2 weeks or older (Ward and McCormick 1982).

Cultural *A. tsugae* crawlers often spread through phoresy or "hitchhiking" on birds, plants, mammals, humans, and by wind. Because of this, caution must be used when moving material from infested areas, especially from Mar-June. Spraying infested branches with water in April-June can dislodge eggs and crawlers. Clipping heavily infested branches can also reduce tree populations (McClure 1995b).

Host Tolerance/Resistance/Hybridization It is suspected that one of the reasons *A. tsugae* is so damaging to eastern hemlock is that there is a lack of evolved host tolerance or resistance to this insect's feeding, relative to Asian or even western species of hemlock. One approach to this problem is to identify *Tsuga canadensis* in the field that seem to be surviving *A. tsugae* infestations better than others. This assumes a certain level of intraspecific genetic variation in *T. canadensis*. However, Zabinski (1992) found eastern hemlock to have unexpectedly low genetic variation among seventeen populations examined throughout its range, with the proportion of polymorphic loci being only 0.10 and the number of alleles per locus (among 10 loci examined) being 1.1, significantly lower than many other gymnosperms. Low genetic variation may indicate a population bottleneck during the Pleistocene. Other researchers have found significant differences in photosynthesis, respiration and transpiration among two disjunct populations of eastern hemlock (Eickmeier et al. 1975).

Another option is attempting to hybridize *T. canadensis* with a more tolerant or resistant host. Susan Bentz and Margaret Pooler at the National Arboretum in Washington DC has been involved with hybridization experiments. Attempts to hybridize *T. canadensis* with three Asian species have been unsuccessful (Bentz et al. 2002). Also, attempts to hybridize *T. canadensis* with the morphologically similar western hemlock (*T. heterophylla*) or mountain hemlock (*T. mertensia*) have been unsuccessful because these species are not well adapted to the east coast climate. Brian Maynard at the University of Rhode Island is also testing *T. heterophylla*. His thought is that the seed source for western hemlock has been taken from

coastal areas and is not cold hardy north of zone 6. Maynard is targeting seed collected from high elevations in Idaho and southeastern British Columbia.

OTHER FACTORS:

Elevation Hemlock woolly adelgid is not known to occur at elevations over 1,980 feet in its native range (McClure and Cheah 1999). Observations suggest that this is also true in some areas of Pennsylvania.

Weather

Drought Because hemlock is a shallow-rooted species, it is vulnerable to drought and windthrow. Drought can intensify impacts of *A. tsugae* and other stressors. Drought stress over the past five years in Pennsylvania has noticeably increased hemlock decline in several areas. Pollen records show that summer drought in eastern North America that occurred between 5,700 and 5,100 years ago was a major contributing factor in a decline in hemlock that lasted over 1,000 years during that period.

Wind Aerial distribution enhances adelgid dispersal, carrying eggs and nymphs at least 1 km away from infested areas. *Adelges tsugae* crawlers are active earlier in the spring than *F. externa* when winds are stronger and more frequent. Exposure to higher winds (along with its parthenogenic mode of reproduction) is suspected to contribute to *A. tsugae* spreading more rapidly than *F. externa* (McClure 1989).

Heavy rain Precipitation can also affect *A. tsugae* survival by dislodging eggs and nymphs from trees (McClure 1989).

Snowfall/Cold Temperatures High winter mortality can occur in conditions of extremely low temperatures, temperature flux, and high snowfall in North America. Conversely, mild winters in the northeast have resulted in explosive adelgid populations the following seasons.

Negative density dependent feedback (McClure): Like many invasive species, *A. tsugae* can prevent hemlock from producing new growth, and thus ultimately harms its own future survival through increased production of sexuparae and lower fecundity of sistens on old growth.

Other Hemlock Pests: Arthropods—such as elongate hemlock scale (*Fiorinia externa* [Homoptera: Diaspidae]), *Agrallaspis ithacae*, and *Nucleolaspis tsuga)*, hemlock borer (*Melanophila fulvogatta* [Coleoptera: Elateridae]), hemlock looper (*Lambdina fiscellaria)*, hemlock needleminer, spider mites, and spittlebugs—and diseases such as Fabrella needle cast, can further weaken trees affected by hemlock woolly adelgid.

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