The Connecticut Agricultural Experiment Station, New Haven

Managing Hemlock Woolly Adelgid in Ornamental Landscapes

BY MARK S. McCLURE

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FACTS TO KNOW ABOUT HEMLOCK WOOLLY ADELGID

What is it and can it be stopped?

Hemlock woolly adelgid (*Adelges tsugae* Annand), is a small aphid-like insect that feeds on several species of hemlock (*Tsuga* spp.) in Asia, its homeland, and in North America where it was introduced. Populations of this pest can not be managed in the hemlock forests of eastern North America at this time. However, hemlocks growing in nurseries and ornamental landscapes can be protected from hemlock woolly adelgid by using an integrated pest management (IPM) approach. This is good news because hemlock is a unique and versatile landscape species for which there is no good substitute. An IPM approach for *A. tsugae* on ornamental hemlocks includes carefully monitoring for the presence of the adelgid, implementing various cultural practices to enhance tree vigor and to discourage pest invasion, using mechanical and chemical control measures as needed to reduce adelgid populations, and promoting biological control by encouraging the activity of natural enemies.

How to recognize it?

A fully grown adult of the hemlock woolly adelgid is only about the size of a period on this printed page. However, this insect is easily recognized during most of the year by the presence of a dry, white woolly substance on the young twigs (Figure 1). The "wool" is associated with all stages of the adelgid, but it is most abundant and conspicuous during spring when egg masses are present. An egg mass resembles the tip of a cotton swab, although somewhat smaller.

What plants are attacked?

Adelges tsugae has only been found on hemlock, but an unknown spruce (*Picea* sp.) probably also serves as a host in Asia (McClure 1987a). The adelgid is a harmless inhabitant of *T. chinensis* in Taiwan and *T. diversifolia* and *T. sieboldii* in Japan. It has also been innocuous on western hemlock (*T. heterophylla*) and mountain hemlock (*T. mertensiana*) from northern California to southeastern Alaska during the 70 years it has been in western North America. However, the situation has been very different in eastern North America where the adelgid has caused extensive damage to forests and ornamental plantings of eastern hemlock (*T. canadensis*) and Carolina hemlock (*T. caroliniana*) from Virginia to New England since its discovery 40 years ago.

What is its life cycle?

Hemlock woolly adelgid completes two generations of development per year on hemlock (McClure 1987b, 1989a). During March and April, adults of the overwintering generation lay 50 to 300 eggs each in a cottony mass on the young twigs (Figure 1). Nymphs (called crawlers) hatch from these eggs during a period of several weeks in April and May. Within a few days, they settle on the twigs near the base of the needles where they insert their piercing and sucking mouthparts. There they feed and remain throughout their development. This spring generation matures by the middle of June. Some of the adults produced at this time are winged individuals that are unable to reproduce on hemlock. Therefore, they leave the hemlock tree in search of spruce,

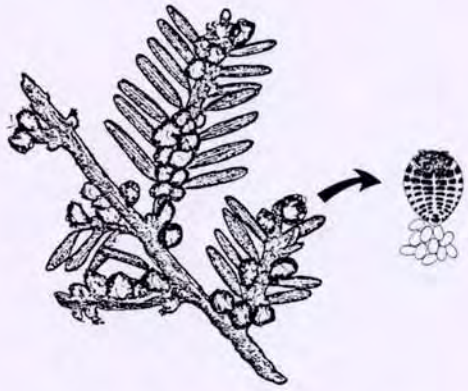

Figure 1. Egg masses and adult of hemlock woolly adelgid on eastern hemlock.

and because no suitable spruce host is available in North America, they soon die (McClure 1987a). Other adults produced at this same time are wingless and are able to reproduce on hemlock. In the middle of June these wingless adults lay 50 to 300 eggs each in a cottony mass on the twigs. Crawlers which hatch in early July settle on the new growth and soon thereafter become dormant until the middle of October when feeding resumes. Nymphs feed and develop during the winter and mature by spring.

How does it disperse?

Adelges tsugae has been spreading relatively rapidly in North America even though its life stages are wingless and are firmly attached to hemlock twigs by mouthparts for most of the year. Eggs and crawlers, the only stages that are unattached, are abundant from March through June when they are readily dispersed by wind, birds, deer and other forest-dwelling mammals, and humans during logging and recreational activities (McClure 1989b, 1990). Moving of infested nursery plants could also facilitate the spread of this pest.

Adelgid feeding and its consequences.

Hemlock woolly adelgid prefers to feed on the youngest available twigs. Therefore, the crawlers which hatch in early spring usually settle on the twig produced during the previous season while those which hatch in late spring usually settle on current year growth. *Adelges tsugae* injures eastern and Carolina hemlock by sucking sap and probably also by injecting a toxic saliva while feeding. This causes the needles on infested branches to desiccate, turn a grayish-green color, and then drop from the tree usually within a few months. Most buds are also killed, so little new growth is produced on infested branches. Dieback of major limbs usually occurs within two years and progresses from the bottom of the tree upwards, even though the infestation may be evenly distributed throughout the tree. Trees often die within four years (McClure 1991a), but some survive longer in a severely weakened condition with only a sparse amount of foliage at the very top of the crown. These weakened trees are unsightly and have little chance for recovery. They often fall victim to wood-boring insects and diseases and are readily broken and thrown by wind.

Patterns of infestation.

An infestation can start anywhere on a given tree depending upon where eggs or crawlers were deposited by wind, birds or other dispersal agents. However, within a year the infestation usually has spread throughout the crown (McClure 1991a). The same pattern is true for the establishment of an infestation among hemlock trees in a forest or ornamental planting. Initially only one or a few individual trees become infested. Usually these are trees that are especially attractive to birds or exposed to winds carrying adelgid eggs and crawlers. Therefore, it is not uncommon to have dying infested hemlocks in close proximity to healthy uninfested trees for several years. These healthy trees are often mistakenly presumed to be resistant to the adelgid. However, in time the infestation will spread throughout the forest or planting and all hemlocks will be affected.

Because *Adelges tsugae* has two generations each year and is parthenogenetic (every individual is a female capable of producing up to three hundred offspring without needing a male), its population increases rapidly on a healthy hemlock. However, when a tree is injured following attack, it becomes nutritionally deficient for the adelgid. This results in high mortality of feeding nymphs, few offspring being produced by survivors, and a sudden crash in the adelgid population on the injured tree (McClure 1991a). Unfortunately, the tree is seldom able to recover from the degree of injury needed to render it unsuitable to the adelgid.

INTEGRATED MANAGEMENT PROGRAM

How to monitor the pest.

Because hemlock woolly adelgid can damage trees so quickly, it is important to detect infestations early and to implement a management program immediately. Frequent visual inspection is the most effective means of determining whether or not a hemlock is infested. For most of the year the dry, white "wool" produced by the adelgid on the twigs is quite conspicuous contrasted against the dark green needles (Figure 1). It is particularly noticeable on the undersides of the young twigs. Only in winter with snow on the branches might the "wool" be difficult to detect. A new infestation could also be difficult to detect during July through September when adelgids are small dormant nymphs with very little "wool" associated with them. However, periodic examination of hemlocks throughout the year would minimize the chance of a new infestation being overlooked. Further evidence of an adelgid infestation is the thinning or grayish-green (not red or yellow) color of the needles on some branches. Usually by the time these symptoms appear, the tattered "wool" of a previous adelgid generation is also present on the branches.

CULTURAL CONTROL METHODS

Reducing invasion by adelgids.

A number of cultural practices may be effective in reducing the risk of hemlocks becoming infested by hemlock woolly adelgid. Because birds, squirrels and deer are important dispersal agents (McClure 1990), any effort to discourage these animals from visiting hemlocks will reduce the risk of those trees becoming infested. Care should also be taken when moving plants, logs, firewood, or bark chips from infested areas onto an uninfested property, especially

from March through June when adelgid eggs and crawlers are abundant. Cleaning vehicles, clothing, etc. after visiting forests, recreational areas, parks or other properties with infested hemlocks is also advisable during this period.

Infestations of *Adelges tsugae* often start on large hemlocks that intercept the prevailing wind or that are especially attractive to birds and other wildlife. When such a tree becomes heavily infested, it can serve as an effective "launch pad" for adelgid eggs and crawlers. Selective removal of these heavily infested reservoir trees from the immediate vicinity will retard the establishment of new infestations.

Improving tree health.

Adelges tsugae 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 in poor sites or experiencing stress from drought and other agents succumb to adelgid attack more quickly. Therefore, maintaining good growing conditions can play an important role in the survival of hemlock. Because hemlock is a shallow rooted tree, it is particularly prone to stress when precipitation is abnormally low. Therefore, during periods of drought, trees should be watered as often as needed to ensure that they receive 1 inch of water per week (including rainfall) over the area beneath the dripline of the crown. Water should be applied slowly so that the roots will be soaked thoroughly.

Pruning may also be of some value in improving the health of hemlock. Removing dead and dying branches and limbs from hemlock will promote new growth by allowing more light to reach the foliage, and will reduce the likelihood of attack by other insect pests and diseases.

Although applying fertilizer may improve the growth and vigor of uninfested trees, fertilizing infested hemlocks with nitrogen also enhances adelgid survival and reproduction (McClure 1991b; 1992a). As a result, a fertilized hemlock becomes more heavily infested and more severely injured than an unfertilized one. Although nitrogen fertilizer should not be applied to an infested hemlock, fertilizing a tree after adelgids have been controlled may encourage growth and stimulate recovery. The potential risks and benefits of applying fertilizers which do not contain nitrogen to adelgid-infested hemlocks are unknown.

Mechanically removing adelgids.

Eggs and crawlers of hemlock woolly adelgid are readily dislodged from the young hemlock twigs by wind and rain. Most of these dislodged individuals are unable to find their way back onto the tree and die. Therefore, intentionally dislodging eggs and crawlers by directing a strong stream of water at infested branches periodically during April through June may be of some value in an integrated approach to managing hemlock adelgid populations. Clipping heavily-infested twigs from branches will also reduce adelgid populations on a tree. However, extensive clipping may have undesirable effects on the appearance and health of the tree.

Planting resistant hemlock species.

The two Japanese and two western North American hemlock species are much more resistant to hemlock woolly adelgid than are their eastern North American counterparts (McClure 1992b). Of these four resistant species, the western hemlock (*T. heterophylla*) is most similar to eastern hemlock in appearance, growth form, and utility. Although adelgids do infest these resistant species, they seldom reach densities high enough to cause injury. Therefore, planting resistant Japanese and western hemlocks should reduce the impact of the adelgid in the ornamental landscape. However, the long term success of these exotic hemlocks in the forests of eastern North America has not been evaluated.

CHEMICAL CONTROL METHODS

Deciding whether or not to use pesticides.

The use of chemical pesticides is an essential component of any integrated approach to managing populations of hemlock woolly adelgid. Even though cultural control measures can significantly reduce adelgid numbers on hemlock, infested trees are usually unable to survive for more than a few years unless chemical pesticides are applied. It is important to understand at the outset that hemlocks will need to be protected from the woolly adelgid as often as necessary until the danger has passed. This may be for a period of several years. Therefore, the initial decision on whether or not to use chemical control measures should consider the value of the trees relative to the anticipated cost of protecting them over the long term. It may be advisable to identify individual trees or groups of trees that have special value or significance on the property and to concentrate control efforts on those trees. This may be more successful than the overly ambitious approach of trying to save all the trees at first, only to lose them all when the resources have been depleted a few years hence.

What to know about pesticides.

Several pesticides are registered for control of hemlock woolly adelgid (McClure 1987, 1991c). Some are available for homeowner use, while others are available for commercial use only by a licensed arborist. Because each of these pesticides has a relatively short life in the environment, treating an uninfested tree with pesticide offers little or no protection from invasion by hemlock woolly adelgid. Therefore, hemlocks should be treated only when an adelgid infestation is known to be present. Before applying any pesticide, read the product label very carefully. It will provide important information on safety, toxicity, and methods and rates of application. Also be aware that regulations governing the use of pesticides for controlling hemlock woolly adelgid may differ between states and are subject to change.

Applying pesticide sprays.

The most common and effective method for controlling hemlock woolly adelgid on ornamental hemlocks is to thoroughly drench infested trees with horticultural oil, insecticidal soap, or any one of numerous petrochemical insecticides that are specifically labeled for this use including diazinon, fluvalinate, imidacloprid and malathion (McClure 1987, 1991c). Horticultural oil and insecticidal soap are used most often because they are highly effective in killing adelgids, and yet they are relatively safe to the applicator, to beneficial insects, and to the environment. Unlike the petrochemical insecticides which kill insects indiscriminately by contact or ingestion, the oil and soap selectively kill soft-bodied insects, such as adelgids, by "suffocation" rather than by poisoning.

It is essential that all parts of the infested hemlock be drenched thoroughly with insecticide. This precludes control on very large trees (usually those greater than about 80 feet tall) and those in forest settings. A backpack or garden hose sprayer may be sufficient to drench trees less than 30 feet tall, but taller trees may require the services of a professional arborist using a hydraulic sprayer. Fortunately, it is unnecessary to target a particular life stage of the adelgid for control; all are equally susceptible. *Therefore, pesticide sprays can be applied at any time during the year, weather permitting.* Two thorough spray treatments each year are necessary for most situations. However, one application each year may be enough, if trees are thoroughly drenched with pesticide and if there are no other infested hemlocks within 100 yards from which adelgids could readily disperse. If two applications each year are needed, an effective strategy is to spray in early April and again during late June. Another option is to spray in late September and again in early June. Either of these schedules will target both adelgid generations and minimize the impact of immigration. Because hemlock adelgid propagates and injures hemlocks so quickly, it is advisable to spray as soon as a new infestation is detected, and then to adopt one of the maintenance schedules described above.

Applying pesticides by stem injection and implantation.

Introducing concentrated chemical pesticides into the stem of infested hemlocks by injection or implantation can control hemlock woolly adelgid on trees that are very tall or growing in areas inaccessible to spray equipment, or where spraying is undesirable such as near waterways and in recreation areas (McClure 1992a). The injection technique involves drilling small shallow holes into the root flares at the base of the tree and inserting into these holes pressurized plastic capsules containing a concentrated liquid pesticide, such as acephate, bidrin or metasystox. The pesticide moves into and up the tree to where it is intercepted by the feeding adelgids. The implantation technique involves drilling larger, deeper holes in a spiral around the trunk of the tree and inserting in these holes a plastic cartridge containing a powdered pesticide, such as acephate, within a gelatin capsule. The sap flow dissolves the capsule and then carries the pesticide throughout the tree. These techniques, when applied in mid-May, have controlled adelgids for up to 6 months (McClure 1992a).

Although stem injection and implantation provide alternatives to spraying for control of hemlock woolly adelgid, several considerations may limit their use. Both of these procedures require the pesticide to move in the sap flow. Therefore, they may be effective only on newly-infested, uninjured trees, because feeding by hemlock adelgid quickly restricts the tree's ability to uptake and distribute water. The degree of wounding of the tree involved in the ongoing use of these drilling techniques is also of concern. Furthermore, because the injection method involves the use of highly concentrated liquid pesticides, its availability to the general public may be restricted.

Applying pesticides by soil injection and drenching.

Introducing systemic insecticides into the roots of infested hemlocks is another alternative for protecting trees that can not be sprayed thoroughly (Steward and Horner 1994). The soil beneath the crown of an infested hemlock can either be drenched or injected, using a hydraulic needle, with imidacloprid. This pesticide is then taken up by the roots and distributed throughout the tree where it can control hemlock woolly adelgid for 5 months or more. Unlike stem injection and implantation, these soil treatments do not wound the tree. However, as was the case with the stem treatments, trees must have a healthy sap flow for these soil treatment methods to be effective.

Evaluating the effectiveness of chemical controls.

Determining whether a chemical control effort has been successful can be a challenge. Because adelgid nymphs are immobile and remain firmly attached to the branches after their death, it is difficult to distinguish living ones from dead ones even with a magnifying glass or microscope. Furthermore, the darkened color and loss of turgidity which characterize a recently killed adelgid are usually not apparent for about 2 weeks. Unfortunately, the presence of "wool" on the twigs is also of little value in assessing the effectiveness of a control effort, because this "wool" can persist for several months after the adelgid has been killed. The simplest way to determine if control measures were effective and if additional ones are needed is to disregard the tattered, off-color "wool" on older twigs, and to look only at young twigs for the fluffy, white "wool" produced by living adelgids.

BIOLOGICAL CONTROL METHODS

Hope on the horizon.

Several native species of insects are occasional predators of hemlock woolly adelgid in North America. Unfortu-

nately, none of these predators has had a significant impact on adelgid populations or has shown much potential for biological control. In Japan, however, there are effective natural enemies including ladybird beetles, green lacewings, mites and flies. Two species in particular, the oribatid mite, *Diapterobates humeralis* and the ladybird beetle, *Pseudoscymnus* new species, are especially effective at locating and destroying infestations of hemlock woolly adelgid in Japan (McClure 1995). The potential of these and other arthropods as biological control agents is now being evaluated at the Experiment Station with the hope that some day they can be included in an integrated program for managing hemlock woolly adelgid in the forests, nurseries and ornamental landscapes of eastern North America.

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The Connecticut Agricultural Experiment Station, founded in 1875, is the first experiment station in America. It is chartered by the General Assembly to make scientific inquiries and experiments regarding plants and their pests, insects, soil and water, and to perform analyses for State agencies. The laboratories of the Station are in New Haven and Windsor; its Lockwood Farm is in Hamden. Single copies of bulletins are available free upon request to Publications; Box 1106; New Haven, Connecticut 06504.

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