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EXOTIC PEST THREATS

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Hemlock Woolly Adelgid

Adelges tsugae Annand (Hemiptera: Adelgidae)

INTRODUCTION:

The Hemlock Woolly Adelgid (HWA) is a tiny, aphid-like insect native to Asia, believed to have accidentally entered North America on imported nursery plants. It is now a serious pest of eastern hemlock (*Tsuga canadensis*) in the U.S. HWA were first reported on the west coast in the 1920's, then near Richmond, VA, around 1950. Although west coast species of hemlocks appear resistant to HWA, eastern species have been ravaged by this pest. The potential ecological impacts of this pest are extensive. Eastern hemlock stands provide critical shelter and a unique habitat for many birds and wildlife, and are important in maintaining forest stream ecosystems. There is not an ecologically equivalent tree species that can take the place of eastern hemlock.

Severe HWA infestation on hemlock twig, showing typical woolly coverings. Connecticut Agricultural Experiment Station Archive, Bugwood.org

DISTRIBUTION/SPREAD:

HWA are native to Asia where they are common but minor pests of several species of hemlock and spruce trees. In the Pacific Northwest, HWA is found in relatively low numbers from northern California to southeastern Alaska. In the eastern U.S., however, HWA is a major pest due to the availability of susceptible host trees and lack of natural control organisms. The eastern distribution of HWA ranges through 16 states from Maine to Georgia and west to Tennessee and includes Connecticut, Delaware, Georgia, Maine, Maryland, Massachusetts, North Carolina, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, South Carolina, Tennessee, Virginia and West Virginia. Isolated infestations were detected on nursery stock in Vermont in 1990 and again in 2004, but were quickly eradicated, making Vermont the only New England state that is HWA free.

Nearly half the range of hemlock in the eastern United States is now infested with HWA, and the entire range is at risk. Eastern hemlock occurs naturally in the Appalachian Mountains from northern Alabama to Nova Scotia, and west into eastern Kentucky and Minnesota. Carolina hemlock is rare, and occupies a narrow range in the southern Appalachians (primarily NC and SC; also western VA, parts of GA and TN) growing on dry, rocky outcroppings. The average rate of HWA spread over the past decade has been about 15 miles/year, but it can be more explosive when conditions are right. HWA were first detected in the Shenandoah Valley in 1988, by 1992 most hemlocks were infested, and by 1995 the majority was dead. Today, large stands of eastern hemlock have essentially disappeared from the Shenandoah National Park.

Isolated infestations and long-distance movement of HWA most often happen when people transport infested nursery stock, accidentally spreading HWA from planted trees to natural stands of hemlocks. Local spread of HWA occurs primarily from the first instar crawler stage and the sticky ovisacs being carried by wind, birds or forest animals. It is thought that HWA initially spread northward because of crawlers clinging to the legs and feathers of birds migrating in the spring when crawlers are plentiful. By the 1980's, HWA had caused extensive hemlock tree mortality from VA to CT, but the current rate of HWA dispersal and tree decline is now most significant at the southern edge due to milder winter temperatures.

HOST PLANTS:

In Asia, HWA infest ornamental and forest hemlocks and spruce, but their numbers are kept in check by host resistance and natural enemies. In the Pacific Northwest, HWA is found on western and mountain hemlocks (*Tsuga heterophylla* Sargent and *Tsuga mertensiana* Carriere), but have little impact as these species are resistant to the adelgid. In the Eastern U.S., HWA is highly destructive on eastern hemlock (*Tsuga canadensis*, also known as Canadian hemlock or Hemlock spruce) and Carolina hemlock (*Tsuga caroliniana*), infesting and killing hemlocks of all sizes and ages, even under seemingly optimal growing

conditions. Though HWA is able to develop and reproduce on all species of hemlock, only eastern and Carolina hemlock are severely damaged when attacked. There are at least 274 known cultivars of eastern hemlock. Research is currently underway examining cultivars of eastern hemlock for differences in susceptibility to HWA.

Eastern hemlock is a keystone species in the streamside forests of the southern Appalachian region, and plays two distinct ecohydrological roles there: one as an evergreen tree with relatively stable water use throughout the year; the other as a streamside tree with high rates of water use in the spring. These traits are critical in helping regulate streamflow and in moderating water temperature. These trees are important to nutrient runoff, erosion control and maintaining wildlife habitats. Carolina hemlock is relatively rare in the areas affected by HWA.

BIOLOGY and DAMAGE:

The life cycle of the HWA is complex. The insect is parthenogenetic (all individuals are females and reproduce without males) and completes two generations (progrediens and sistens) a year, each having six stages of development: egg, four nymphal instars, and adult. The two generations differ in notable ways. The progrediens, or spring generation, hatch in early spring (around March) from eggs laid in late winter. Progrediens live about 3 months. Upon hatching, progredien nymphs may take one of two forms: one is wingless and remains on hemlock to complete its life cycle, but the other develops into winged adults called sexuparae. Sexuparae fly in search of spruce (alternative host), where sexual reproduction takes place, but there are no known suitable spruce species in N.A. for this to occur, so the winged forms simply die. The wingless crawlers that remain behind on hemlocks settle permanently at the base of needles, begin feeding, and secrete a protective woolly covering. After completing nymphal development, new adults begin oviposition in June, each laying 20-75 eggs in cottony masses attached to twigs from which the sistens generation hatches.

In June and July, the wingless sistens generation hatches from progredien eggs as crawlers, or 1st instar nymphs, and will live about 9 months. The crawler stage is not protected by a woolly covering, and is the only life stage of HWA able to move about. Within days the crawlers either disperse to new hosts or remain on their birth tree, attach at the base of hemlock needles, and shortly thereafter aestivate (enter a period of dormancy). HWA are unusual in that they enter this period of aestivation during the hot summer months. During aestivation, nymphs have only a tiny halo of woolly wax outlining their bodies. When cooler weather arrives around mid-October, sisten nymphs break aestivation and resume feeding, secrete a woolly covering and continue developing throughout the winter months, maturing by late winter or early spring. Sisten adults lay eggs in March, or earlier in southern states or during mild winters. Each cottony ovisac contains up to 300 eggs, which give rise to a new progrediens generation. The two generations of HWA

White, woolly ovisacs are found clustered on the underside of hemlock twigs. Michael Montgomery, USDA Forest Service, Bugwood.org

Inside each ovisac is a mass of HWA eggs (exposed in image above). Pennsylvania Department of Conservation and Natural Resources - Forestry Archive, Bugwood.org

Crawlers hatch and emerge from ovisacs, then move about seeking a spot to settle and feed. Pennsylvania Department of Conservation and Natural Resources - Forestry Archive, Bugwood.org

Aestivating 1st instar nymphs with halos of woolly filaments outlining their bodies. Scott Salom, Virginia Tech.

Adult HWA with woolly covering removed. Michael Montgomery, USDA Forest Service, Bugwood.org

Close-up of severe HWA infestation on a hemlock twig. Chris Evans, River to River CWMA, Bugwood.org

overlap in mid to late-spring.

HWA kills hemlocks by feeding on their stored starch reserves. The pest has thread-like piercing/sucking mouthparts that penetrate deep into the vascular cortex, suck up sap, and secrete toxic saliva. As nutrient stores are depleted, tree growth slows, needles desiccate and drop, and most buds die, reducing new growth on infested branches. This usually occurs within a few months of initial infestation, and within a couple of years major limbs start dying off and the tree crown begins to thin. Infested trees often die in about 3 to 10 years.

HWA has successfully established in the eastern U.S. for a number of reasons: they have a very high reproductive rate; they have no natural predators in the east; susceptible hosts are abundant; they can tolerate temperature extremes and prolonged periods of low temperatures; and they are adapted to high elevations. Although populations fluctuate greatly in response to factors such as cold winter temperatures, declining tree health, and drought, their potential for further spread is great due to their wide environmental tolerance.

IDENTIFICATION:

- Adult HWA are tiny, about 1/16” long (1-2 mm), oval-shaped, aphid-like insects, dark reddish-brown to purplish-black in color.
- Eggs are brownish-orange, darken as they mature, and covered with white, woolly filaments.
- Flat, naked reddish-brown crawlers (nymphs) hatch out and move about actively.
- The wingless nymphs resemble adults but are smaller.
- Once crawlers settle down, they turn black with a white halo of fringe outlining their body.
- As HWA mature, they produce a covering of fluffy, white wool-like wax filaments.
- Woolly masses are about ⅛” in diameter (3 mm), are present throughout the life of the adelgids, and are most conspicuous from late fall to early summer at the base of the needles on the underside of the outermost branch tips of hemlock trees.

WHAT TO LOOK FOR:

- Heavily infested trees look grayish green (not yellow/brown) within a few months as needles desiccate and die.
- Needles drop and most buds are killed so that little or no new foliage is produced.
- HWA are easily recognized on infested branches by their white, fluffy, wool-like coverings.
- Dieback of major limbs, which progresses from the bottom to the top of the tree.
- Foliage is usually sparse at branch tips and the top of the crown.
- Weakened trees are often attacked by other diseases and

insects, and are easily broken by wind.

- A tree may defoliate and die within 4 to 10 years of infestation in the northern range of HWA, or as little as 3 to 6 years in its southern range.

MONITORING:

Because HWA can damage trees so quickly, it is important to detect infestations early. Frequent visual inspection for adelgids and damage symptoms is the most effective means of determining HWA infestation. For most of the year the fluffy, white "wool" produced by HWA on twigs is readily noticed, particularly in spring on the undersides of young twigs. Hyperspectral remote sensing technology is being investigated to help monitor hemlock health across large areas of natural forests. A commercially available sensor (Specim's AISA Eagle) was successfully used to map hemlock decline (early stress symptoms) due to HWA infestation in the Catskill Mountains of New York. The AISA Eagle was able to classify hemlock health and to predict decline below the level when dieback first becomes noticeable in the field. This technology will enable land managers to assess and monitor detailed changes in forest health across the landscape so that IPM programs can be effectively implemented.

MANAGEMENT:

Early detection and rapid response are critical to curbing the spread of HWA infestations. Regulatory, cultural, biological, and chemical controls can reduce HWA rate of spread and protect individual trees. Different control methods are needed for HWA in ornamental settings than for forests. In the landscape, an IPM approach combining cultural and chemical controls is more effective than biological controls. In forests with large stands of hemlocks, chemical control can be difficult and costly, whereas biological controls would be more effective and practical.

Regulatory

State quarantines have been initiated in several areas with severe HWA infestation. Quarantines require the inspection of hemlock nursery stock and materials, and restrict the movement of infested material into uninfested areas. Hemlock logs, lumber with bark, and chips have not been found to be a cause of HWA spread and are therefore not part of the quarantine.

Cultural Control

In landscape settings, steps that can be taken to manage/reduce HWA infestations include:

- Improve hemlock health: water as needed to provide 1 inch (2.5 cm) per week, soaking the entire drip line area; prune out and destroy dead, dying or infested branches and twigs.

- Beware of fertilizing: nitrogen enhances HWA survival and reproduction, so it is not recommended that infested hemlocks be treated with nitrogen containing fertilizers.

Hemlock branch with severe infestation of HWA. USDA Forest Service - Region 8 Archive, USDA Forest Service, Bugwood.org


Close-up of damage after 2-3 years severe infestation with HWA. Chris Evans, River to River CWMA, Bugwood.org

Infested hemlock needles turn grayish/green. James Johnson, Georgia Forestry Commission, Bugwood.org

Thorough coverage with foliar pesticide sprays is essential for control. Great Smoky Mountains National Park Resource Management Archive, USDI National Park Service, Bugwood.org

Soil drenching with a systemic pesticide. Great Smoky Mountains National Park Resource Management Archive, USDI National Park Service, Bugwood.org

- Birds, squirrels and deer are important dispersal agents, so discourage these animals from visiting hemlocks. Locate bird feeders away from hemlocks.
- When visiting areas infested with HWA, take care not to bring crawlers home, especially from March-June when eggs and crawlers are abundant: do not move plants, logs, firewood, or bark chips from infested areas onto non-infested property; clean vehicles, clothing, etc., after visiting forests, recreational areas, parks or other infested locations.
- Plant resistant hemlock varieties: nearly a dozen crosses with high resistance to HWA have been developed, however the long term success of these trees in the eastern U.S. is unknown. Resistant varieties include: *T. mertensiana, T. diversifolia, T. chinensis,* and *T. heterophylla*, which is most similar to eastern hemlock in appearance, growth form, and utility.
- Purchase locally propagated nursery hemlock trees to prevent importation of infested stock.

In forest settings with infested hemlocks, silviculture options include:

- Do nothing: Infested hemlocks will gradually die over 4-12 years and the amount of light reaching the ground will gradually increase, aiding the establishment of other hardwood trees and herbaceous plants. Hemlock branches, treetops, and boles will fall over a period of 15+ years with little or no soil disturbance, and the dead materials will provide valuable wildlife habitat for a variety of bird, mammal, and invertebrate species.
- Light selection cut or shelterwood cut: Removal of 20-50% of the dying and heavily damaged trees throughout the stand. More light enters the stand with this treatment than with the previous, so other hardwood, conifer and herbaceous species will be stimulated to compete.
- High intensity cutting: Removal of more than 50% of the tree basal area, used if the stand is heavily damaged and/or recovering timber value is the main goal. High light reaches the forest floor, often leading to regeneration of black birch and, potentially, weedy or invasive species. If cutting is done without any regeneration on steep slopes or near streams, it may lead to erosion and nutrient export to streams.
- Replanting options: research continues in breeding HWA-resistant hemlock cultivars. In some settings, native conifer species like white or red pine (*Pinus strobus* and *Pinus resinosa*), or white or red spruce (*Picea glauca* and *Picea rubens*) might be appropriate. The exotic Norway spruce (*Picea abies*) is planted for its full crown of dark green foliage.

Mechanical/Physical Control

Severely infested trees can be cut down and destroyed. In April and June, eggs and crawlers may be dislodged by hosing infested branches with a strong stream of water. Heavily infested twigs can be pruned out and destroyed. Neither of

the last two practices, however, is effective enough to attain control without the use of other control options.

Biological Control

The best option for managing HWA in forests is classical biological control. There are no known parasitoids of HWA world-wide, and insect predators native to the eastern U.S. that feed incidentally on HWA have not been effective to date at reducing populations to harmless levels. Therefore, research into biological controls for HWA from its native range in Asia was initiated in the 1990's as a team effort involving Virginia Tech and several other universities, the USDA and the U.S. Forest Service. Ultimately, a complex of natural enemies will probably be necessary to maintain HWA populations at below damaging levels, rather than reliance on any one organism.

Four species of predatory beetles that have passed rigorous USDA evaluation are currently utilized in release programs in the U.S. These include three ladybird beetle species, *Sasajiscymnus tsugae* (formerly *Pseudoscymnus tsugae*) from Japan, *Scymnus sinuanodulus* and *Scymnus ningshanensis* (both from China), and a species of fungus beetle, *Laricobius nigrinus*, which is native to western North America. *S. tsugae* has been the most frequently released predator to date.

Sasajiscymnus tsugae: is a tiny (<0.12" or 3 mm) black ladybird beetle collected from HWA infested hemlocks in Japan in 1992 that belongs to a group of specialist predators of aphids, scales, mealybugs, and adelgids. *S. tsugae* prefers adelgids to aphids, both larvae and adults feed voraciously on all stages of HWA, and it can complete development on other adelgids present in the U.S. (balsam woolly adelgid, pine bark adelgid, and Cooley spruce gall adelgid) as well as on HWA. Its life cycle is synchronous with that of HWA and *S. tsugae* is also adapted to a wide range of climatic conditions. The beetle has a long life span (one year with overwintering) and a high lifetime fecundity (females lay an average of 280 eggs over an average period of 14 weeks), producing two generations annually in the NE. Female *S. tsugae* lay eggs throughout the spring into mid-summer on both the sistens and progrediens adelgid generations. The first generation of adult beetles, which generally emerges in June or July, can survive the late summer period by feeding on dormant HWA nymphs. *S. tsugae* can be reared continuously in the laboratory, and several labs have been established in the eastern U.S. to mass produce the beetles.

S. tsugae were first free-released in North America in 1995, and by 2004 over 1 million *S. tsugae* had been released on more than 100 sites in 15 eastern states from South Carolina to Maine. Long-term monitoring of *S. tsugae* release sites has shown the beetles generally reduce HWA numbers in those areas, and successfully overwinter, reproduce and locally disperse. The beetles are less successful at sites where HWA populations are initially high and the trees are already stressed. However, at sites where hemlock growth conditions are good, HWA densities have remained low and trees have shown recovery after 4 to 7 years.

In situations where HWA populations thrive due to a series of mild winters, trees have generally continued to decline in spite of the successful establishment of *S. tsugae*. Because of the lag time often required for a biological control agent to successfully establish following release, and the rapid rate with which HWA kills hemlocks, control of HWA through the use of *S. tsugae* alone may not be viable. Research into other biological control agents that can be introduced as part of a complex to create a long term HWA control solution continue to be pursued.

Scymnus sinuanodulus, *Scymnus ningshanensis*: are ladybird beetles native to China that feed primarily on HWA and were imported to the U.S. in the 1990's. These predatory beetles share a synchronized life cycle with HWA, being active and reproducing during the fall and winter months, and going dormant during the summer. These beetles prefer HWA eggs, but will feed on all life stages of the adelgid. In 2004, a field release of adult *S. sinuanodulus* beetles was made in the Southern Appalachians, and in 2006 additional beetles were released in the Monongahela National Forest, WV. Generally, newly matured *Scymnus* adults overwinter one season before laying eggs, and unlike *S. tsugae*, they produce only one generation per year. Scientists continue to evaluate all three species of beetles to find the most effective use of these predators to protect hemlock trees.

Laricobius nigrinus Fender (Coleoptera: Derodontidae): is a small Derodontid beetle native to northwest North America found feeding on HWA in hemlock seed orchards in British Columbia. Virginia Tech scientists began importing the beetle in 1997 for study under quarantine, and field releases and mass rearing studies began in 2001. *L. nigrinus* produces one generation per year, emerges at the same time as HWA, undergoes the same diapause (summer dormant period), and prefers to feed on HWA, although it will feed on other adelgids. *L. nigrinus* is active in the winter at the same time as HWA, preferring temperatures between 54°-59°F (12°-15°C). Adults feed on all HWA life stages present from November to May, and begin laying eggs in HWA ovisacs (one per ovisac) in February. Larvae feed exclusively on HWA eggs.

Field evaluations at Virginia Tech revealed that *L. nigrinus* adults survive Virginia winters and feed voraciously on HWA

sistens, while producing a very high number of predator eggs. The majority of *L. nigrinus* activity occurs earlier than that of *S. tsugae* and the generalist ladybird beetle, *Harmonia axyridus*. Although *L. nigrinus* and *S. tsugae* will feed on each others' eggs, they only do so when HWA density is very low. There was concern that *H. axyridus* might be a formidable predator on the other two, but evidence suggests it is not as damaging as was expected. A worldwide search for additional *Laricobius* species began in 2002 and two new species were discovered in China, one of which is currently being reared and studied at Virginia Tech. In 2006, another new species of *Laricobius* was discovered in Japan feeding on HWA and was brought back to the U.S. for study.

Other biological control possibilities: Other potential biological control organisms have been investigated, including an oribatid mite (*Diapterobates humeralis*) from Japan, and several entomopathogens (insect disease pathogens) from the U.S. and China. In 2002, thousands of HWA showing signs of fungal infection were collected from hemlock forests in the eastern U.S. and southern China. Research yielded several virulent isolates (*Verticillium lecanii*, *Beauvaria bassiana*) that were selected for further testing as control agents for HWA and for any impact on non-target predator insects (no impact detected on *S. tsugae* under field conditions; tests are needed for *Scymnus* spp. and *Laricobius* spp.). Field tests were conducted to determine optimal formulations and spray delivery systems, rates, and timings (fall sprays appear more effective than spring, perhaps due to minimal woolly covering in fall). Technology has been developed for mass production of the fungi.

Identifying, studying and mass rearing more natural enemies of HWA, and combining known biological control organisms into an integrated HWA management strategy, is essential to the effective control of HWA and the survival of hemlock trees in North America.

Chemical Control

In the landscape, hemlock trees not infested with HWA do not need preventive treatment unless adjacent trees are infested. To control HWA infestations of trees in the landscape, sprays of horticultural oil can be used. To prevent or control infestations of individual high-value hemlocks in the landscape or in naturalized settings, any of several other recommended chemical insecticides can be sprayed, injected or implanted directly into the trunks of trees, or applied as a soil drench or injection. Aggressively treating a newly infested tree while it is still in good health is the best way to control HWA and maintain a healthy tree.

FOLIAR SPRAYS:
Many products are labeled for use on HWA as foliar sprays. Horticultural oils and insecticidal soap are two products labeled for control of HWA that have reduced impacts to non-target organisms. Oils have been shown to provide high levels of control. Follow label precautions concerning timing, temperature and humidity regimes, and compatibility with other materials when applying oil.

Other insecticides labeled to be applied as foliar sprays that offer control of HWA include active ingredients such as acetamiprid, bifenthrin, carbaryl, deltamethrin, dinotefuron, fluvalinate, and imidacloprid. Larger trees may need to be treated by a commercial pesticide applicator with a high pressure sprayer.

SOIL DRENCHES/SOIL INJECTIONS:
For large trees where it is difficult to spray the crowns, soil drenches or injections may be a better option. Tree roots absorb the product and move it up into the foliage where the feeding insect is then killed. Soil drenches should be applied in the spring or fall when there is adequate soil moisture for the tree to take up the product. Do not use near streams or ponds or where the soil is too rocky. Products labeled for use as soil drenches and soil injections include active ingredients such as dinotefuron and imidacloprid. Imidacloprid applied as a soil injection or drench may provide more than one year of protection. Unlike trunk injection, these soil treatments do not wound the tree.

TRUNK INJECTIONS:
For large trees inaccessible to spray equipment, near surface water, or where the soil is too rocky for soil injections or drenches, trunk injections can be used. This method injects the chemical directly into the tree, where vascular tissue conducts the insecticide to the branches. An experienced commercial pesticide applicator should be hired for these treatments. Insecticides labeled for use as trunk injections include the active ingredients abamectin, dinotefuron, imidacloprid, and oxydemeton-methyl.

Any of these treatments can last one to several years before adelgids become a problem again. Even if the products are working properly, it may take a year or longer for soil or trunk injections to show control. Success is usually a function of a tree's initial health and the amount of soil moisture when treatments were made. If a tree is severely defoliated or stressed, these methods may not work well as they are dependent on adequate sap flow to move the pesticide throughout the tree.

If a tree is already in a state of decline, first try to improve its health by spraying as much of it as possible with a foliar insecticide, and keeping it well watered. To determine if control is successful, monitor only the new growth of hemlocks to find the small, pepper-like nymphs or the clean, new white wax of adults. Retreat if HWA are commonly found on new growth.

Regardless of the application method, insecticide treatments can unintentionally lead to an increase in secondary pests, such as spider mites, which may have to be controlled. Chemical runoff into nearby open water such as streams or ponds, onto adjacent property, or into any environmentally sensitive areas must be prevented. Chemical treatments offer a short-term solution, and multiple, repeated applications in subsequent years may be necessary for control. Read and follow all label directions.

How to Report a Possible Sighting/Infestation

In Maryland:
University of Maryland Cooperative Extension Exotic Pest Threats Website: http://hgic.umd.edu/faq/sendAQuestion.cfm

Maryland Department of Agriculture: call 410-841-5920 to report suspect pests; visit http://www.mda.state.md.us/plants-pests/invasive_species.php for information.

Nationally: USDA-Animal and Plant Health Inspection Service (APHIS)
http://www.aphis.usda.gov/services/report_pest_disease/report_pest_disease.shtml

HWA Woolly Mass Actual Size:

Where to Get More Information:
UMD Cooperative Extension Exotic Pest Threats Website: http://www.PestThreats.umd.edu/index.cfm
Clemson University, Biological Control for HWA: http://entweb.clemson.edu/eiis/pdfs/bb8.pdf
USDA Forest Service FHTET-2004-04: http://www.invasive.org/hwa/
USDA Forest Service Pest Alert: http://www.na.fs.fed.us/spfo/pubs/pest_al/hemlock/hwa05.htm
University of TN case study: http://www.ipmimages.org/spdn/invasive/presentations/10Hale.pdf

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