

MARYLAND DEPARTMENT OF AGRICULTURE
FOREST PEST MANAGEMENT
HEMLOCK CONSERVATION PLAN



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MARYLAND HEMLOCK CONSERVATION PLAN

PURPOSE

This plan was developed in an effort to slow or control the damage to Maryland's eastern hemlock forests caused by an invasive insect called the hemlock woolly adelgid (*Adelges tsugae*). It is also the intent of this plan to serve as a request for project review and the pre-approval of a series of treatment options that can slow the spread of the adelgid and other hemlock pests in Maryland for the period of 2024 through 2027. This will allow MDA Forest Pest Management to react quickly when new infestations are found, or new treatment options are appropriate. The plan will also allow us to direct our efforts to timely treatments of sites with damaging levels of hemlock pests.

GOALS

- Identify and regularly update a list of high-risk eastern hemlock stands in the state of Maryland on which to focus hemlock conservation.
- Treat prioritized high-risk stands to suppress hemlock pest populations.
- Survey, map, and monitor the efficacy of chemical treatments, hemlock stand health, and the yearly extent/density of HWA infestations across the state.
- Utilize all available approved biological controls and continue monitoring for predator/parasitoid establishment.
- Create viable insectaries for established predators to facilitate increased establishment of biological controls.
- Assist in studies and restoration plantings of HWA-resistant hemlock trees.
- Cooperate with partner organizations to preserve hemlock genetic material.
- Explore new treatment options as they become available.
- Collaborate with partners on HWA control strategy research.

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INTRODUCTION

Eastern hemlock (*Tsuga canadensis*) is the most shade-tolerant of all North American tree species, requiring as little as 5 percent full sunlight (Goodman and Lancaster 1990). This slow growing conifer, which can take 250 to 300 years to reach maturity, can exceed 800 years of age. When mature, the eastern hemlock is one of the largest east coast trees, reaching heights of over 160 ft, and basal diameters of 6ft. The native range of eastern hemlock extends from Nova Scotia to the mountains of Georgia, and as far west as Minnesota (Figure 1). Because of its shade tolerance and susceptibility to fire, it is usually found growing in riparian areas or in steep cove forests across much of eastern North America, and is generally restricted to regions with cool, humid climates and moist, well-drained acidic soils (Goodman & Lancaster 1990, Farr & Tyndall 1992).

The hemlock forests of Maryland are part of a unique and fragile habitat. Hemlocks are concentrated in the northern and western counties of Maryland, with the highest density of hemlocks occurring in the mountainous regions of Garrett County. It is estimated that more than 42,000 acres of hemlock forests exist in Maryland, comprised of over 2.8 million individual hemlock trees (USDA Forest Service 2008). Mature stands of eastern hemlock in western Maryland represent some of the last remaining old-growth forests in the state, with some trees estimated at over 350 years old and over 140 ft tall (Davis 2003). Patches of eastern hemlock also exist on Maryland's Eastern Shore and in far-southern Calvert County (Figure 2). These singular, isolated stands represent eastern hemlock at the physiographic extent of their range and are some of the few rare examples of eastern hemlock growing naturally on the Atlantic Coastal Plain (McAvoy & McAvoy 2003).

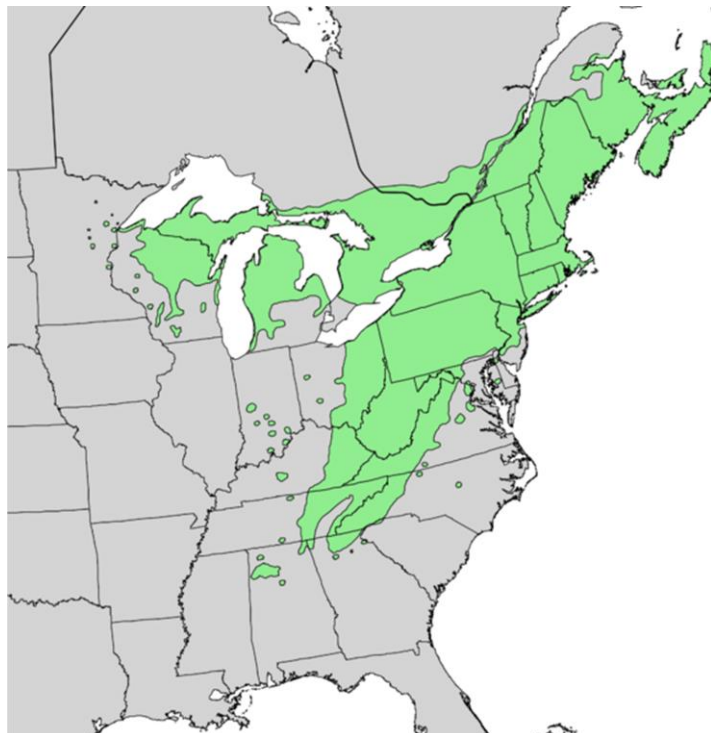


FIGURE 1: Native distribution of eastern hemlock (USGS 1999).

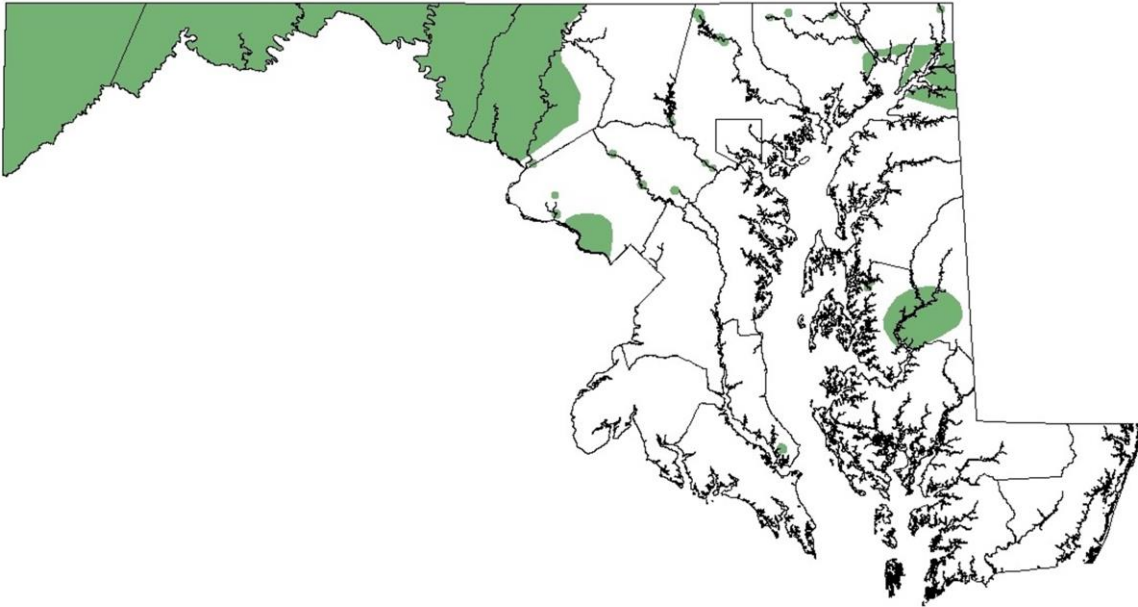


FIGURE 2: Distribution of eastern hemlock in the State of Maryland. Isolated stands in southern Maryland and on the Eastern Shore occur outside of the tree's typical physiographic range (USGS 1999; MDA 2020).

ECOLOGICAL SIGNIFICANCE

Eastern hemlock occupies an important ecological niche that is unmatched by other tree species in the state. When found in healthy stands, the unique shade tolerance and dense evergreen canopies of eastern hemlock create a cool, moist microclimate in which very little understory develops (Figure 3). This habitat is ideal for numerous charismatic wildlife species; 96 bird and 47 mammal species are associated with eastern hemlock forest systems in North America (Yamasaki et al. 2000). Three Maryland bird species, the blue-headed vireo (*Vireo solitarius*), black-throated green warbler (*Setophaga virens*), and northern goshawk (*Accipiter gentilis*), are all obligate hemlock-nesting species whose populations decline with loss of hemlock (Becker et al. 2008). In Maryland, the northern goshawk is state endangered; breeding populations were nearly extirpated from the state in 2006, and populations are still dangerously low (MDNR 2016).

Eastern Hemlock is an important cover species for a number of game animals, including whitetail deer, turkey, rabbit, and ruffed grouse (Goodman and Lancaster 1990, Yamasaki et al 2000). Ruffed grouse populations have been declining throughout the Appalachian region for decades, with habitat loss as a main factor in their decline (ACGRP 2004). Snowshoe hare (*Lepus americanus*) were once found in Maryland's hemlock forests, but this species has been extirpated from the state since 1986 (MDNR 2016).

The unique soil composition of eastern hemlock forests in Maryland produces a complex of vegetation found nowhere else in the state, often dominated by fern and moss species that benefit from the cool, moist microclimate (Battles et al. 1999, Beane et al. 2010). Eight species of plant that are threatened or endangered in Maryland are only found in hemlock-associated habitats (MDNR 2019).

This microclimate also supports a rich variety of arthropods: literature reviews revealed 484 arthropod species from 21 different taxonomic orders that are associated with eastern hemlock. Five of these species, *Gyponana arcta* (Hemiptera: Cicadellidae), *Plagiognathus tsugae* (Hemiptera: Miridae), *Megastigmus hoffmeyer* (Hymenoptera: Torymidae), *Coleotechnites macleodi* (Lepidoptera: Gelechiidae) and *Nalepella neosuga* (Trombidiformes: Eriophyidae) are considered hemlock obligates and would likely experience local extirpation along with declining hemlock populations (Turcotte 2016). Hemlock forests also harbor a more abundant, rich, and diverse



FIGURE 3: Typical riparian hemlock forest of western Maryland. The dense canopy regulates water temperature and limits understory growth.

community of spiders than deciduous forests, with four times the number of web-building spiders present in hemlock canopies (Mallis and Rieske 2011). Rapid loss of hemlock forests will lead to a total change in arthropod communities as species composition shifts to organisms that favor deciduous forests (Rohr et al. 2009, Sackett et al. 2011).

The heavy shade and damp microclimate produced by eastern hemlock moderates stream temperature throughout the year. This makes hemlock systems extremely beneficial for organisms that rely on fast-moving cold-water streams: Brook trout (*Salvelinus fontinalis*), Maryland's only native salmonid, are four times more abundant in streams draining from hemlock forests (Snyder et al. 2005, Siderhurst et al. 2010). Of the remaining 151 streams in Maryland where brook trout are found, over half are in the hemlock-rich forest systems of western Garrett County (MDNR 2006). The eastern hellbender (*Cryptobranchus alleganiensis*) and the green salamander (*Aneides aeneus*), both endangered in the state of Maryland, are only found in the rocky, fast-moving waters of Garrett County's hemlock forests (MDNR 2016). Aquatic macroinvertebrates, used as indicators of stream health, are more diverse in hemlock forests: The average number of aquatic macroinvertebrate taxa found in hemlock streams is 37% greater than that found in deciduous hardwood streams (Snyder et al. 2002, Willacker et al. 2009).

ECONOMIC SIGNIFICANCE

Eastern hemlock is not a particularly valuable timber species. Hemlock wood is relatively lightweight, coarse-grained, and moderately hard, but it is often subject to splitting from windshake (USDA Forest Service 1970, USDA NRCS 2002). In the 18th and early 19th centuries, the tree was sought after for its tannin-rich bark, used by the leather industry as part of the tanning process. Trees were often felled only for their bark; the trees were cut, stripped, and the heartwood was left to rot. However, even at the height of the state's leather-tanning industry, most Maryland tanneries opted to use the similarly tannin-rich and more common chestnut oak (*Quercus montana*) (Bradstreet 1866). Today, hemlock is used by the pulp and paper industry and its lumber is used for barn siding and other specialty uses (USDA Forest Service 1970, USDA NRCS 2002).

Although its value as a timber species is minimal, eastern hemlock has significant aesthetic and recreational value. Hemlock is planted regularly as a popular and low-maintenance ornamental tree, recognized for its beauty and ease of care (Quimby et al. 1996). In western Maryland the pristine eastern hemlock forests of parks like Swallow Falls State Park and New Germany State Park are a major draw for outdoor enthusiasts. The hemlock-lined shores of Deep Creek Lake and the surrounding area attract millions of visitors to Garrett County each year as part of a booming tourism industry that employs one in five people in the county and brings in more than \$49 million in county tax revenue (Garrett County 2009).

THREATS TO HEMLOCK HEALTH

HEMLOCK WOOLLY ADELGID

The health of Maryland's hemlock forests and their associated ecosystems are being threatened by the hemlock woolly adelgid (HWA) (Orwig and Foster 1998, Jenkins et al. 1999, Stadler et al. 2005, Eschtruth et al. 2006, Letheren et al. 2017). This small aphid-like insect was first described on the west coast of North America in the 1920's, where it affects western hemlock (*Tsuga heterophylla*). Genetic evidence, along with a wide variety of existing natural predators, suggest that populations of HWA in the Pacific Northwest are the result of natural dispersal; these populations have been present and naturalized in North America for thousands of years (Havill et al. 2016).

The genotype currently present in eastern North America originated in southern Japan and was probably introduced unintentionally with ornamental Japanese hemlocks as early as 1911 (Stoetzel 2002, Havill et al. 2006). The first record of HWA on the east coast was officially reported in Richmond, Virginia in 1951. At first the insect spread slowly, but by the 1980's HWA had made its way to Maryland. Landscape hemlocks in the Baltimore-Washington area were infested in the late 1980's and natural stands in the

area became infested by 1990. The infestation steadily moved westward and native stands of hemlock in Frederick and Washington Counties became infested in the early to mid-1990's. Infested hemlocks in Allegany County were found in 1999, and the first infested hemlock in Garrett County was found in December 2001. By the end of 2001, HWA had spread through central Maryland, western Maryland, and Maryland's Eastern Shore, impacting all major hemlock forests in the state. Since 2012, HWA has been present in all Maryland counties with eastern hemlock populations (Figure 4).

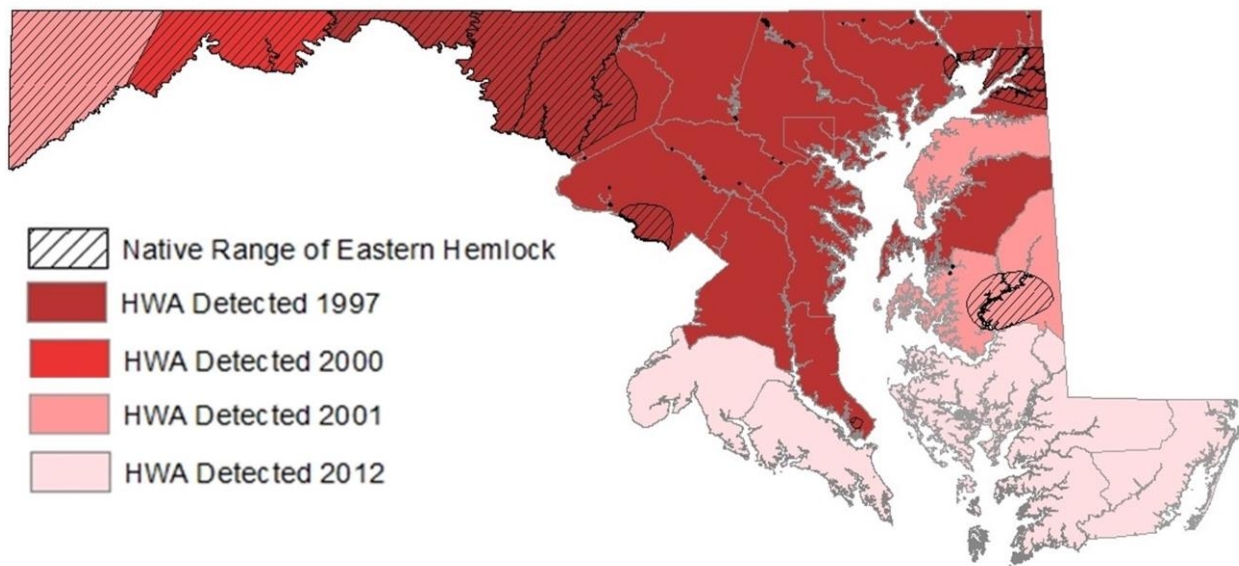


FIGURE 4: Spread of hemlock wooly adelgid through Maryland counties from 1997-2012. Detections in counties without significant eastern hemlock populations represent infestations of singular or isolated ornamental trees (MDA 2020; USGS 2020).

Heavy infestations of HWA result in tree health decline and eventual mortality. Decline is caused by slow depletion of the tree's starch reserves from the continued feeding processes of high adelgid populations. It has also been hypothesized that extensive HWA feeding can elicit a hypersensitive response in eastern hemlock, stimulating a tree-wide necrotic effect (Radville et al. 2011).

Mortality is usually a slow process, taking 4 to 12 years to cause serious decline (McClure 1987, Trotter and Shields 2009, Miller-Pierce et al. 2010). The severity of decline and mortality is often hastened by drought or pests such as elongate hemlock scale and hemlock borer (Raupp et al. 2008). Several stands in Maryland, mostly those which have been infested with HWA for more than 10 years, have experienced extensive decline and some mortality.

HWA hemlock mortality and decline has been most severe in Virginia, New Jersey, Pennsylvania, and Connecticut. In New Jersey, 55% of the state's 26,000 acres of hemlock have been severely impacted (NJDEP 2010). Observations from permanent

plots in Connecticut have seen wide fluctuations in mortality from site to site, but some plots have experienced mortality rates of up to 99% (Small et al. 2005). Continued monitoring sites of HWA infestations in Delaware Water Gap on the New Jersey-Pennsylvania border have recorded a 30% mortality rate in hemlock stands from 1995-2008. Estimates based on HWA levels and new twig growth rates suggest that mortality rates in Delaware Water Gap will have increased to 80% by 2022 without effective management (Evans 2009).

HWA is rapidly spreading throughout the range of eastern hemlock. As of 2022, HWA has colonized more than 50% of eastern hemlock's native range (Figure 5). It is estimated that in the past decade it has spread at a rate of 20-30 km per year. Wind, migrating birds, deer, and humans are factors in both short and long-distance dispersal (Mclure 1990, Turner et al. 2011, Russo et al. 2019). Recent establishments in Michigan and Nova Scotia have also occurred, outside of HWA's contiguous range. HWA has now been detected in 21 states on the east coast, Ontario, and Nova Scotia.

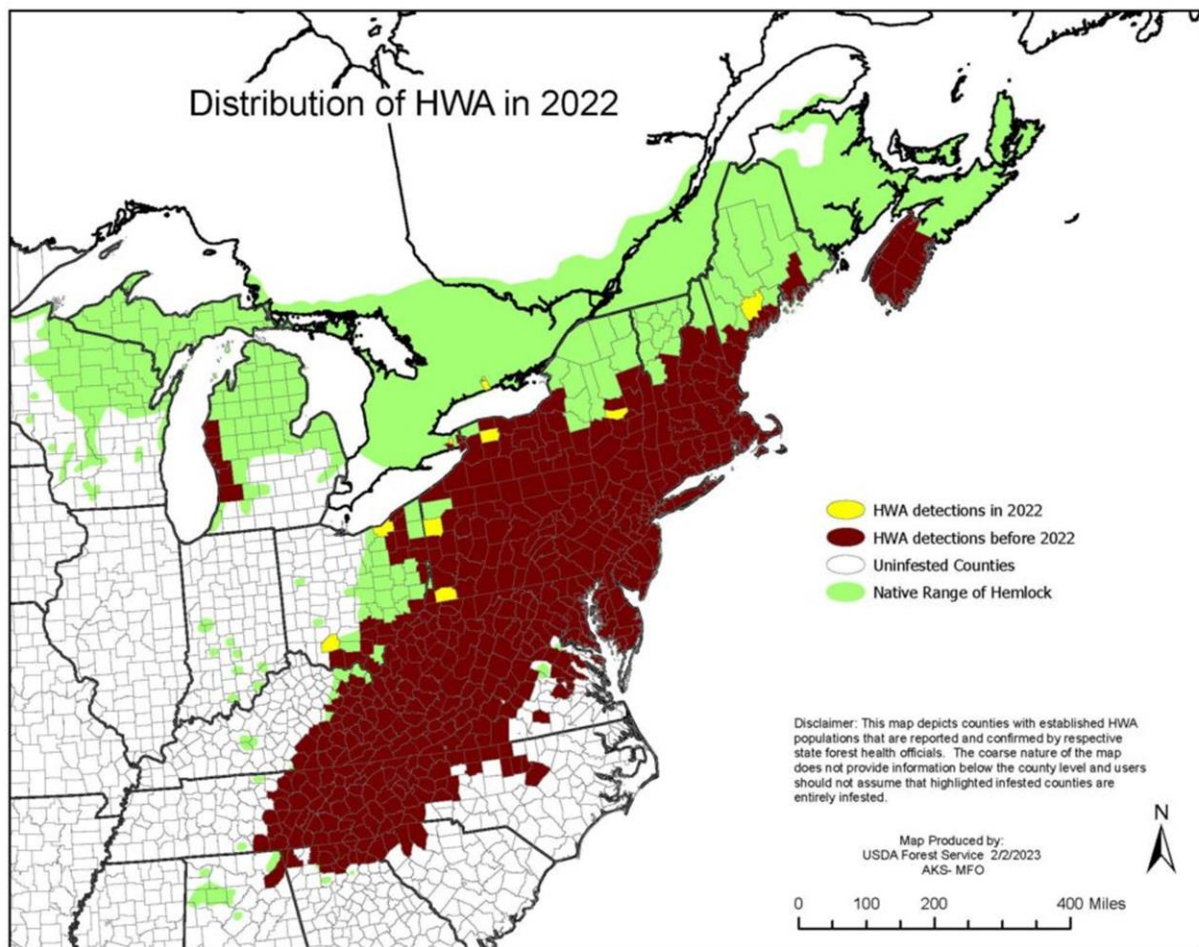


FIGURE 5: Current distribution of hemlock woolly adelgid in the United States and Canada. HWA has infested more than 50% of eastern hemlock's native range (USDA Forest Service 2023).

HEMLOCK WOOLLY ADELGID BIOLOGY

Hemlock woolly adelgid is most easily recognized by the white “woolly” wax it produces on young hemlock twigs (Figure 6). The “wool” is present all year but is most abundant and conspicuous during the spring and fall when egg masses are present (Havill & Footitt 2007, Havill et al. 2016). Most other stages in the life cycle are much harder to see; fully grown adults are only about the size of a period on a printed page.

There are two generations of hemlock woolly adelgid per year, the overwintering “sistens” generation, and the “progrediens” generation in spring. HWA completes most of its development from autumn to early spring (Figure 7).

The life cycle of the hemlock woolly adelgid, like most members of the adelgid family, is very complex. There are two forms of the insect, with each form going through six life stages (egg, four nymphal stages and adult). The following is a simplified version of their life cycle: Overwintering sistens adults lay eggs in April and May under the white woolly mass they produced. Nymphal “crawlers” hatch and settle at the base of hemlock needles within a few days. Attached crawlers will feed and remain attached to the twig through their maturation into 1st generation adults in late May. Wingless adults then lay eggs which hatch by July. The new progrediens crawlers settle on the hemlocks’ new growth and become dormant until October, when they resume feeding and develop during the winter, maturing by spring (Havill & Footitt 2007, Havill et al. 2016).

In North America, the hemlock woolly adelgid does not complete sexual reproduction. In its native range the cycle is even more complex, including a sexually reproducing generation that forms pineapple-shaped galls on tigertail spruce (*Picea torano*) (Havill et al. 2016). There is no suitable host species for HWA’s sexual reproduction stage in North America; all HWA individuals on the continent are parthenogenetic females (Havill et al. 2016). This ability to dramatically increase population by quick asexual reproduction twice a year is part of what makes HWA such a deadly pest.



FIGURE 6: White woolly masses of HWA on a heavily infested hemlock.

Adelgids feed by inserting their tube-like mouthparts into the underside of the base of hemlock needles. As feeding progresses, needles desiccate, turn pale green and drop from the tree. Buds may also die and in heavy infestations crown thinning, dieback of major limbs, and tree mortality are likely to occur (Figures 8,9).

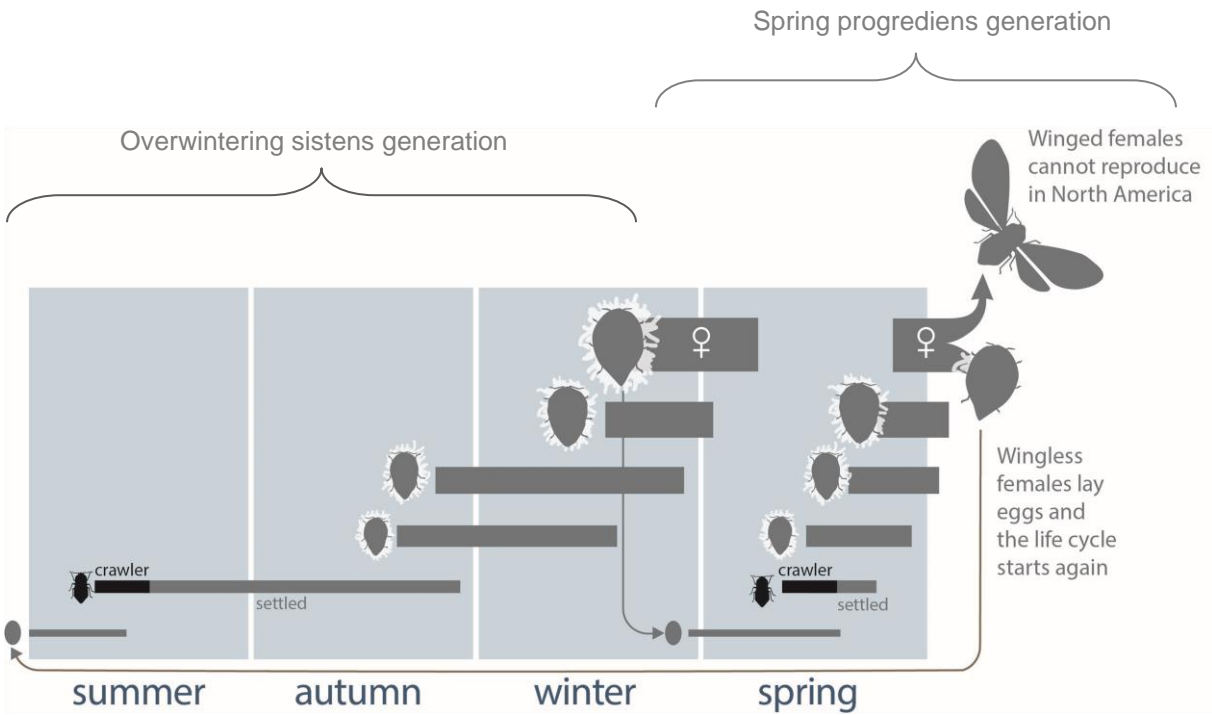


FIGURE 7: Simplified annual life cycle of hemlock wooly adelgid in North America. In native Japan and China, full sexual reproduction occurs (Modified illustration by N. P. Havill and V. D’Amico).



FIGURE 8: Crown thinning from HWA damage on hemlock trees.



FIGURE 9: Mortality of hemlock can occur in as little as 2 years.

ELONGATE HEMLOCK SCALE

Elongate hemlock scale (*Fiorinia externa*) is an armored scale insect that sucks sap from the needles of conifers and causes yellowing and needle drop. In Maryland, this insect has two generations per year. Like HWA, elongate hemlock scale is an introduced pest from Asia. This species was first recorded in New York in 1908, and has since spread to 20 states, as far south as Georgia, north to Maine, and west to Ohio and Michigan (Ferris 1942, Abell & Driesche 2008). However, the highest and most damaging populations of elongate hemlock scale are still centered on New York and surrounding states (USDA Forest Service 2019).

Elongate hemlock scale has a much wider host range than HWA and has been reported feeding on at least 57 host species, including species of hemlock, cedar, fir, pine, spruce, and yew (Abell & Driesche 2008). While not as damaging as HWA, elongate hemlock scale is a serious pest in its own right and can cause hemlock mortality (Raupp et al. 2008). In Maryland, elongate hemlock scale has caused decline at treated sites in the eastern and central regions.

Elongate hemlock scale is often present concurrently with HWA, and interactions between HWA, elongate hemlock scale, and eastern hemlock are surprising; some research suggests that co-occurring infestations benefit hemlock health (Pressier & Elkington 2008). The presence of elongate hemlock scale causes competition for the hemlock food resource, effectively decreasing populations of the more damaging HWA and stopping the more dangerous adelgid from reaching population densities that would cause hemlock mortality (Pressier & Elkington 2008). However, elongate hemlock scale presents a management issue at sites infested with HWA; the most widely used insecticide for HWA control, Imidicloprid, does not successfully control elongate hemlock scale (Raupp et al. 2008). Dinotefuran and horticultural oils are labeled for the control of elongate hemlock scale.

CRYPTOMERIA SCALE

Cryptomeria scale (*Aspidiotus cryptomeriae*) is a very similar armored scale insect to elongate hemlock scale. Cryptomeria scale is also an Asian species first detected in New York, in 1937 (Miller et al. 2005). This insect has the same two-generation life cycle in the state of Maryland, has a wide variety of host plants, and can cause similar needle-drop from excessive feeding. However, cryptomeria scale rarely causes hemlock mortality in forests, and is more of a problem for Christmas tree plantations (Raupp et al. 2008).

NATIVE PEST SPECIES

Eastern hemlock plays host to a suite of native pest arthropods, such as the hemlock looper (*Lambdina fiscellaria*), hemlock borer (*Melanophila fulvoguttata*), and spruce spider mite (*Oligonychus ununguis*). These pests rarely cause hemlock mortality; they are more often stressors that can exacerbate already damaged trees (MFS 2001; PDA 2002; USDA Forest Service 1967). Occasionally, populations can drastically rise and cause serious defoliation. In particular, hemlock looper is a common cause of small-scale hemlock mortality in New England (Maine FS 2001). In Maryland however, these pests almost never reach outbreak levels. Only hemlock borer has caused eastern hemlock mortality in the state, and only at two isolated sites in Garrett and Allegany counties.

Eastern hemlock also has a number of native fungal pests, including several species of *Armillaria* root rot, hemlock tip blight (*Sirococcus tsugae*), and fabrella needle cast (*Fabrella tsugae*) (Brazee & Wick 2011, Penn State Extension 2016). While these fungal pests can be a factor in hemlock death, they are rarely if ever the sole cause of tree decline.

ABIOTIC FACTORS

The shallow root system and soil moisture requirements of eastern hemlock make the tree susceptible to windthrow, fire damage, and drought. Of these, drought is the most serious abiotic stressor of hemlock trees, especially during the seedling stage (Godman & Lancaster 1990). Paleoecological pollen and temperature analyses suggest that, around 5800-6000 years ago, major drought events caused an 80% reduction in hemlock across its North American range (Godman & Lancaster 1990, Oswald and Foster 2011). Hemlock populations did not recover for another 1,000 years, and have never returned to pre-calamity levels.

This historic evidence is particularly disquieting in light of recent climate-temperature increases. In the northeastern United States annual temperatures have increased by an average of 0.14 °F (0.08 °C) per decade in the last century. Current climatic models predict this rate to increase (Hayhoe et al. 2006). It is likely that rising temperatures will cause drought-related stress to eastern hemlock forests, and habitat suitability models suggest that eastern hemlock is one of the top ten tree species in the northeast most likely to be negatively affected by climate change (Iverson et al. 2008).

In addition, cold weather seems to be a major limiting factor for HWA. Lethal temperatures for HWA vary, but winter mortality can be as high as 80% (Paradis et al. 2007, Trotter and Shields 2009). Spread of HWA occurred more slowly in the north (8.1 km / year) than in the southern areas (15.6 km / year) of eastern hemlock's range (Evans & Gregoire 2007). Current northern range expansion has been limited to areas where mean winter temperature is -5°C , the absolute minimum winter temperature is -35°C or lower, or when there are at least 79 days in which the average daily minimum temperature

is below -10°C (Paradis et al. 2007). It is likely that increasing climatic temperatures will allow HWA to continue its northward range expansion (Ellison et al. 2018, Kantola et al. 2019). Already drought-stressed trees being attacked by HWA, along with areas of previously uninfested trees being opened to HWA invasion, spell an alarming future for North America's eastern hemlock forests.

THE HEMLOCK CONSERVATION PLAN

HISTORY, ASSESSMENT, AND RANKING PROCESS

When adelgid populations first moved into much of Maryland in the 1980's and 1990's, there were very few management tools available to stop the spread. Native stands of hemlock, especially in Harford and Frederick Counties, were heavily infested with adelgid and elongate hemlock scale and were vulnerable after several years of drought. By the late 1990's these areas showed significant decline and mortality. In 2003, the Hunting Creek Hemlock Woolly Adelgid Management Team was assembled to address the dead and dying hemlocks along Hunting Creek in Frederick County, especially in Cunningham Falls State Park. A management plan was developed to remove hazard trees near the high use trails in the park and chemically inject hemlocks that were still healthy enough to benefit from treatment. Treatments took place in late 2003, and follow-up assessments took place in 2004 and subsequent years.

The development of new tools for the treatment of HWA, along with the movement of HWA into high value hemlock stands in western Maryland, necessitated development and implementation of this statewide HWA management plan.

In July 2003, a task force was created to assess and prioritize vulnerable hemlock forest stands across Maryland. This multidisciplinary task force was made up of members of the Maryland Department of Agriculture, Maryland Department of Natural Resources, USDA Forest Service, USDI Park Service and other partners. Task force disciplines included entomology, forestry, wildlife management, park and recreational management, fisheries management, agricultural inspectors, geographers and ecologists. The group met to agree on criteria and to begin assessing vulnerability and value of hemlock stands statewide. The criteria used to prioritize each stand was based on the overall hemlock forest ecosystem values arrived at by evaluating fisheries, wildlife, natural heritage, recreational and forestry values. Experts in each of these areas ranked each stand based upon their knowledge of stands in their region of the state, and in their field of expertise according to the questions outlined in Appendix A. Since more than half of the identified stands were in Garrett County, where climate and topography favor the development and perpetuation of hemlock forests, the ranking process also attempted to make sure that representative hemlock stands from diverse areas of the state were included among the top ranked stands.

A list of approximately 75 priority stands were identified and rated, and later further refined to the original “top 50” list of priority hemlock stands throughout the state on which this management plan will concentrate its efforts. This list has been regularly updated and finalized to include only public owned and public use sites which are those eligible for treatment under this plan. Additions to this list must be public owned lands or public use lands and be approved by MD DNR and MDA FPM (Appendix B).

Since 2003, Maryland FPM has identified and mapped over 100 public owned hemlock stands, comprising roughly 19,000 acres of hemlock forest in the state. In these stands, MDA FPM and MD DNR have collectively treated over 124,000 at-risk hemlock trees (Appendix C).

FUNDING

The Maryland Department of Agriculture, Forest Pest Management Section has received special funding from the US Forest Service to develop and implement a statewide hemlock woolly adelgid suppression plan. This funding has helped support HWA control efforts including soil and trunk injections from July 2004 to the present. The US Forest Service has also supported MDA’s HWA monitoring and evaluation activities. The use of biological control agents (as discussed in Treatment Options) has increased and is promising, although many potential species are still in the research evaluation stage. HWA predators that are part of this biocontrol effort are currently supplied by the US Forest Service at no cost to the State.

MONITORING

Evaluating the health of hemlocks and the level of HWA infestations is integral to the successful implementation of a management plan. Since the late-1980’s, MDA’s Forest Pest Management Section has been conducting HWA detection and impact surveys across the State. This Management Plan seeks to solidify those priority stands on which FPM will focus hemlock health and management efforts.

Detection and monitoring are critical components of an Integrated Pest Management plan. Treatment decisions begin with knowing the location and density of the pest. Priority hemlock stands identified in the plan will be annually surveyed to assess HWA populations. These surveys will begin as soon as summer aestivation ends, and the white, woolly masses are evident, usually in early October.

Surveys will classify HWA densities into the following four categories:

None: no adelgids observed.

Light: less than 25% of the trees are infested and most often individual trees have less than 25% of the branches infested.

Moderate: 26-50% of the trees appear to be infested and most often individual trees have less than 50% of the branches infested.

Heavy: more than 50% of the trees are infested and most often the majority of the branches on individual trees are infested.

An assessment of hemlock health in these stands will be conducted simultaneously with the assessment of HWA densities. Tree health information will be reported on a stand level basis in the following categories:

Healthy: Trees appear to be in reasonably good health with less than 10% of the trees showing signs of stress such as: defoliation, needle discoloration, and/or branch tip dieback. Hemlock mortality less than 10% throughout the stand.

Light Decline: Trees appear minimally stressed with many trees showing 11-25% defoliation, needle discoloration and/or branch tip dieback. Larger branch mortality may be present but not frequent on trees within the stand. Hemlock mortality less than 10% throughout the stand.

Moderate Decline: Trees generally appear under stress with most trees showing 26-50% defoliation, needle discoloration and/or tip dieback. Larger branch mortality is relatively common throughout the stand. Hemlock mortality 11-25% throughout the stand.

Severe Decline: Trees appear obviously stressed with most trees showing >50% defoliation, needle discoloration and/or branch tip dieback. Larger branch mortality is common throughout the stand. Hemlock mortality may be more than 25% throughout the stand.

Information from HWA and hemlock health surveys will be entered annually into a stand database. This information will be used to direct additional surveys, public information, and treatment and restoration efforts.

Efficacy Surveys: To determine the efficacy of treatments, surveys will be conducted to determine pre and post HWA levels at a sampling of currently treated hemlock stands each year. A small sample of control and treated trees at these sites will be checked at time of treatment and again one year later. The data collected will be entered into a database managed by MDA FPM.

Winter Mortality Surveys: In order to determine HWA population health and inform yearly treatments, winter mortality surveys of the sistens generation are completed after the coldest part of winter. Recovery of the progrediens generation is assessed in late May/early June by comparing population levels to surveys of the sistens generation. Mortality surveys are completed at sites that have not been chemically treated.

TREATMENT OPTIONS

The selection of treatment options for landscape or forest areas will be based upon HWA population levels, hemlock health, access to the trees/stand and proximity to sensitive riparian areas. The decision to treat a stand and its inclusion in this plan is based upon management objectives and the aesthetic, wildlife, recreation, fishery, forestry, and natural heritage values of the stand.

There are currently no proven methods available to suppress HWA in a large-scale forest setting. However, FPM has been able to treat significant sized areas or parts of stands over the years by efficiently using methods which are available for individual tree treatment or treatment of groups of trees. Current insecticide treatment options include the use of foliar sprays or systemic insecticides. Foliar sprays involve the application of horticultural oil or insecticidal soap via hydraulic sprayers and are limited to trees where access is possible by truck mounted equipment and areas where insecticide drift would not contaminate streams and lakes. Systemic insecticides can be applied either through soil injections, soil applied tablets, soil drenches, trunk sprays, or stem injections. Although the various types of soil treatments have proven to be the most effective method of systemic applications, stem injections are performed for hemlocks growing within 50 feet of open waterways.

Treatment options for hemlocks in the landscape are much different than those available for forest situations (Table 1). Easier access for application equipment and lack of sensitive riparian areas allow for a wider range of treatments in the landscape environment.

LANDSCAPE TREE TREATMENT OPTIONS: Options for trees or parts of stands that are easily accessible AND do not have environmentally sensitive areas (such as streams) nearby:	FOREST STAND TREE TREATMENT OPTIONS Options for stands that are inaccessible or have environmentally sensitive areas nearby:
Cover sprays with insecticidal soap, dormant oil or horticultural oil	Trunk injection with imidacloprid (when environmentally sensitive areas are an issue).
Cover sprays with contact or foliar absorbed insecticides	Soil injection with imidacloprid
Trunk injection with imidacloprid	Soil drench with imidacloprid
Soil injection with imidacloprid	Imidacloprid tablets applied in soil
Soil drench with imidacloprid	Trunk sprays with Dinotefuran (In areas affected with both HWA and Elongate Hemlock Scale)
Trunk sprays with Dinotefuran (In areas affected with both HWA and Elongate Hemlock Scale)	Biological control: release of natural enemies as they become available

TABLE 1: Available treatment options for landscape trees and forested areas. Methods for available options are detailed below.

The most widely used and effective systemic insecticide for HWA is imidacloprid. Various formulations of imidacloprid are available depending on the method of application and equipment to be used to deliver the product. Treatments with imidacloprid are normally done in the early spring or late fall when there is adequate soil moisture present. Systemic insecticides are translocated by the tree up to the crown where the pest is feeding, and control usually occurs within 2-6 months. Systemic insecticides can be injected into the soil around the base of the tree, injected into the trunk of the infested hemlock, or sprayed on to the trunk of an infested tree. Trunk injections are not recommended on trees less than 4" in diameter. Soil injections and trunk sprays are used according to the label and should only be used around trees that are a safe distance from water sources.

Studies on the effects of imidacloprid treatments on non-target arthropods in a terrestrial setting have shown that treatments can cause decline (Dilling et al. 2009). However, the pesticide only negatively affects a small number of hemlock-associated arthropods that feed directly on eastern hemlock, and significant declines in these organisms are only observed in plots treated with the soil drench method. There is also evidence to suggest that populations of nontarget organisms rebound after a year from treatment and, in some cases, treatments may increase species diversity (Hakeem 2008, Kung et al. 2015, Turcotte 2016).

HWA population densities often fluctuate normally as a result of two generations per year, declining tree vigor caused by heavy adelgid infestations, and/or other variables such as drought and other insects. Extreme cold winter temperature will also impact adelgid survival. As such, final treatment decisions are made near the time of treatment to identify the need and specific trees to be treated.

Ultimately, treatment decisions will be made considering numerous factors including rank, infestation level, tree health, available treatments options, funding and likelihood of success.

FOLIAR SPRAYS AND CHEMICAL TREATMENTS

COVER SPRAYS

Individual hemlocks or small groups of landscape trees greater than 50' from sensitive areas or streams can be treated with insecticides using ground equipment, such as mist blowers or hydraulic sprayers. The use of this ground equipment limits the selection of this option to areas with good road access adjacent to the trees needing treatment, such as parking lots or RV camping areas in State Parks. The insecticide, as well as the equipment used, will be site specific and dependent upon tree size, location and health, HWA population levels and time of year. Dormant oil, horticultural oil,

insecticidal soap or foliar absorbed insecticides can be used as cover sprays. The application of any of these insecticides will follow EPA-approved label guidelines.

Dormant Oil: This option will be used on individual trees or small groups of trees <30' in height. Dormant oils suffocate adelgids so must be applied directly to the insect when they are immobile. Dormant oils are applied during the 'dormant' season for most insects, from November to March. Although HWA are active during this time, it is still the appropriate time for dormant oil treatment of HWA.

Horticultural Oil and Insecticidal Soap: The selection and application of horticultural oil will follow the same guidelines as dormant oil, with the exception of time of year for application. These oils are used when temperatures are warmer, and will be used from April through June, and September.

Foliar Absorbed Insecticides: The use of foliar absorbed insecticides is restricted by the proximity of the hemlocks to open water. While cover sprays using registered insecticides such as abamectin and imidacloprid are very effective in reducing HWA populations, they will be used only when there is sufficient distance from water, and will closely follow label restrictions. The timing for use of cover sprays with insecticides is during the season when there are immature or unprotected life stages; usually from July through October.

SOIL TREATMENTS

Soil treatments eliminate the concern for drift of insecticides from mist blowers or hydraulic sprayers. However, insecticides injected into the soil can move short distances and thus will not be used within 50ft of waterways. Soil treatments have many advantages: they can be used on large trees with canopies beyond the reach of ground application equipment, the chemical is absorbed through the roots, and control may extend 5 to 7 years after application. The distribution and transport of the insecticide within a tree is affected by its health; trees under drought stress, with needle loss and dieback may not effectively transport the chemical. As compared to trunk injections, soil treatments have the advantage of not wounding the tree.

Soil Injection: A liquid flowable insecticide formulation of imidacloprid (e.g. Imidacloprid 2F) applied using a Kioritz injector, EZ-Ject soil injector, or backpack soil injector around the base of infested hemlocks will be the treatment option of choice for stands of hemlocks at least 50ft away from water. Individual trees or small groups of trees that are 50ft or more away from streams will be treated using soil injection. Larger stands will be treated in increments over time using this method.

Tablets: Imidacloprid tablets (i.e. CoreTect) will be applied into the soil around the base of trees at a rate of 2 tablets per inch DBH. These can be used in the same areas as soil injections but have the advantage of ease of application and less equipment to carry, which is useful in hard to reach or long hike areas. Tablets will be used at a rate of

one tablet/seedling during restoration plantings to give newly planted seedlings protection against HWA.

Soil Drench: A liquid flowable insecticide formulation of imidacloprid (e.g. Imidacloprid 2F) may also be applied using a soil drench method to treat hemlock shrubs or saplings. These treatments consist of uniformly applying the dosage in no less than 10 gallons of water per 1000 square feet as a drench and targeting the root zone. Soil drench methods would be used in areas where protecting hemlock regeneration is important.

TRUNK INJECTION

Direct tree trunk injections will be the treatment of choice for trees or groups of trees less than 50ft from water. Treatments will be conducted in the spring and fall. Treatments will utilize a formulation of imidacloprid (i.e. IMA-jet) in conjunction with the Arborjet Tree IV or F12 series systems.

TRUNK SPRAY

Dinotefuran (i.e. Safari) can be used as soil drench, a soil injection (1 oz mix per inch DBH), or as a trunk spray (2 oz mix per inch DBH). It has a quick knockdown effect against HWA and is also effective against the elongate hemlock scale (Cowles & Lagalante 2009, Cowles 2010). However, dinotefuran does not have the same long-lasting effect of Imidacloprid; treatments are only effective for two years (Cowles & Lagalante 2009). A mixture of imidacloprid and dinotefuran has been used as a basal trunk spray in NY, and dinotefuran is currently being incorporated into treatments in MD in areas where elongate hemlock scale is damaging trees in conjunction with HWA.

BIOLOGICAL CONTROL

The ultimate control and management of HWA will involve the long-term regulation of populations utilizing biological control agents. Research by Crandall et al. 2022 indicates that HWA in the Pacific Northwest is more strongly regulated by native predators than innate host resistance. University and federal researchers have investigated several species of predatory beetles for biocontrol, and since the late 1990's there have been numerous experimental releases. These releases are still being investigated, and Maryland has participated in evaluating the effectiveness of using these biocontrol agents at several locations over the past 20+ years. Biocontrol agents can play an important role in the regulation of HWA populations, but because of the time needed for evaluation and establishment they should not be looked at as a short-term control measure. A map of historic biocontrol releases from 1999-2022 is included in Appendix D.

FPM will assist with wild collections of HWA predators both within and outside of Maryland, release predators to establish new sites and augment old sites, monitor predator populations at release sites, and attempt to determine efficacy of biological control efforts as part of this plan. Predator release and monitoring data will be entered

into the web-based HWA Predator database maintained by Virginia Tech and funded by USFS. As part of this plan, as biological control agents are evaluated and approved for release by APHIS (e.g. species of Coccinellid beetles, Derodontid beetles, and *Leucotaraxis* flies) they will be considered for release in the state of Maryland.

PREDATORS CONSIDERED FOR RELEASE

Sasajiscymnus tsugae: This Coccinellid beetle is a voracious predator of all life stages of HWA and was the first predator approved for release in the United States (Cheah et al. 2005). Since its approval and initial release in 1995, more than 3 million *S. tsugae* (formally known as *Pseudoscymnus tsugae*) have been released in the United States (Grant 2008, Salom et al. 2008, Mayfield et al. 2023b). This species, native to Japan, has been released in several locations in Maryland from 1999 to 2005. 20,410 beetles were released in the state, and populations have been recovered. While cooperators in New England have seen some success with this beetle (Cheah 2021), MDA has seen minimal establishment. MDA FPM will continue to survey for beetle presence. No additional releases are proposed at this time.

Laricobius nigrinus: This Derodontid beetle, native to northwest US and British Columbia, is one of the most important species for HWA biocontrol. Approved for release in 2000, *L. nigrinus* is an avid predator of HWA eggs; ovisac disturbance and predation by *L. nigrinus* can be as high as 80% in some cases (Mausel et al. 2010, Jubb 2019), although 30-60% disturbance is more common (Mausel et al. 2008, Mayfield et al. 2015, Jubb et al. 2020). In 2003, MDA and Virginia Tech released *L. nigrinus* near Frostburg, and since then it has been released at many sites in the state. By 2022, MDA FPM had released 34,653 *L. nigrinus* in the state. Established reproducing populations are now found at several locations in Maryland, and redistribution efforts from established populations are ongoing. Additional releases, monitoring efforts, and efficacy surveys will be proposed as part of this plan.

Scymnus sinuanodulus is a Coccinellid beetle from China that was approved for release in 2004 (Salom et al. 2008). Two releases were made in Maryland between 2005 and 2006, with a total of 945 beetles released. To date, there has been no recovery of this organism in the state. No additional releases are proposed.

Laricobius osakensis: In 2010 this Derodontid beetle, native to Japan, was approved for HWA biocontrol in the United States (Lamb et al. 2011). In predation studies, *L. osakensis* was shown to feed on more HWA ovisacs than *L. nigrinus*, and hybridization experiments suggest *L. osakensis* is far less likely to hybridize with native *L. rubidus* than *L. nigrinus* (Lamb et al. 2011, Viera et al. 2012). MDA is cooperating with the USFS and Virginia Tech University to evaluate the ability of this beetle to become established and reduce HWA populations. By 2022, 6,475 *L. osakensis* individuals have been released at five sites in the state, with hopes of releases at several more. Releases, monitoring, and efficacy surveys are proposed for this plan.

Scymnus coniferarum is a Coccinellid beetle native to the western US which was approved for release in the eastern US in 2012 (USDA 2012). In 2015, 105 *S. coniferarum* individuals were released at one site in Maryland. While *S. coniferarum* is a voracious predator of HWA in the west, research suggests that *S. coniferarum* may rely on multiple adelgid species, including native pine adelgids, to reproduce and establish in the eastern United States (Darr et al. 2018). No recovery for this species has been found in Maryland, and no additional releases are proposed.

Scymnus camptodromus is a Coccinellid beetle from China undergoing evaluation. This species is approved for release from quarantine but has not yet been field released (Montgomery et al. 2011, Limbu et al. 2015). In HWA's native range, *S. camptodromus* is often the most abundant predator. Unlike some other predators of HWA, *S. camptodromus* eggs go into diapause after being laid. While this behavior makes the organism highly synchronized with HWA's life cycle and helps it survive cold-winter temperatures, it also drastically increases the time it takes for research and evaluation to occur (Montgomery et al. 2011, Limbu et al. 2015). No field releases in MD have yet occurred.

Leucotaraxis argenticollis and **Leucotaraxis piniperda** are two species of predatory Chamaemyiid silver flies native to the west coast of the US. *L. argenticollis* and *L. piniperda* are important predators of HWA on the west coast and have shown potential in unique biological control of HWA; unlike other predators who do much of their feeding on the winter sistens generation, *Leucotaraxis* flies may be able to target both yearly generations of HWA, especially the spring progridiens generation (Ross et al. 2011, Motley et al. 2017, Crandall et al. 2020). Experimental releases in partnership with USFS and VA Tech were conducted in 2022. Additional releases, monitoring efforts, and efficacy surveys are proposed as part of this plan.

FIELD INSECTARIES

Part of MDA's biological control plan includes establishment of insectaries to supplement out-of-state collections and reared releases of biological control organisms. In 2004, MDA established its first insectary at Rocky Gap State Park, using *L. nigrinus* beetles gathered in situ from the Pacific Northwest and lab-reared beetles from Virginia Tech University. Thanks to a long-standing collaborative effort between MDA FPM and the US Forest Service's Hemlock Woolly Adelgid Initiative, Rocky Gap State Park has become one of the most successful sites on the east coast for establishment of this biological control. Since 2004, the Rocky Gap insectary has produced thousands of *L. nigrinus* beetles that have been released across the east coast. From 2020-2023 this multi-state cooperative project has moved *L. nigrinus* beetles to imperiled hemlock forests in Maine, New Hampshire, Rhode Island, Ohio, Pennsylvania, Maryland, and West Virginia, including sites in National Parks.

In 2016 a new insectary was established at Big Run State Park by planting 100 hemlock seedlings received from PA DCNR Penn Nursery near a row of established

hemlocks. In 2018, 275 *L. nigrinus* from the Rocky Gap insectary were introduced to this new plot. Augmentation of *L. nigrinus* populations to the insectary began in fall of 2019, and recovery of beetles has been observed in 2023.

MDA FPM will continue to establish healthy populations of *L. nigrinus* from these founding insectaries and will supply insects to surrounding states for their own biological control efforts. In addition to increasing the viability of *L. nigrinus* populations, this work will allow rearing laboratories to focus research and development on new biocontrol organisms.

SILVICULTURE AND GENETIC RESISTANCE

Of the eight extant species in genus *Tsuga* the eastern hemlock is the most susceptible to HWA and the least genetically diverse (Potter et al. 2008, Bentz et al. 2008, Oten et al. 2014, Letheren et al. 2017). Phylogenetic analyses have shown that eastern hemlock is fairly unique among its genus; even the Carolina hemlock (*Tsuga caroliniana*), which completely overlaps the southern range of eastern hemlock, is more closely related to Asian *Tsuga* species (Havill et al. 2008). While the Carolina hemlock is also being seriously threatened by HWA, its genetic lineage allows for resistant hybrids crossed with Asian species to be bred. Research at USDA's South Farm in Beltsville, Maryland suggests that some of these natural hybrids between *T. chinensis* and *T. caroliniana* show good survival and resistance to HWA. Eastern hemlock, however, cannot be crossed with resistant members of its genus (Bentz et al. 2008). The western species, *T. heterophylla* and *T. mertensiana*, show some resistance to HWA but they do not grow well on the east coast, suggesting that much of their success against HWA comes from the assemblage of associated native predators (Jetton et al. 2008, Crandall et al. 2022).

While this bodes well for the eventual success of establishing a host of classical biological controls, the fact remains that hybridization of eastern hemlock to protect against HWA is highly unlikely. However, isolated instances of naturally HWA-resistant eastern hemlock have been found among dead and dying trees in Connecticut, New Jersey, Pennsylvania, and Maryland (Ingwell et al. 2009, Kinahan et al. 2020). These "bulletproof" stands may offer another avenue for management of HWA.

In 2015, a restoration plot at Cunningham Falls State Park included plantings of eastern hemlocks from the "bulletproof" stand in New Jersey. This plot was inoculated with HWA in 2017, and research into the health of these trees is ongoing. Current research indicates that these trees are resistant to both HWA and elongate hemlock scale (Kinahan et al. 2020). MDA will continue monitoring this plot for HWA resistance.

Light availability plays a major role in HWA mortality and hemlock decline, with increased light availability improving hemlock growth and tolerance to HWA infestation (Sussky and Elkington 2015, Mayfield and Jetton 2020, Mayfield et al. 2023a). Selective cutting to create canopy gaps, as outlined in Mayfield et al. 2023a may be a potential

strategy to preserve individual high-value trees or produce high-quality hedges for biocontrol establishment.

From 2016-2019, MDA FPM received 2,200 eastern hemlock seedlings from PA DCNR Penn Nursery produced using Maryland seed stock. In partnership with MD Department of Natural Resources, these seedlings are used in hemlock restoration projects at critical areas throughout the state. Future restoration plots are chosen in close partnership with MDNR. Areas with significant loss of hemlock resource are identified by MDNR and MDA FPM staff for potential restoration projects. Restoration tree plantings are mapped using ArcGIS Field Maps.

PRESERVATION OF GENETIC MATERIAL

In light of the real threat of extirpation and extinction of eastern and Carolina hemlock, the US Forest Service has partnered with Camcore, a non-profit international tree breeding organization, to preserve hemlock genetic material. Seeds of eastern and Carolina hemlock have been collected throughout the plants' native ranges to be stored in long-term seed banks. In addition, plantings of seeds from North American eastern and Carolina hemlock across 78 native populations have been established in Chile, southern Brazil, and Arkansas to act as seed reserves that are geographically protected from HWA (Jetton et al. 2011, Camcore 2019). If HWA is ever thoroughly controlled, these banks of genetic information will be invaluable for healthy and diverse restoration plantings.

MDA FPM conducts yearly surveys of treated hemlock sites for viable hemlock cones. Cones are harvested and prepared as outlined in Jetton et al. 2007. This supply of Maryland hemlock genetic information is provided to PA DCNR Penn Nursery for continued seedling production so that state restoration projects can continue with Maryland native seedlings. MDA also provides collected seed for Camcore's seed bank project, to ensure the state's hemlock genetic material is preserved.

RESEARCH AND PARTNERSHIPS

MDA-FPM will continue its longstanding commitments with its cooperators to assist with research on efficacy, winter mortality, hemlock resistance, regeneration, new biological control agents, and explore new treatment options as they become available.

MDA FPM collaborates with the MD Department of Natural Resources (DNR) and the Maryland Conservation Corps on fall and spring projects where hemlock trees on state park lands are treated. MD DNR Forest Service & Park Service also collaborate on other treatments and in restoration plantings. MDA FPM has collaborated with The Nature Conservancy and Maryland Ornithological Society to treat hemlocks on their properties to ensure larger corridors of hemlocks and their habitat are conserved.

APPENDIX A: QUESTIONS USED TO ASSESS AND RANK TREATMENT AREAS

WILDLIFE, HABITAT, AND ECOSYSTEM SERVICES	RECREATION AND CULTURAL HERITAGE	ECONOMIC IMPACT	POTENTIAL FOR TREATMENT SUCCESS
Is there significant or unique fisheries habitat within or adjacent to the stand?	Is this site in close proximity to other sites that have significant natural heritage value?	Is there significant forestry value in this stand, including, but not limited to wood products?	Is there significant hemlock regeneration in this stand to sustain a healthy hemlock forest?
Do the hemlocks in this stand contribute significantly to the water quality of the stream?	Are there significant recreation activities dependent upon the health of hemlocks at this site?	Would the loss of this stand have a significant economic impact on private landowners?	Is the current vitality of this stand at a level where management of HWA will be effective?
Are the riparian areas of this stand dependent upon the hemlocks and are they significant or unique?	Are there significant aesthetic values at this site dependent upon healthy hemlocks?	Is this stand in close proximity to other stands that have significant forestry value?	
Is this site in close proximity to other sites that have significant fisheries value?	Are there significant historical or cultural heritage issues associated with the hemlocks at this site?	Would the loss or decline of hemlocks at this site have a significant economic impact and public use of the park or forest.	
Is there significant wildlife habitat in this stand and is it dependent upon the health of the hemlocks?	Would the decline or mortality of hemlocks at this site impact public safety?		
Would the loss of hemlocks in this stand impact the wildlife in the area?	Is this stand in or adjacent to a designated Wildlands Area?		
Is this site in close proximity to other sites that have significant wildlife value?	Is this site in close proximity to other sites that have significant recreational value?		
Are there sensitive, threatened or endangered species in this stand that are dependent upon healthy hemlocks?			
Would the loss of hemlocks in this stand alter conditions so that they would become unfavorable to sensitive, threatened or endangered species?			

APPENDIX B: MARYLAND HEMLOCK PRIORITY STANDS

Stand Number	Stand Name	County	Acres	Public Facility
ABD1	SUSQUEHANNA SP	HARFORD	1.15	SUSQUEHANNA SP
ABD2	SUSQUEHANNA SP	HARFORD	1.00	SUSQUEHANNA SP
ACC4A	LITTLE BEAR CREEK	GARRETT	167.48	SAVAGE RIVER SF
ACC4B	LITTLE BEAR CREEK	GARRETT	43.66	SAVAGE RIVER SF
ART2	DEEP RUN	ALLEGANY	175.11	GREEN RIDGE SF
ART3	FIFTEEN MILE CREEK	ALLEGANY	103.82	GREEN RIDGE SF
ART4	GRSF	ALLEGANY	518.16	GREEN RIDGE SF
AVI2	WOLF SWAMP	GARRETT	212.87	SAVAGE RIVER SF
AVI3	UPPER POPLAR LICK	GARRETT	314.10	SAVAGE RIVER SF
AVI4	BLUE LICK AREA	GARRETT	752.29	SAVAGE RIVER SF
AVI5	MUDLICK	GARRETT	405.97	SAVAGE RIVER SF
BAR10A	BEAR PEN	GARRETT	359.53	SAVAGE RIVER SF
BAR10B	BEAR PEN	GARRETT	71.40	SAVAGE RIVER SF
BAR12,13	SAVAGE RIVER	GARRETT	832.15	SAVAGE RIVER SF
BAR14	PINE SWAMP RUN	GARRETT	227.24	SAVAGE RIVER SF
BAR1A	POPLAR LICK	GARRETT	735.89	SAVAGE RIVER SF
BAR1B	POPLAR LICK	GARRETT	104.26	SAVAGE RIVER SF
BAR3	ELK LICK RUN	GARRETT	311.75	SAVAGE RIVER SF
BAR6	LITTLE SAVAGE RIVER	GARRETT	384.58	SAVAGE RIVER SF
BAR7	LITTLE SAVAGE RIVER	GARRETT	173.75	SAVAGE RIVER SF
BEA1A	STONEY FOREST DEMONSTRATION AREA	HARFORD	28.08	STONEY FOREST DEMONSTRATION AREA
BEA1B	STONEY FOREST DEMONSTRATION AREA	HARFORD	1.32	
BEL1	BEL1 COMPLEX	ALLEGANY	135.29	SIDELING HILL WMA
BEL2	SIDELING HILL WMA	ALLEGANY	83.01	SIDELING HILL WMA
BET1	LLOYD CREEK	KENT	3.47	
BGP1	FORT FREDERICK SP	WASHINGTON	6.66	FORT FREDERICK SP
BIT5	POPLAR LICK WATERSHED (PART)	GARRETT	192.04	SAVAGE RIVER SF
BIT7	BIG RUN	GARRETT	242.45	SAVAGE RIVER SF
BIT8	BIG RUN	GARRETT	141.52	SAVAGE RIVER SF
BIT9	BIG RUN	GARRETT	84.23	SAVAGE RIVER SF
BIT11	BIG RUN	GARRETT	209.76	SAVAGE RIVER SF
BIT12	BIG RUN	GARRETT	126.76	SAVAGE RIVER SF
BIT13	MONROE RUN	GARRETT	257.01	SAVAGE RIVER SF
BIT14	BIG RUN ST PARK	GARRETT	276.21	BIG RUN SP, SAVAGE RIVER SF
BIT16	DRY RUN	GARRETT	166.03	SAVAGE RIVER SF
BIT17,18,21A	MIDDLE FORK DRAINAGE	GARRETT	241.64	SAVAGE RIVER SF
BIT17,18,21B	MIDDLE FORK DRAINAGE	GARRETT	6.54	SAVAGE RIVER SF
BIT17,18,21C	MIDDLE FORK DRAINAGE	GARRETT	292.96	SAVAGE RIVER SF
BIT22	MONROE RUN	GARRETT	207.55	SAVAGE RIVER SF
BIT23	CUNNINGHAM WMA	GARRETT	6.335189	CUNNINGHAM SWAMP WMA
BIT24	WESTERN MD 4H CENTER	GARRETT	5.100243	UNIVERSITY OF MARYLAND
BLU1	HUNTING CREEK	FREDERICK	280.68	CUNNINGHAM FALLS SP
BLU2	LITTLE OWENS CR	FREDERICK	34.70	
BUC1	SUGARLOAF 1	FREDERICK	5.68	SUGARLOAF MOUNTAIN
BUC2	SUGARLOAF 2	FREDERICK	0.95	SUGARLOAF MOUNTAIN
BUC3	MONOCACY NBP	FREDERICK	12.35	
CAT1,2A	LITTLE HUNTING CREEK	FREDERICK	0.78	CUNNINGHAM FALLS SP
CAT1,2B	LITTLE HUNTING CREEK	FREDERICK	1.33	

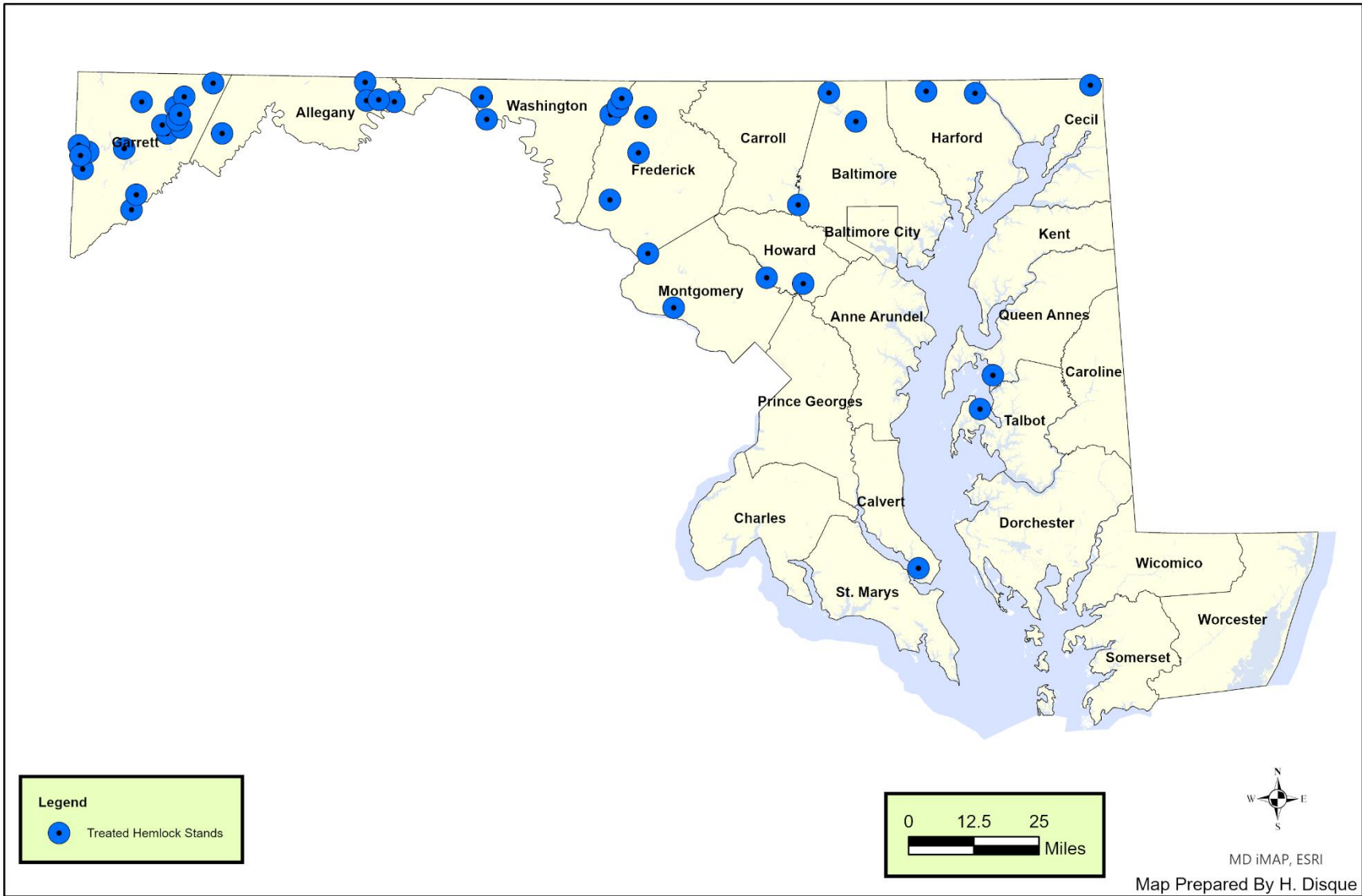
CAT3,4,5	FREDERICK CITY WATERSHED/FISHING CREEK	FREDERICK	276.90	FREDERICK CITY WATERSHED
CAT6	BUZZARD BRANCH	FREDERICK	12.39	
CAT7	PRYORDS ORCHARD	FREDERICK	5.74	
CAT8	MANOR AREA CFSP	FREDERICK	0.19	CUNNINGHAM FALLS SP
CHE1	LICKING CREEK	WASHINGTON	194.11	LICKING CREEK (TNC)
CHS1	ISLAND CREEK	QUEEN ANNE'S	0.83	
CLA1	PATUXENT RIVER	HOWARD	32.45	MIDDLE PATUXENT ENVIRONMENTAL AREA
DAV1 1587	KEMPTON BOG	GARRETT	183.37	
DAV2 1559A	RED OAK RUN	GARRETT	285.86	
DAV3 1559B	RED OAK RUN	GARRETT	80.39	
DAV4 1592	N BRANCH POTOMAC KEMPTON	GARRETT	10.06	
DEE1	LOSTLAND RUN 2	GARRETT	44.65	POTOMAC SF
DEE2	HAMMEL GLADE SWAMP	GARRETT	139.28	HAMMEL GLADE PRESERVE (TNC)
DEL1	BROAD CREEK	HARFORD	101.60	BROAD CREEK MEMORIAL SCOUT CAMP AND EXELON
EAR1	STONEY POINT 1 (BOHEMIA RIVER)	CECIL	2.95	
EAR2	STONEY POINT 1 (BOHEMIA RIVER)	CECIL	2.08	
EAS1	PICKERING CREEK	TALBOT	10.57	CHESAPEAKE AUDUBON SOCIETY - PICKERING CREEK AUDUBON CENTER
EVC1	ROCKY GAP GORGE	ALLEGANY	144.94	ROCKY GAP SP
FGR1	DEER CREEK	HARFORD	11.14	ROCKS SP
FGR2	DEER CREEK	HARFORD	3.27	ROCKS SP
FGR3A	KILGORE FALLS	HARFORD	3.89	ROCKS SP
FGR3B	KILGORE FALLS	HARFORD	0.17	ROCKS SP
FGR4	UREY RD/DEER CREEK	HARFORD	10.57	
FGR5	HILLS GROVE	HARFORD	0.25	ROCKS SP
FIL1 392A	INDIAN LICK	ALLEGANY	101.61	GREEN RIDGE SF
FIL2 392B	INDIAN LICK	ALLEGANY	10.11	
FIL3 205	TOWN CREEK 1	ALLEGANY	38.47	GREEN RIDGE SF
FIL4 288,299 (288, 299, 248B)	TOWN CREEK OLD WILLIAMS ROAD	ALLEGANY	10.00	GREEN RIDGE SF
FIL5 288,299 (288, 299, 248A)	TOWN CREEK OLD WILLIAMS ROAD	ALLEGANY	13.35	GREEN RIDGE SF
FIL6 439,506 (439, 506, 412A)	TOWN CREEK BELLS HILL	ALLEGANY	57.69	GREEN RIDGE SF
FIL7 439,506 (439, 506, 412B)	TOWN CREEK BELLS HILL	ALLEGANY	45.38	GREEN RIDGE SF
FRI1	BUFFALO RUN WATERSHED	GARRETT	244.30	
FRO1	FROSTBURG WATERSHED	GARRETT	808.55	FROSTBURG CITY WATERSHED
FRO2 360	CALLAHAM SWAMP	GARRETT	145.63	SAVAGE RIVER SF
FRO5	FINZEL SWAMP	GARRETT	64.46	FINZEL SWAMP PRESERVE (TNC)
FRO7	CAREY RUN	GARRETT	52.40	CAREY RUN SANCTUARY
FRO8	EVERGREEN	ALLEGANY	2.51	EVERGREEN HERITAGE CENTER
FRV1	YOUGHIOGHENY RIVER KENDALL	GARRETT	121.22	YOUGHIOGHENY RIVER NEA
FRE1	GAMBRILL STATE PARK	FREDERICK	9.84	GAMBRILL STATE PARK
FUN1	GREENBRIER SP	WASHINGTON	0.321	GREENBRIER SP
GER1	LITTLE SENECA CR	MONTGOMERY	0.26	SENECA CREEK SP
GOR1	LOSTLAND RUN 1	GARRETT	373.63	POTOMAC SF
GOR3	LAUREL RUN	GARRETT	209.08	POTOMAC SF
GRA2	PUZZLEY RUN	GARRETT	250.45	SAVAGE RIVER SF
GRA11	AMISH ROAD SWAMP	GARRETT	145.95	SAVAGE RIVER SF
GRA14	NEW GERMANY SP UPPER POPLAR LICK	GARRETT	385.89	NEW GERMANY SP
GRA15	CASSELMAN RIVER BRIDGE SP	GARRETT	3.060743	CASSELMAN RIVER BRIDGE SP
HAR1	CAMP MANIDOKAN	WASHINGTON	0.51	
HAR2	SAW MILL CREEK	WASHINGTON	10.47	

HAR3	HARPERS FERRY RD	WASHINGTON	1.28	
HAR4	BACK RD	WASHINGTON	3.32	
HAV1	ARARAT FARM RD	CECIL	1.65	UNIVERSITY OF MARYLAND
HER1	PRETTYBOY DAM/SOUTH GUNPOWDER	BALTIMORE	5.31	PRETTYBOY WATERSHED
HER2	PRETTYBOY DAM/SOUTH GUNPOWDER	BALTIMORE	0.75	GUNPOWDER FALLS SP
HER3	PRETTYBOY DAM/SOUTH GUNPOWDER	BALTIMORE	4.14	GUNPOWDER FALLS SP
HER4	PRETTYBOY DAM/SOUTH GUNPOWDER	BALTIMORE	6.74	GUNPOWDER FALLS SP
HER5	PRETTYBOY DAM/SOUTH GUNPOWDER	BALTIMORE	4.61	GUNPOWDER FALLS SP
HER6	PRETTYBOY DAM/SOUTH GUNPOWDER	BALTIMORE	12.16	GUNPOWDER FALLS SP
HER7	PRETTYBOY DAM/SOUTH GUNPOWDER	BALTIMORE	12.76	GUNPOWDER FALLS SP
HER8	PRETTYBOY DAM/SOUTH GUNPOWDER	BALTIMORE	0.85	PRETTYBOY WATERSHED
HER9	PRETTYBOY DAM/SOUTH GUNPOWDER	BALTIMORE	1.83	GUNPOWDER FALLS SP
HOB1	MILL CREEK	CAROLINE	2.08	
HOB2	WATTS CREEK	CAROLINE	12.69	
KTZ1	WOLF DEN SHORT RUN	GARRETT	48.71424	WOLF DEN RUN SP
KTZ2	WOLF DEN STATE PARK	GARRETT	12.43489	WOLF DEN RUN SP
KTZ3	WOLF DEN RUN	GARRETT	63.17884	WOLF DEN RUN SP
LIN1	PRETTYBOY WATERSHED	BALTIMORE	41.84	PRETTYBOY WATERSHED
LIN2	PRETTYBOY WATERSHED	BALTIMORE	100.98	PRETTYBOY WATERSHED
LIN3	PRETTYBOY WATERSHED	BALTIMORE	7.83	PRETTYBOY WATERSHED
LIN4	PRETTYBOY WATERSHED	BALTIMORE	38.41	PRETTYBOY WATERSHED
LON3	DANS MNTN STATE PARK	ALLEGANY	69.72	DANS MOUNTAIN SP
MCH10	DEEP CREEK LAKE SP	GARRETT	18.18	DEEP CREEK LAKE SP
MCH11	DEEP CREEK LAKE SP	GARRETT	32.57	DEEP CREEK LAKE SP
MCH2A	BEAR CREEK	GARRETT	110.92	SAVAGE RIVER SF
MCH2B	BEAR CREEK	GARRETT	69.27	SAVAGE RIVER SF, BEAR CREEK HATCHERY FMA
MCH3	DEEP CREEK LAKE ST PARK	GARRETT	103.07	DEEP CREEK LAKE SP
MID1	CATOCTIN CREEK	FREDERICK	1.34	CATOCTIN CREEK PARK
MID2	WASHINGTON MONUMENT	WASHINGTON	0.17	WASHINGTON MONUMENT SP
MIL1	JACOBS CREEK1	KENT	16.36	
MIL2	JACOBS CREEK2	KENT	2.92	
MTS1	WOLF DEN POTOMAC RIVER	GARRETT	23.34997	WOLF DEN RUN SP
MYE1	SPRUCE RUN	FREDERICK	253.03	
MYE2	GREENBRIER LAKE	WASHINGTON	0.10	GREENBRIER SP
NOR1	UREY RD/DEER CREEK	HARFORD	16.86	
NOR2	UREY RD/DEER CREEK	HARFORD	15.19	
NOR3	UREY RD/DEER CREEK	HARFORD	5.40	
NOR4	UREY RD/DEER CREEK	HARFORD	5.00	
NOR5	UREY RD/DEER CREEK	HARFORD	6.37	
NOR7	UREY RD/DEER CREEK	HARFORD	3.47	
NWK1	FAIR HILL NRMA	CECIL	1.85	FAIR HILL NRMA
OAK1,2	BULL GLADE RUN	GARRETT	89.24	GARRETT SF
OAK3	HERRINGTON MANOR SP	GARRETT	4.56	HERRINGTON MANOR SP
OLD1 904,901,981A	LOWER TOWN CREEK	ALLEGANY	95.15	GREEN RIDGE SF
OLD2 904,901 (904, 901, 981B)	LOWER TOWN CREEK	ALLEGANY	23.65	GREEN RIDGE SF
OLD3 1030	BIG RUN HIKING TRAIL	ALLEGANY	187.32	GREEN RIDGE SF
OLD4 835A	LOG ROLL AREA OF GRSF	ALLEGANY	28.45	GREEN RIDGE SF
OLD5 835B	LOG ROLL AREA OF GRSF	ALLEGANY	20.36	
OLD6 705	TOWN CREEK WAGNER ROAD	ALLEGANY	54.18	GREEN RIDGE SF, TURKEY CAMP SHALE BARREN HCF
PHO1	TORREY C BROWN TRAIL (ADJACENT)	BALTIMORE	4.15	

PHO2	TORREY C BROWN TRAIL (ADJACENT)	BALTIMORE	5.42	
PHO3	TORREY C BROWN TRAIL (ADJACENT)	BALTIMORE	3.12	
POO1	MONOCACY NRA	FREDERICK	4.40	MONACACY NRA
REL1	ORANGE GROVE AREA	HOWARD	0.16	PATAPSCO VALLEY SP
REL2	AVALON AREA	HOWARD	0.60	PATAPSCO VALLEY SP
REL3	PATAPSCO VALLEY COMPLEX	HOWARD	1.00	PATAPSCO VALLEY SP
RID1	STONY POINT	CAROLINE	8.06	
RID2	SOUTH OF STONY POINT	CAROLINE	3.03	
RID3	CAROLINE TUCKAHOE CREEK	CAROLINE	3.27	
RID4	TALBOT TUCKAHOE CREEK	TALBOT	12.14	
SAN1	SANG RUN STATE PARK	GARRETT	106.45	SANG RUN STATE PARK, YOUGHIOGHENY RIVER NEA
SAN10	TOLIVER RUN	GARRETT	731.43	GARRETT SF, SWALLOW FALLS SP
SAN11	SWALLOW FALLS	GARRETT	375.23	SWALLOW FALLS SP, GARRETT SF, YOUGHIOGHENY RIVER NEA
SAN13	LOWER DEEP CREEK	GARRETT	54.32	YOUGHIOGHENY RIVER NEA, LOWER DEEP CREEK HCF
SAN14	MUDDY CREEK DRAINAGE	GARRETT	566.43	
SAN15 1038	SOUTH CRANESVILLE SWAMP	GARRETT	131.40	CRANESVILLE SWAMP PRESERVE (TNC)
SAN16 (670)	WHITE ROCK RUN	GARRETT	242.63	YOUGHIOGHENY RIVER NEA
SAN17 436	YOUGH RIVER	GARRETT	29.993	
SAN5	YOUGHIOGHENY	GARRETT	161.45	YOUGHIOGHENY RIVER NEA
SAV1	MIDDLE PATUXENT	HOWARD	10.17	GORMAN PARK
SEN1	GREAT SENECA CK	MONTGOMERY	4.02	SENECA CREEK SP
SEN2	SENECA CREEK SP	MONTGOMERY	2.67	SENECA CREEK SP
SMI1	SOUTH MOUNTAIN	WASHINGTON	199.46	HAGERSTOWN WATERSHED, SOUTH MOUNTAIN SP
SMI2	SOUTH MOUNTAIN WOLFVILLE RD	WASHINGTON	49.31	SOUTH MOUNTAIN SP
SMI3	SOUTH MOUNTAIN WARNER HOLLOW	WASHINGTON	78.20	HAGERSTOWN WATERSHED
SMI4	PENMAR PARK	WASHINGTON	0.34	PEN MAR PARK
SOL1	HELLEN CREEK	CALVERT	67.32	HELLEN CREEK PRESERVE (TNC)
SOL2	COVE POINT NHT	CALVERT	40.90	COVE POINT NHT
SYK1	PATAPSCO VALLEY SP	BALTIMORE	17.27	PATAPSCO VALLEY SP, LIBERTY WATERSHED
SYK2	PATAPSCO VALLEY SP	CARROLL	0.79	PATAPSCO VALLEY SP
TAB1	WILSON CORONA ROAD	GARRETT	820.24	
TAN1	HARNEY RD	FREDERICK	4.95	
WAL1	HEMLOCK POINT	FREDERICK	4.19	
WOO1	HIPSLEYS MILL	HOWARD	0.50	PATUXENT RIVER SP
WOO1A	HIPSLEYS MILL	HOWARD	0.19	PATUXENT RIVER SP
WYE1	WYE ISLAND NRMA	QUEEN ANNE'S	4.56	WYE ISLAND NRMA
WYE2	WYE INSTITUTE	QUEEN ANNE'S	0.83	
WYE3	WYE EAST RIVER FARM	TALBOT	3.38	
Total Acres			19,002.70	

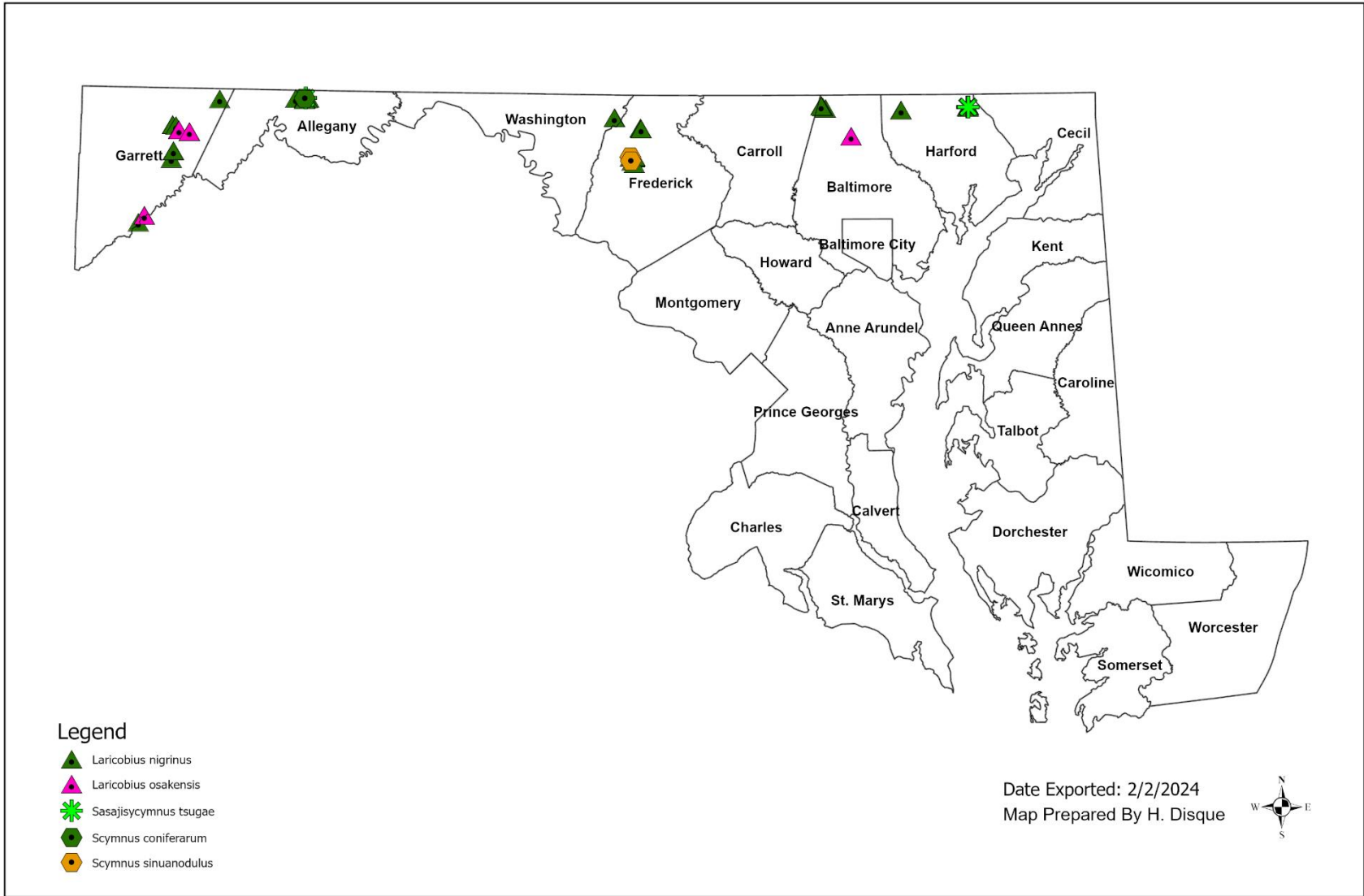
APPENDIX C

Maryland Department of Agriculture Maryland Hemlock Stands Treated for Control of Hemlock Woolly Adelgid 2004 to 2022 Forest Pest Management Section



APPENDIX D

Maryland Department of Agriculture Hemlock Woolly Adelgid Predator Releases in Maryland Hemlock Stands 1999 to 2022 Forest Pest Management Section



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