Forest Health Technology Enterprise Team

TECHNOLOGY
TRANSFER

Introduced Pest

Hemlock Woolly Adelgid

Mark S. McClure
Scott M. Salom
Kathleen S. Shields

Forest Health Technology Enterprise Team - Morgantown, WV

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Preface

This leaflet updates information from Pest Alert NA-PR-06-91. "Hemlock Woolly Adelgid," which was published in 1991. This leaflet contains information on the importance of hemlocks in eastern forest ecosystems, and hosts, life cycle, control, and population trends of the hemlock woolly adelgid.

For copies of this publication or information concerning hemlock woolly adelgid, contact Dr. Mark McClure in Windsor, CT at (860) 683-4979. Dr. Scott Salom in Blacksburg, VA at (540) 231-2794, Dr. Kathleen Shields in Hamden, CT at (203) 230-4320, Dr. Richard Reardon in Morgantown, WV at (304) 285-1566, or the local Cooperative Extension Service Office.

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Hemlock Woolly Adelgid

Mark S. McClure[1], Scott M. Salom[2], and Kathleen S. Shields[3]

[1]Connecticut Agricultural Experiment Station, Windsor, CT 06095

[2]Department of Entomology, Virginia Polytechnic Institute and State University,
Blacksburg, VA 24061-0319

[3]Northeastern Forest Experiment Station, USDA Forest Service,
Hamden, CT 06514

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Introduction

The hemlock woolly adelgid (HWA) *(Adelges tsugae* Annand) is a destructive introduced pest of forest and ornamental hemlock trees *(Tsuga* spp.) in the eastern United States. The adelgid feeds at the bases of needles, causing them to desiccate and the tree to take on a gray cast. The result is needle loss *(figure I),* which prevents trees from producing new apical buds. Heavy infestations have kil1ed trees in as little as 4 years, yet some trees have survive infestations for more than 10 years. Other stress factors may affect *Tsuga* spp. tolerance to insect attack.

HWA is native to Japan and possibly China where it is a common, but innocuous inhabitant of forest and ornamental hemlock *(Tsuga diversifolia* Masters and T. *sieboldii* Carriere) and spruce (probably *Picea jezoensis hondoensis* [Sieb. & Zucc.] and P *polita* [Camere]). HWA occasionally attains high densities on hemlock in Japan, but only on ornamental trees that are growing on very poor sites. However, even under these circumstances, Japanese hemlocks are not significantly injured, because of host resistance and several arthropod predators that are believed to help regulate HWA populations.

HWA was first observed in western North America in the early 1920's in British Columbia and in eastern North America some 30 years later in Virginia. Although the details of these early infestations are unknown, they undoubtedly resulted from accidental introductions from Asia.

Figure 1. *A heavy infestation of hemlock woolly adelgid.*

Hosts and Potential for Spread in North America

In western North America, HWA occurs on mountain hemlock (T. *mertensiana* (Bong.) Carr.) and on western hemlock (T. *heterophylla* (Raf.) Sarg.), from northern California to southeastern Alaska. These two hemlock species are resistant to HWA, although it can be found on trees stressed by other factors.

In eastern North America, HWA is a destructive pest of eastern hemlock (T. *canadensis* (L.)) and Carolina hemlock (T. *caroliniana* Engelm.). These hemlock species have shown little or no resistance to HWA attack and many trees growing under a wide variety of natural and ornamental conditions have died.

The geographic range of eastern hemlock extends from the Canadian Maritimes, west to the Lake States, and as far South as northern Georgia and Alabama *(figure 2).* Carolina hemlock is a rare species with isolated pockets in *Virginia*, North Carolina, South Carolina, and Georgia. Currently, HWA occupies a small part of eastern hemlock's natural range *(figure 2).* However, during the past decade it has spread at a rate of about 20 - 30 km each year and its population levels have increased dramatically. Wind, birds, deer, and humans help spread HWA throughout the Northeast. Because HWA is adapted to high elevations in Japan where winter temperatures commonly drop below -35° C (-63° F), it should continue to spread in eastern North America until it occupies the entire range of eastern hemlock.

Ecological Importance of Hemlock

Eastern hemlocks are long-lived, late successional climax trees that, if left undisturbed, eventually dominate stands. Historically, this species was found in *about* 20% of upland forest ecosystems, but harvesting practices at the mm of the century and land use have reduced that to less than 6%. Although it is no longer an abundant component of eastern forest ecosystems, this species occupies a very important ecological niche. Hemlock stands provide important cover for ruffed grouse, turkey, deer, snowshoe hare, and rabbit. Almost 90 species of birds in Connecticut use hemlock as a food source, nesting site, roost site, or winter shelter. Black-throated warbler, solitary vireo, and northern goshawk require hemlock forest habitats. Plant species that flourish include leatherwood, rattlesnake plantains, bunchberry, goldthread, bluebeard, Canada mayflower, wood sorrels, and many other herbs and shrubs. Brook trout are found more commonly in streams bordered by hemlocks because of the cooling effect of the canopy. Additionally, the shade they provide makes for ideal recreational settings. Hemlock stands are cooler than hardwood stands in the summer due to dense shading, yet warmer in the winter because of protection from wind that their dense crown provide. Although hemlock is not a valuable timber species, it is used widely for pulpwood and for building barns, sheds, and other structures. Hemlocks are greatly valued for their beauty and are a very important landscape tree. There are 274 cultivars of eastern hemlock, making it one of the most cultured and cultivated landscape trees in the U.S.

Hemlock Woolly Adelgid Distribution - 1996

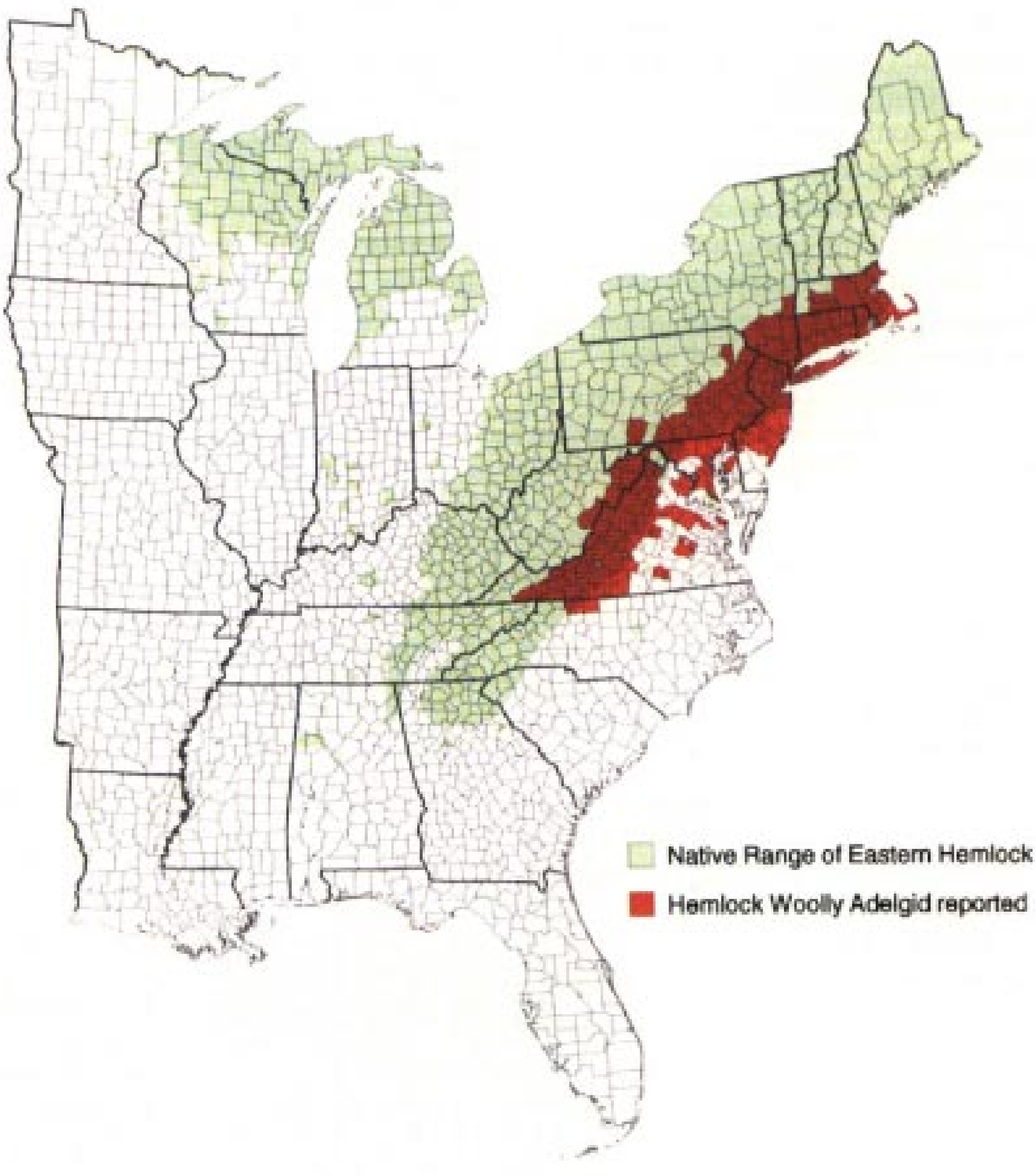

Figure 2. *Native range of hemlock (green) and range of hemlock woolly adelgid (red) in 1996.*

Life Cycle of Hemlock Woolly Adelgid

Hemlock woolly adelgid has a complex life cycle that may involve both hemlock and spruce *(Picea* spp.) as hosts *figure 3).* In Japan and North America, HWA has three generations that develop each year on hemlock. Two generations develop simultaneously in the spring: winged sexuparae and nonwinged progrediens. Sexuparae adults leave hemlock in search of a spruce on which to oviposit. Their developing progeny, called sexuales, have not been observed to develop successfully on any spruce species in North America.

Progrediens progeny are called sistens. The sistens generation develops during autumn and winter, following a summer aestivation period. Although the developmental stages and generations of HWA on hemlock in Japan and in North America are the same, adelgid phenology varies significantly with elevation, latitude, and weather conditions. In Japan, sistens eggs hatch and develop more slowly due to lower temperatures at higher elevations and latitudes, reducing the length of the summer aestivation period.

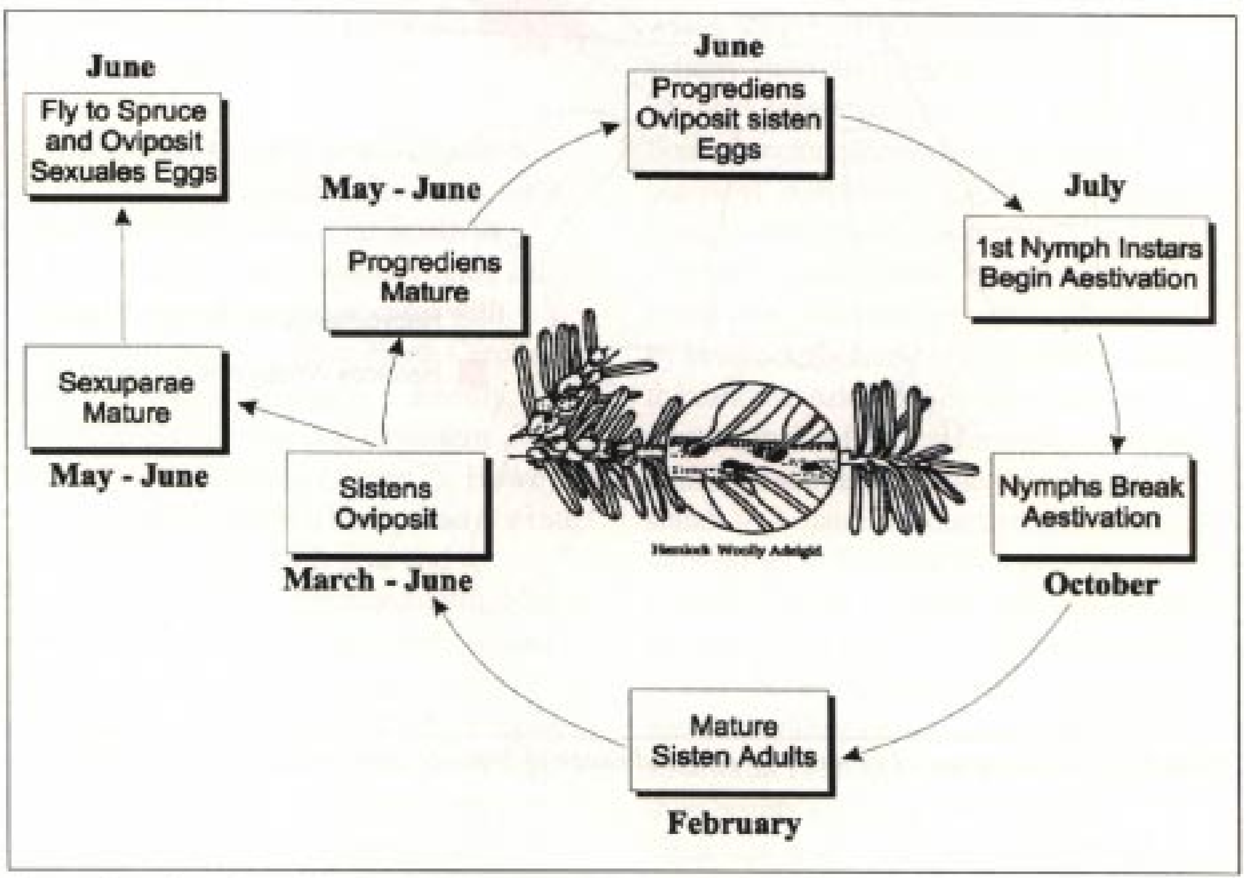

Figure 3. *Life cycle of the hemlock woolly adelgid.*

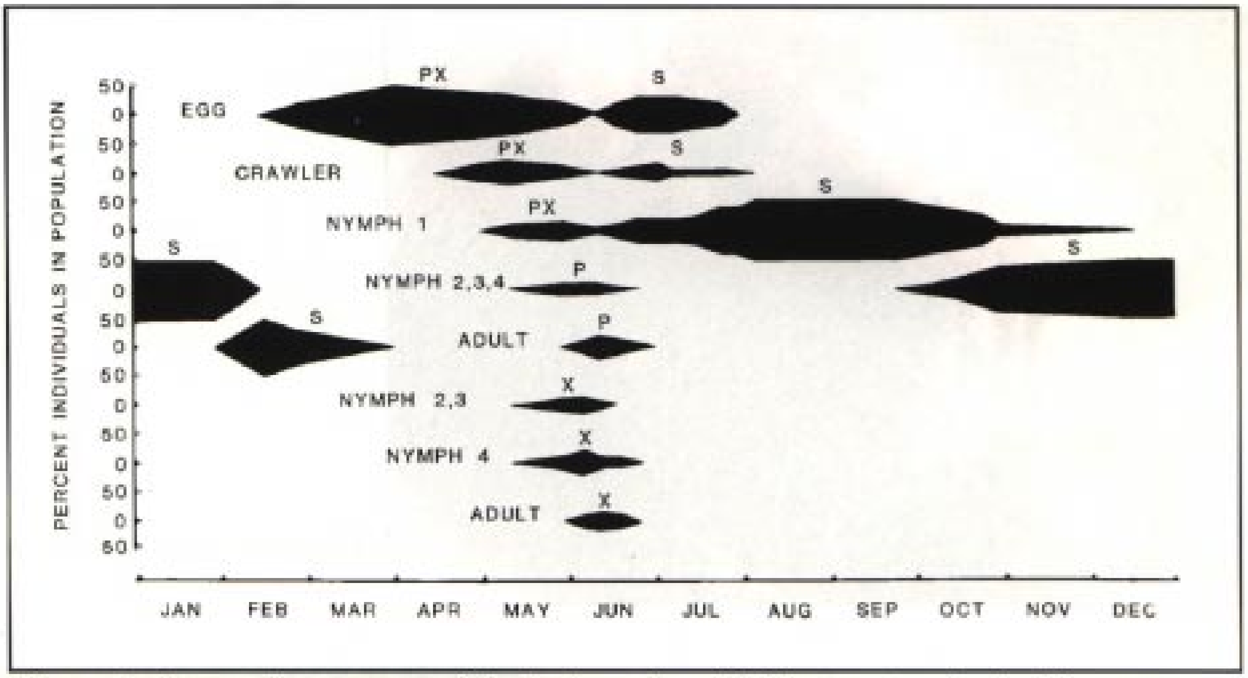

Figure 4. *Seasonal occurrence of hemlock woolly adelgid on eastern hemlock in Connecticut. Generations are sistens (S), progrediens (P), and sexuparae (X).*

The seasonal development of HWA on hemlock in Connecticut is characterized by enormous temporal overlap of life stages *(figure 4).* Most sistens mature in February, and from March through May they each produce a single white cottony ovisac *(figure 5)* containing up to 300 eggs *(figure 6).* These white ovisacs are very apparent and an easy way to identify trees infested with HWA. The proportion of eggs that become sexuparae increases with adelgid density probably in response to reduced host nutritional quality. Nymphs of both types begin hatching in April. Crawlers search for a suitable site to settle *(figure 7),* always near the base of the needle, where they usually remain attached for the rest of their lives *(figure 8).* The nymphs quickly develop through four instars and mature in June. Progrediens adults remain on hemlock, and during June and July they produce cottony ovisacs like those produced by the sistens. The sistens crawlers, which hatch from these eggs, settle on young hemlock branches within a few days, begin to feed, and then enter an aestival diapause that lasts for several months. In October, aestivating nymphs resume development and mature by early February.

Figure 5. *Closeup of woolly ovisacs — the most obvious sign of HWA infestation.*

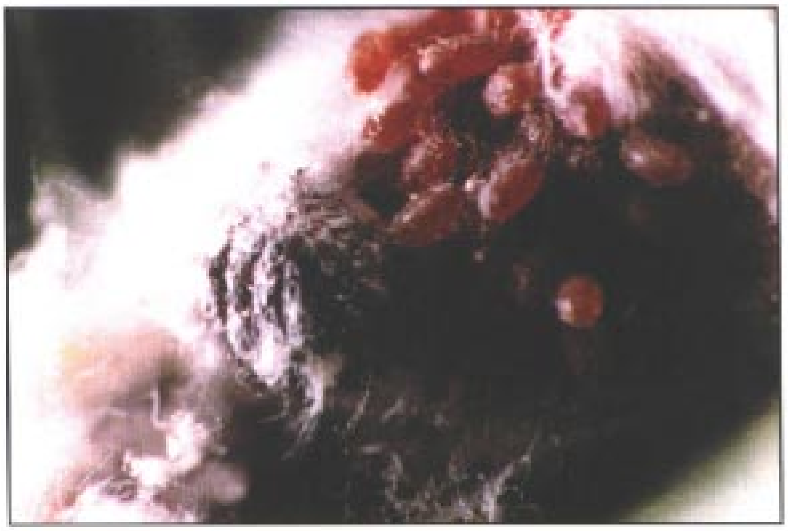

Figure 6. *Adult female and eggs in ovisac.*

Figure 7. *Crawler searching for a place to settle.*

Figure 8. *First instar nymphs settled at the bases of needles.*

The winged adult sexuparae that mature and leave hemlocks in June presumably die in the absence of a suitable spruce species in North America. The few that remain on hemlock also die without producing eggs.

In southwest Virginia, adult sistens are first observed from mid-January to early February. The earliest progrediens or sexuparae eggs are observed from early February to mid-March. The first progrediens adults appear from late May to early June, and sistens eggs are observed throughout June. Second instar nymphs break aestivation and begin developing from late September to early October. Although duration of some life stages may be reduced in the southern part of HWA's range, no differences have been detected in the basic life cycle from that observed in Connecticut.

As in Connecticut, enormous temporal overlap of HWA lifestages occurs in Virginia, especially in late spring, when as many as 12 lifestages are observed on one date (nymphs to adults for both progrediens and sexuparae, and sistens eggs). Mortality is greatest during the egg (60-80%) and first nymphal instar (crawler) (50-60%) stages.

Feeding

After hatching from the eggs, the crawlers settle at the base of hemlock needles where they insert their feeding stylets into the plant tissue *(figure* 9). HWA has a stylet bundle which is located on the underside of the insect and composed of four individual stylets within a sheath *(figure 10,* arrow). The stylet bundle is inserted into the underside of the base of the needle, very near the juncture with the stem *(figure 10,* arrowhead). The stylet bundle is more than three times the length of the insect, and penetrates deep within the plant tissues *(figure 11).*

HWA inserts its stylet bundle through the epidermal cells at the plant surface and the stylets work their way to the vascular tissue by piercing cells and traveling through them. Once the stylet bundle has reached the vascular system, it travels along the vascular bundle in the xylem, passing between cells, until it reaches its ultimate feeding site, the parenchyma cells of the xylem rays *(figure 12).* These cells transfer and store nutrients in the plant and connect the phloem to the xylem and the pith.

Figure 9. *HWA nymphs settled and feeding at the bases of needles.*

Figure 10. *HWA nymph with stylet bundle (arrow) inserted into base of needle. Arrowhead indicates point of stylet insertion.*

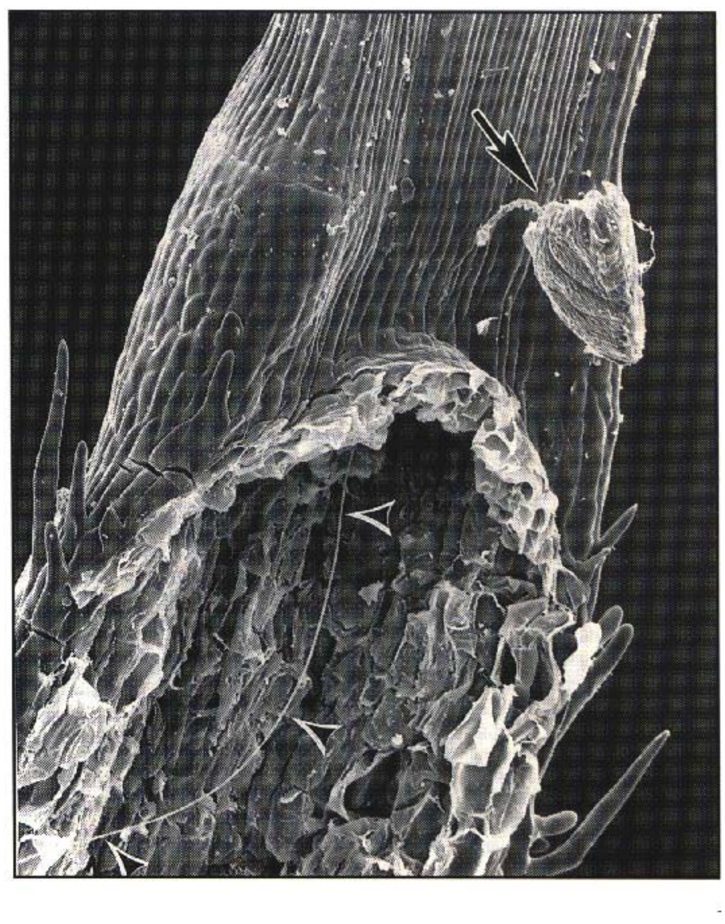

Figure 11. *Hemlock needle torn away from stem shows position of nymph (arrow) and its stylet bundle (arrowheads) within the plant.*

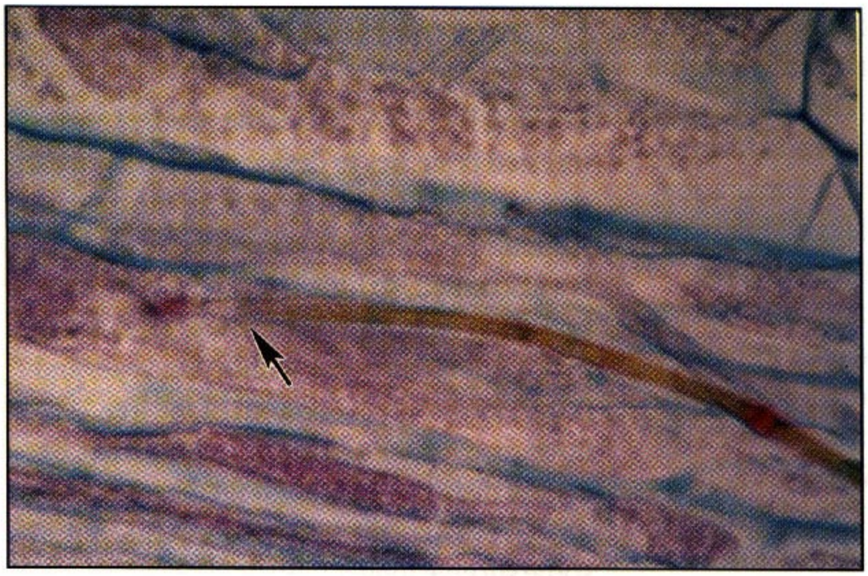

Figure 12. *Section of tissue showing tip of stylet bundle in xylem ray parenchyma cell (arrow).*

Figure 13. *Section of tissue showing stylet bundle and salivary secretions (arrows).*

Figure 14. *Section of tissue showing stylet bundle and salivary sheath (arrow).*

The adelgid probes with its stylet bundle and secretes considerable amounts of saliva within the plant tissues *(figure 13). The* saliva hardens around the styler bundle and forms a salivary sheath *(figure 14)* which remains in the plant after the styler bundle is withdrawn. At each molt, the stylet bundle is retracted from the plant and the stylet cuticle is shed. The styler bundle is reinserted after its new cuticle has hardened. The feeding site, xylem ray parenchyma, is the same for each life stage of the insect. Thus, HWA does not deplete nutrients directly by feeding on the sap, but it does deplete food reserves from the tree's storage cells.

Impact on Hemlock

Feeding by HWA causes the needles on infested branches to desiccate, turn a grayish-green color, and then drop from the tree, sometimes within a few months. Most buds are also killed, so little if any new growth is produced on infested branches. Dieback of major limbs can occur within two years and progresses from the bottom of the tree upward, even though the infestation may be evenly distributed throughout the tree *(figure* I 5). Trees may die within four years, but some survive longer with only a sparse amount of foliage at the very top of the crown. There is evidence that some weakened trees may recover. The factors that lead to recovery are not well understood.

Figure 15. *Trees with varying levels of damage due to hemlock woolly adelgid.*

Adelgid Population Trends

Populations of HWA are injurious and unmanageable in hemlock forests of the eastern United States. Adelgid densities fluctuate mainly in response to density-dependent changes in the nutritional quality of hemlock. In the most severe cases, HWA multiplies rapidly and attains peak density during the first year of the infestation when trees are still healthy and producing abundant new growth. Adelgid numbers then drop sharply during the following year, when trees decline or grow very little. During the third year, trees respond to reduced adelgid density by producing some new growth, albeit severely stunted. Adelgids quickly colonize this young growth and resurge to a second, modest population peak, only to crash again during the fourth year in the absence of new tree growth. At this point trees may decline severely or die.

When a tree is injured following HWA attack, **it** becomes nutritionally deficient for the adelgid. This causes reduced survival and fecundity of HWA, and results in a greater percentage of nymphs becoming sexuparae, which die without reproducing in the absence of a suitable spruce host. Density-dependent production of the unsuccessful sexuparae is a major mortality factor for HWA in eastern North America and plays an important role in the decline of adelgid populations on the deteriorating host. Unfortunately, the tree is seldom able to recover from the degree of injury needed to render it unsuitable to the adelgid.

Suppression Options in Landscaped Settings

Hemlocks infested with HWA can be kept healthy in a landscaped setting by using an integrated management approach that includes the following:

Taking care when moving plants, logs, lurewood, or bark chips from infested to uninfested areas, especially from March through June when adelgid eggs and crawlers are abundant.

Watering hemlocks during periods of drought and soaking the roots thoroughly. Also, pruning dead and dying branches and limbs from hemlock to reduce the likelihood of attack by insect pests and diseases, by allowing the formation of cellulose tissue to "close off' the stub wounds more rapidly. HWA infests and kills eastern and Carolina hemlocks of all sizes and ages, even in habitats with seemingly optimal growing conditions. However, trees that are growing off site or experiencing stress from drought and other agents succumb to adelgid attack more quickly.

Fertilizing a tree after adelgids have been controlled to encourage growth and stimulate recovery. Fertilizing infested hemlocks with nitrogen enhances survival and reproduction of HWA. Therefore, nitrogen fertilizer should not be applied to an infested hemlock.

Planting resistant hemlock species to reduce the impact on ornamental landscapes.

Applying chemical insecticides is an essential component of any integrated approach to managing populations of HWA. Even though the measures described above can help maintain and improve overall tree health, infested trees are usually unable to survive for more than a few years without chemical insecticides.

The most common and effective chemical method for controlling HWA on ornamental hemlocks is to thoroughly drench infested trees with horticultural oil, insecticidal soap, or any one of numerous petrochemical insecticides specifically labeled for this use.

Oil and soap are used most often because

they are highly effective in killing adelgids, and yet they are relatively safe to the applicator, beneficial insects, and the environment. Two spray treatments each year are usually necessary, one in the fast week of April and the other during the first haft of June. Another option is to spray during the second haft of September instead of in April. Consult your local extension agent or State pesticide guide (1) identify which insecticides are registered for use in your state and (2) determine the proper timing for chemical application.

Injecting or implanting chemical insecticides directly into the stem of infested hemlocks in mid-May can control HWA for up to six months. In both techniques the insecticide moves into and up the tree to where it is ingested by the adelgids. This approach is especially useful on trees that are very tall, growing in areas inaccessible to spray equipment, or where spraying is undesirable such as near waterways and in recreation areas.

Introducing systemic insecticides into the roots of infested hemlocks in May is another alternative to protecting trees that can not be sprayed thoroughly. The soil beneath the tree can either be drenched or hydraulically injected with insecticide which is taken up by the roots and distributed throughout the tree where **it** can control HWA for five months or more. Unlike stem injection and implantation, these soil treatments do not wound the tree. However, as is the case with the stem treatments, trees must have a healthy sap flow for these soil techniques to be effective.

Management Options in Forest Settings

Chemical control options available for use in landscaped settings are inappropriate for treating hemlocks in forest settings. Stands are too scattered, full insecticide coverage is hard to achieve, and the trees are often located in sensitive areas near streams.

Permanent plots have been established in hemlock stands in New Jersey, Pennsylvania, and West Virginia, to track HWA spread and infestation levels. At the time of plot establishment, the stands were not infested. Stands are assessed annually using Visual Crown Rating Standards established by USDA Forest Service, Forest Health Monitoring Program, and by estimating new growth on lateral shoots.

Development of pest management tactics for HWA in the forest requires adequate sampling techniques for estimating population levels of HWA, and for developing economic thresholds and economic injury levels. To estimate population density (number of HWA/ 25 cm) on individual trees, a binomial sampling protocol has been developed that allows estimates to be made based on the proportion of twigs sampled that have two or more live ITWA *(figure* 16). This relationship for both progrediens and sistens is consistent between sample sites in southwest Virginia and eastern Pennsylvania. A twig is defined for this sampling procedure as the segment of a branch from an apical bud to the first node.

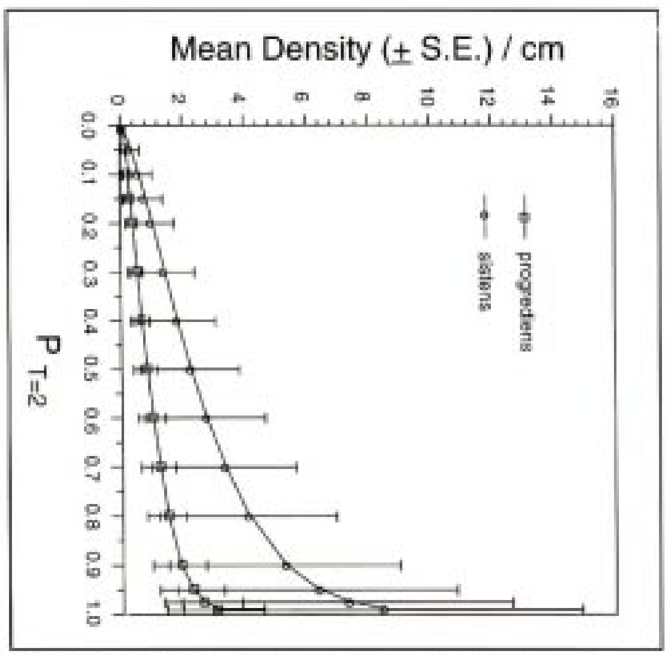

Figure 16. *Relationship between HWA mean density ±S.E. and proportion of twigs infested ($P_{T=2}$) for each generation, when eight twigs are sampled from each of eight branches on a tree.*

Efforts are underway to evaluate and possibly introduce potential natural enemies of HWA for use in a biological control program. As an exotic pest, the probability for success with biological control tends to be higher than for native pests. Natural enemies from Japan and China are currently being investigated.

The coccinellid beetle *(Pseudoscymnus tsugae* Sasaji and McClure n. sp.) shows the most promise of five HWA predators identified in Japan. Both larvae and adults actively prey on all stages of HWA on hemlock branches. The beetle's life cycle is well synchronized with HWA. The beetle can feed on any life stage of HWA, and even during HWA aestival diapause, can survive on the diapausing nymphs. This predator was released at four sites in Connecticut during 1995 1996 and survived a severe winter. Initial studies reveal that the beetle significancy reduced HWA numbers.

Several potential predators native to North America or introduced to balsam woolly adelgid *Adelgespiceae (Ratz.)),* may also serve as natural enemies for HWA.

Other approaches to managing HWA include evaluating the numerous *Tsuga* cultivars for resistance to HWA and susceptibility to HWA.

References

Gray, D.R.; Evans, R.A.; Salom, S.M. 1996. Population density estimation of the hemlock woolly adelgid (Homoptera: Adelgidae) by a binomial sampling procedure. Final Report to USDI Natural Park Service

Delaware Water Gap. 25 p.

McClure, M.S. 1989. Evidence of a polymorphic life cycle in the hemlock woolly *adelgid,Adelges tsugae* (Homoptera: Adelgidae). Annals Entomological Society America 82:50-54.

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. 1995. Managing hemlock woolly adelgid in ornamental landscapes. Bulletin 925. Connecticut Agricultural Experiment Station. 7 p.

Salom, S.M.; Tigner, T.C.; Reardon, R.C. 1996. Proceedings of the First Hemlock Woolly Adelgid Review. 1995 October 12; Charlottesville, VA. FHTET 96-10. Morgantown, WV: USDA Forest Service. 129 p.