

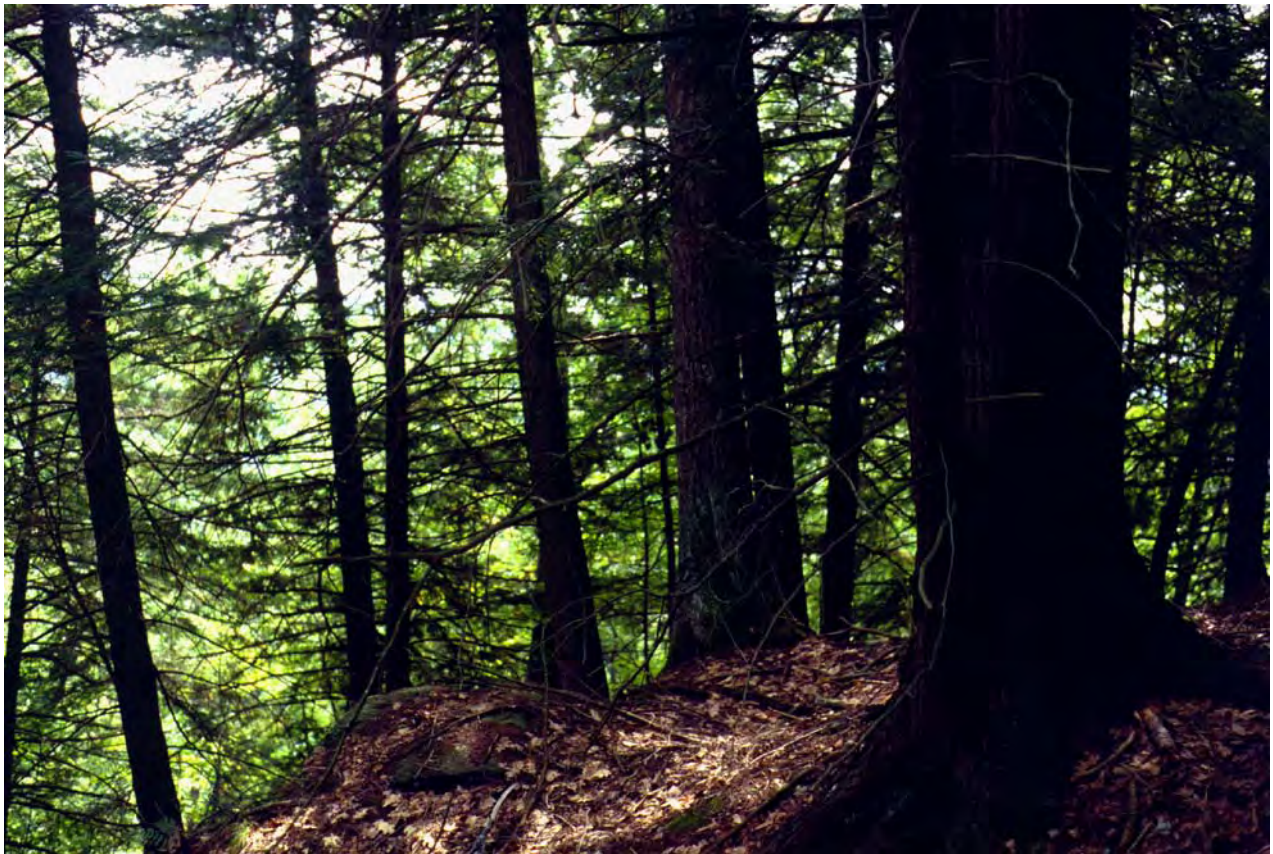
National Park Service
U.S. Department of the Interior

Northeast Region
Boston, Massachusetts



Hemlock Woolly Adelgid Risk Assessment for Marsh-Billings-Rockefeller National Historical Park

Technical Report NPS/NER/NRTR—2005/017



ON THE COVER

Hemlock Forest at the Marsh-Billings-Rockefeller National Historical Park
Photograph by: Tom Lautzenheiser

Hemlock Woolly Adelgid Risk Assessment for Marsh-Billings-Rockefeller National Historical Park

Technical Report NPS/NER/NRTR—2005/017

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U.S. Department of the Interior
National Park Service
Northeast Region
Boston, Massachusetts

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Abstract

Marsh-Billings-Rockefeller National Historical Park (MABI) includes a remarkable hemlock (*Tsuga canadensis*) resource within the historic Mount Tom Forest, which is a focal point of the Park's cultural landscape. The non-native invasive insect hemlock woolly adelgid (*Adelges tsugae* Annand [Homoptera: Adelgidae]) (HWA) has heavily impacted hemlock ecosystems in the eastern United States. HWA has spread steadily, and by 2004 had advanced to within 120 km (75 mi) of the Park.

As part of a coordinated effort to reduce the spread and impacts of HWA and assess potential impacts at the Park, a geographic information system (GIS)-based risk assessment was implemented for MABI. The model incorporated a literature search, interviews, and historical documentation in identifying: 1) factors associated with the risk of HWA introduction and establishment ("susceptibility"); and 2) potential impact of HWA infestations ("vulnerability/resistance").

Results indicated that although cold temperatures may currently be a limiting factor for northward spread of HWA, cold hardiness zones in which the pest is already established extend to within 16 km (10 mi) of MABI. Hemlock is ubiquitous in the area, presenting ample opportunity for natural spread, and historical introductions of the insect highlight risk factors such as nurseries and seasonal residences in conjunction with potential movement corridors. Prevention, monitoring, and management recommendations are discussed.

Executive Summary

Hemlock woolly adelgid is a small insect native to southeast Asia that has heavily impacted hemlock ecosystems throughout the eastern U.S., with several National Parks questioning their ability to maintain a hemlock component of their forests for the future. As of 2004, this pest had advanced close to the Massachusetts/Vermont border and eradication efforts have been required to address importations of infested stock in Vermont. Vermont has an extensive and valuable hemlock resource, and Marsh-Billings-Rockefeller National Historical Park (MABI) is home to some prime examples including a number of highly valued remnant old-growth specimens.

To address pests and non-native invasive species (NNIS), the National Park Service (NPS) is strongly committed to implementation of a coordinated strategy based on cooperation among land managers and the principles of integrated pest management (IPM). In late 2004, a risk assessment for hemlock woolly adelgid (HWA) was undertaken at MABI. This assessment was conducted by Redstart Forestry, which has developed a Geographic Information System (GIS)-based HWA risk assessment for the southern six counties of Vermont in cooperation with the University of Vermont; the Vermont Agency of Natural Resources Dept. of Forests, Parks, and Recreation; the USDA Forest Service State and Private Forestry, and the Vermont Agency of Agriculture. The work presented here incorporates methodology from this cooperative effort and offers an example of how systems that integrate spatial data can assist land managers in evaluating the threats of NNIS and developing response strategies.

Based on this assessment, we concluded there is a risk for HWA impacts at the Park, although cold temperatures may limit northward spread of the pest. Unique resources present at MABI, along with proactive efforts by federal and state agencies, offer outstanding opportunities for cooperation to extend and strengthen education, prevention, early detection, and rapid response efforts that have shown good results to date.

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Introduction

Hemlock ecosystems throughout much of the eastern US are being severely impacted by the non-native invasive hemlock woolly adelgid (*Adelges tsugae* Annand [Homoptera: Adelgidae]) (HWA), an accidental import from Asia. This pest affects both Eastern (*Tsuga canadensis* [L.] Carriere) and Carolina (*Tsuga caroliniana* Engel.) hemlocks, and has caused extensive defoliation and mortality in areas where it is present. HWA has been detected in numerous National Parks at varying levels of intensity, and its range has steadily spread. Some biologists and land managers believe potential impacts of HWA could have considerable implications for water quality, biodiversity, and wildlife habitat among other important resource values. Eastern hemlock is the species of concern for HWA in the northeast (Carolina hemlock is a southern species). Eastern hemlock occurs in many forest associations, but has developed a strong niche in eastern forests in moist soils and riparian zones (Godman and Lancaster 1990). Once established, it tends to create a cool, dark, moist and stable environment that provides unique habitat for mammals, birds, and water-dependent species as well as a distinctive experience for human visitors.

As of 2004, no persistent HWA infestations have been noted in Vermont. The insect was accidentally introduced to the state on several occasions, including a summer 2004 importation of nursery stock to a White River Junction nursery (approximately 10 mi east of MABI) that contained trees infested with the pest (some of these trees were eventually planted less than a mile from the Park, but later destroyed). All of these importations were rapidly addressed and associated eradication efforts appear to have been successful. Persistent populations of HWA have, however, been documented in the Connecticut River Valley of Massachusetts in towns bordering southern Vermont. Because HWA poses a significant risk to hemlock ecosystems it warrants further management attention under National Park Service Management Guidelines (NPS 2004a), which have been used to frame the structure of this report:

High priority will be given to managing exotic species that have, or potentially could have, a substantial impact on park resources, and that can reasonably be expected to be successfully controllable....

For species determined to be exotic and where management appears to be feasible and effective, superintendents should (1) evaluate the species' current or potential impact on park resources; (2) develop and implement exotic species management plans according to established planning procedures; (3) consult, as appropriate, with federal and state agencies; and (4) invite public review and comment, where appropriate. Programs to manage exotic species will be designed to avoid causing significant damage to native species, natural ecological communities, natural ecological processes, cultural resources, and human health and safety.

(NPS 2004a - NPS Management Policies 4.4.4.2)

The NPS utilizes integrated pest management (IPM) as the basis of planning procedures related to these goals. IPM is a decision-making process that coordinates knowledge of pest biology, the environment, and available technology to prevent unacceptable levels of pest damage, by cost-effective means, while posing the least possible risk to people, resources, and the environment (NPS 2004a, Sec. 4.4.5.2). This process is integral to the Park-wide IPM plan being developed for MABI (MABI, Christina Marts, Natural Resource Manager, phone conversation, Oct. 28, 2004).

A GIS-based HWA risk assessment developed in Vermont addresses these goals and offers a starting point for ongoing collaboration between Park staff, federal and state agencies, and other involved parties in developing effective strategies to address HWA. Non-native invasive species (NNIS) such as HWA present increasing challenges to conservation and stewardship of forest resources. MABI was established expressly to interpret the history of conservation and land stewardship in America, and highlights the evolution of management practices on some of the oldest surviving examples of conservation and reforestation efforts in this country (NPS 2004b; NPS 2004c). Forest resources at the Park are managed as part of a cultural landscape, and are a living exhibit of the evolution of forest stewardship practices from early scientific silvicultural practices borrowed from nineteenth-century Europe to contemporary practices of sustainable forest management (NPS 2004c). As such, MABI places a high value on efforts to protect such resources as the hemlocks at the Park, which bear witness to a legacy of effective conservation and management.

I. Evaluation of Potential Impact on Park Resources

A. The Hemlock Resource at MABI

The Mount Tom Forest is a key component of the cultural landscape at MABI (NPS 2004b; NPS 2004c). Eastern hemlock plays a vital role in the character and experience of that forest, ranging from its strong influence in the ecology of the stream along the northeast portion of the park to the remarkable presence of a number of old-growth hemlocks (250-400 years old) scattered through the forest. Stand composition data compiled for the 2004 Forest Management Plan indicated 22 stands with hemlock components (38.6% of 57 forested stands delineated within the Park), ranging from 2% to 93% hemlock on a basis of stand basal area (NPS 2004c) (Fig. 1). These stands represented 52.9% (120.6 ha [298 ac]) of the total stand area (including non-forested “stands” such as hayfields and pastures) in the Park. Hemlocks have historically been a valuable timber commodity and appreciably harvested throughout the Northeast, but MABI has retained the majority of its hemlocks for their unique ecological and aesthetic value.

Hemlock represents a significant component of four out of sixteen natural communities identified within the Park: Hemlock-Northern Hardwoods Forest (80 ha [197.7 ac]), Hemlock Forest (22.7 ha [56.1 ac]), Hemlock-Red Oak Forest (2.5 ha [6.3 ac]) and Hemlock Swamp (1.3 ha [3.2 ac]) (Lautzenheiser 2002). Cumulatively, natural community types with significant hemlock components were delineated in 46.8% of the Park’s forested area (Fig. 2).

The unique environment of hemlock ecosystems provides habitat for approximately 96 bird and 47 mammal species in the northeastern US (Yamasaki et al. 1999). In Vermont, hemlock environs are extensively used for deer wintering areas, and the Vermont Department of Fish and Wildlife maintains maps of these important wintering areas that include some of the hemlock stands at MABI (VCGI 2004a)(Fig. 3).

A bird inventory conducted at MABI identified 14 bird species of conservation priority in northern New England. Eight of these species prefer mature mixedwood or softwood habitats (Faccio 2003), habitats in which hemlock plays a prominent role in the Park. Two of these were Partners in Flight Tier 1 species (High Overall Conservation Priority), Blackburnian Warbler and Wood Thrush. Barred Owls and Broad-winged hawks were among numerous other species observed in hemlock areas within the Park (Faccio 2003).

A study comparing hardwood to hemlock ecosystems in the Delaware Water Gap National Recreation Area (DEWA) in New Jersey and Pennsylvania indicated that streams within hemlock stands had greater macroinvertebrate diversity, lower nitrate levels, more stable temperature and hydrologic regimes, and greater populations of aquatic predators and brook trout than similar streams in hardwood environments (Lemarie et al. 1999; Snyder et al. 2002). At MABI, extant closed-canopy, hemlock-dominated cover has been identified as critical to the health of the stream corridor in the northeast portion of the Park and the habitat it provides for Northern Dusky and Two-lined salamander populations in particular (Faccio 2001).

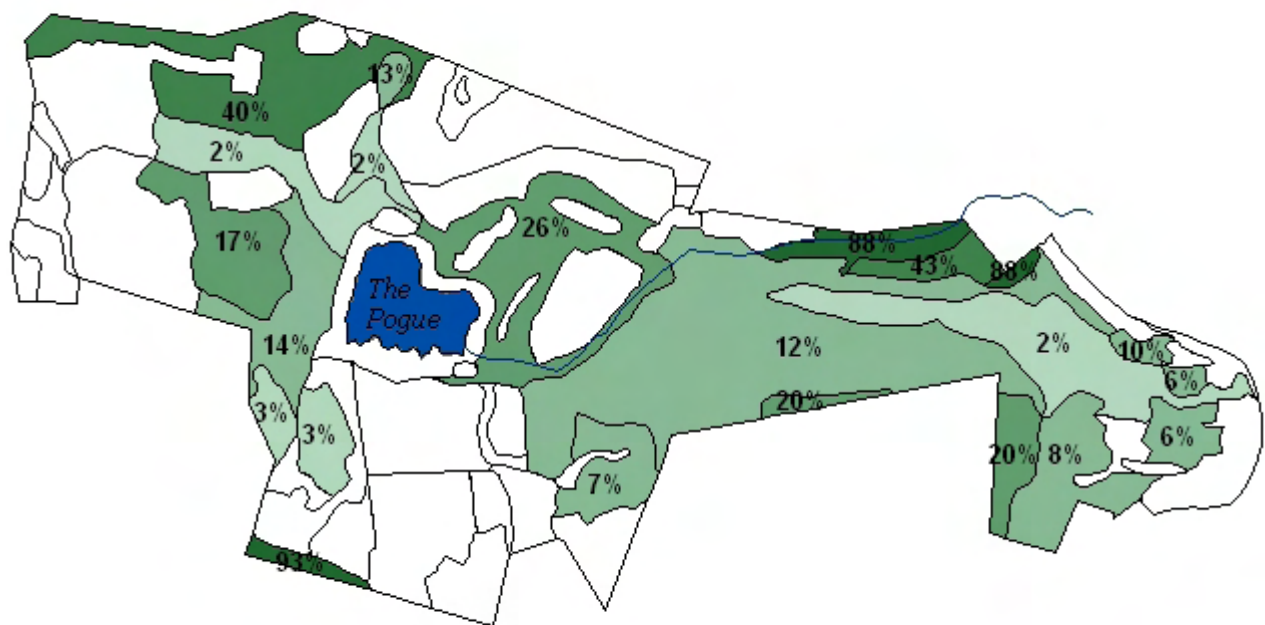
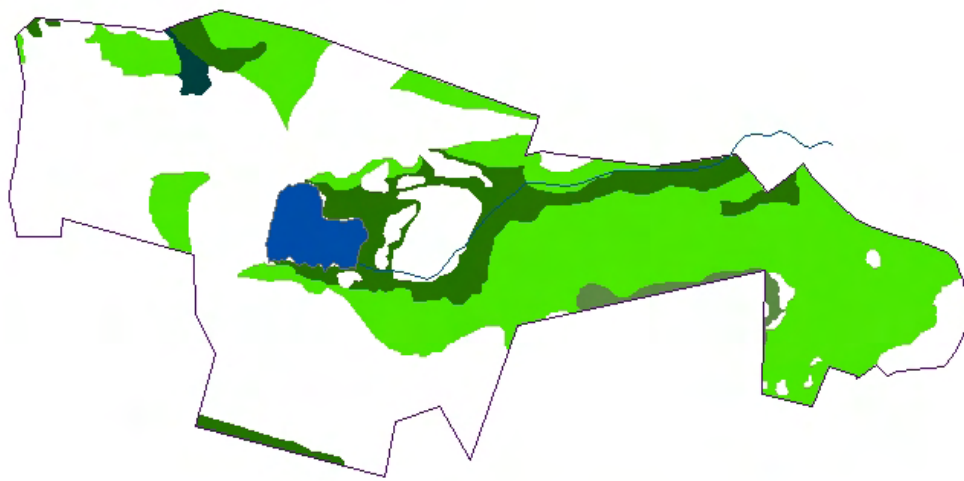


Figure 1. Forest stands with hemlock components indicated as percentage of stand basal area, MABI 2004 overstory inventory (USFS 2001). In addition to these stands, hemlock is a primary component of the historic mansion grounds where specimen trees and extensive hedges are featured.

Natural communities with
hemlock components at
Marsh-Billings-Rockefeller
National Historical Park
(Lautzenheiser 2002)



Legend

-  The Pogue
-  Pogue Stream
-  MABI boundary

NATURAL COMMUNITY

-  Hemlock Forest
-  Hemlock Swamp
-  Hemlock-Northern Hardwood Forest
-  Hemlock-Red Oak Forest

Figure 2. Hemlock natural communities at MABI.

Similarly, parts of hemlock stands on the southern border of MABI lie within the delineation of a 200-meter buffer zone surrounding vernal pools on adjacent conserved properties; stands surrounding the Pogue constitute comparable habitat. The MABI Forest management plan incorporates these buffer zones for several vernal pools in the area, treating the pools as a complex and thus allowing management options to better accommodate important dynamics and travel corridors for breeding populations of the rare Jefferson's salamander and other amphibians and reptiles inventoried in the area (Faccio 2001; NPS 2004c)(Fig. 4).

Biodiversity and cultural landscape forest management issues at MABI emphasize the value and importance of remnant old growth and wolf trees present on the property (NPS 2004c). Hemlocks account for 19% (18 of 97) of the "legacy trees" documented within the park. These trees offer structural diversity, important denning sites and cavity nesting habitat, and numerous other important ecological functions (Keeton 2004). Some of these hemlocks date to ca. 1600 and represent some of the few extant ties to the Marsh and pre-settlement eras of the Park's history (NPS 2004b; NPS 2004c).

Hemlock also plays an important role in the experience and ecology of the carriage roads and the area surrounding the Pogue, a water body that has been a central landscape feature since its development under Frederick Billings' management in the late 1800s (NPS 2004b). It is clear that whether examined from a cultural, aesthetic, ecological, or silvicultural perspective, hemlock is essential to MABI.

B. Hemlock Woolly Adelgid

Hemlock woolly adelgid (HWA) was first noted in the early 1950s in Virginia. HWA has spread steadily and now occupies portions of 15 eastern states, from southeastern Maine to northern Georgia and west to eastern Tennessee (Fig.5). As of 2002, HWA had been documented in roughly half of the native range of hemlock in the eastern US, with extensive areas of mortality and decline noted throughout the area of infestation. The United States Department of Agriculture Forest Service (USFS) has launched a coordinated effort to reduce the impacts and spread of hemlock woolly adelgid. As part of this effort, the USFS maintains a website to act as a central clearinghouse for research and information related to HWA (USFS 2004).

In Asia, HWA is controlled by a combination of host resistance and natural predators, neither of which appear to be present in North America (McClure 1995). HWA is parthenogenetic; late winter/early spring unmated females produce egg masses that contain up to 300 eggs, while a second annual generation of unmated females in late spring/early summer produce ovisacs containing 20-75 eggs (McClure et al. 2001). A portion of the spring generation nymphs develop into winged adults capable of sexual reproduction, but these adults appear to die off in North America due to lack of a suitable spruce host for continuation of their life cycle (McClure 1989). Production of this winged form is density dependent, with a greater proportion being produced when the host tree is declining. Production of unmated females, also density dependent, is greatest in initial phases of infestation on healthy hemlocks and exhibits a "boom and bust" cycle related to the health of the host trees: HWA causes large impacts the first year, declines due to lack of new growth on damaged hemlocks in the second year, recovers to a modest second

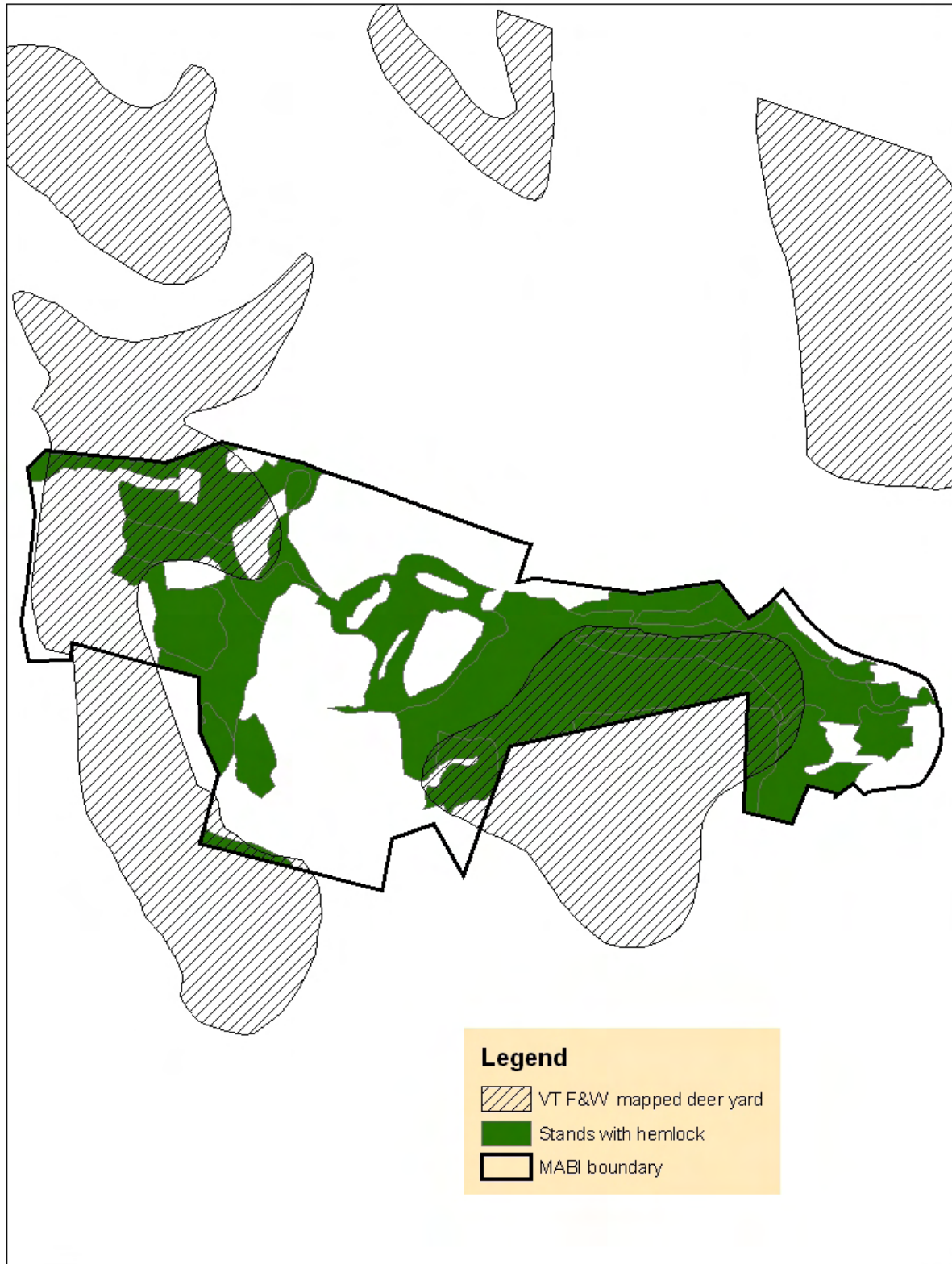


Figure 3. Significant deer wintering yards mapped by the Vermont Department of Fish and Wildlife in relation to stands with hemlock at MABI (VCGI 2004a).

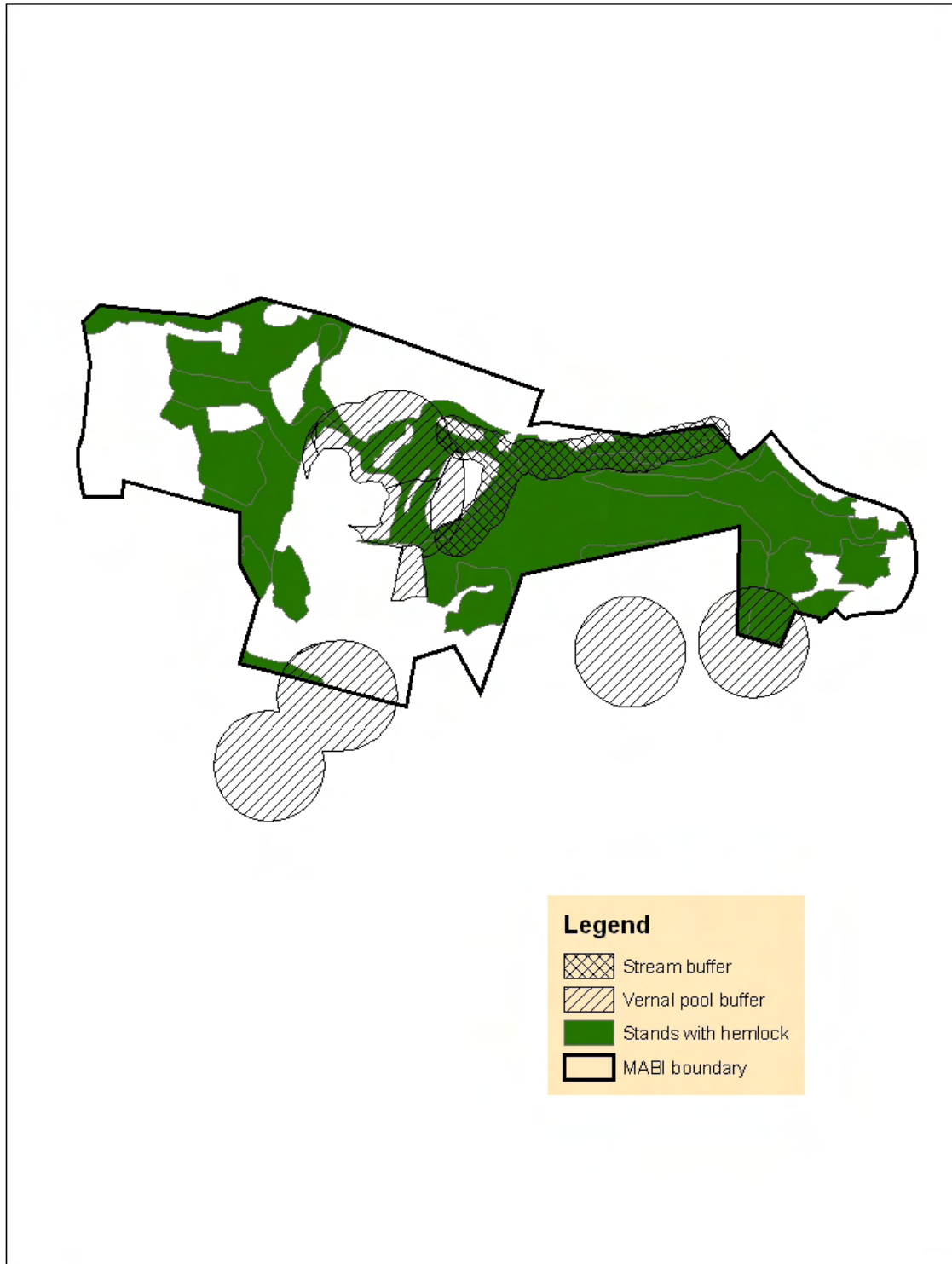


Figure 4. Important amphibian habitat: recommended stream and vernal pool buffers in relation to stands with hemlock components at MABI (Faccio 2001).

population peak the third year as the trees flush some new growth, and crashes again in the fourth year with a lack of nutritional resources (McClure 1991a). While the insect produces two generations per year, it completes most of its active development on hemlock between October and May (depending on location); nymphs that enter a period of summer aestivation become active again towards October (McClure 1989). Figure 6 gives a simplified visual representation of the HWA life cycle.

Production of two all-female generations per year, timed to avoid high predation periods, makes hemlock woolly adelgid capable of explosive rates of population expansion, particularly when healthy hemlocks are numerous (Ward et al. 2004). Once established, HWA can cause rapid tree decline and mortality, with mortality often occurring within 2-10 years of initial infestation (McClure et al. 2001). Extensive damage occurred quickly enough in Shenandoah National Park to potentially preclude protection of the hemlock component of the forest there (Young and Morton 2002). When hemlocks are killed by HWA, they are often replaced by opportunistic hardwood species, making these ecosystem changes significant and long lasting (Orwig and Foster 1998; Kizlinski et al. 2002; Orwig 2002). In light of the numerous functions fulfilled by hemlock ecosystems (many noted above in relation to the hemlock resource at MABI), the full implications of such changes are difficult to assess.

Dissemination of HWA to new host material occurs primarily by wind, though birds and deer have also been implicated (McClure 1990). In a “natural” pattern of dissemination, continuity or proximity of hemlock stands is an important factor in spread of the pest and it tends to spread slowly across the landscape unless accelerated by human factors or extreme weather events. Hemlock is a widely distributed species occurring in many forest associations in the eastern US, providing ample avenues for such a pattern (Morin et al. 2005).

Spread of HWA by humans has been documented in the northeastern US through activities such as logging (McClure 1990) and tree planting. Primary avenues of dissemination through planting have included: a) distribution of infested trees by nurseries and b) transport of stock by seasonal residents who unwittingly bring trees from infested areas for planting in seasonal home landscapes (Bofinger 2002; Ouellette 2002). These planting pathways have been involved in two documented introductions of HWA in Vermont. The first introduction occurred in 1990 when a seasonal resident planted approximately 175 hemlock seedlings in Stockbridge, Vermont. These seedlings originated in Maine but were held in a nursery in an infested area of New Jersey before outplanting in Vermont. Although only a few of the trees were clearly infested upon inspection in Vermont, all but 55 were destroyed as a precautionary measure. The following year (1991), three more trees were found to be infested and destroyed. These eradication efforts over a two year period appear to have eliminated this first introduction, as follow-up monitoring indicated no further infestations (Vermont Department of Forests, Parks, and Recreation, Barbara Burns, Protection Forester, phone conversation, Feb. 6, 2003).

The second documented HWA introduction in Vermont is of particular interest for MABI, involving a 2004 importation of infested stock to a White River Junction nursery and subsequent outplantings of that stock (see results section below). The situation was rapidly addressed with an eradication effort by the Vermont Agency of Agriculture and Vermont Department of Forests,

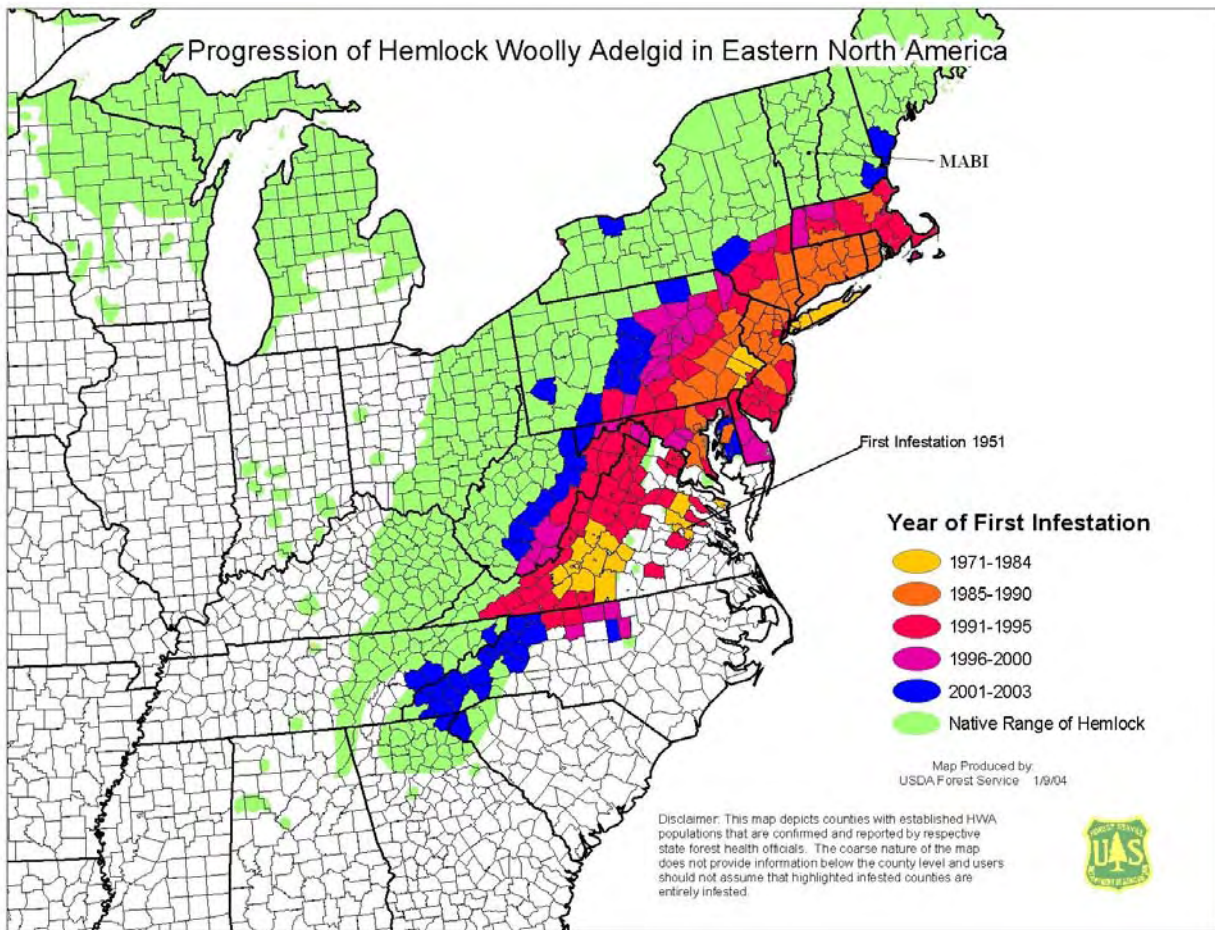
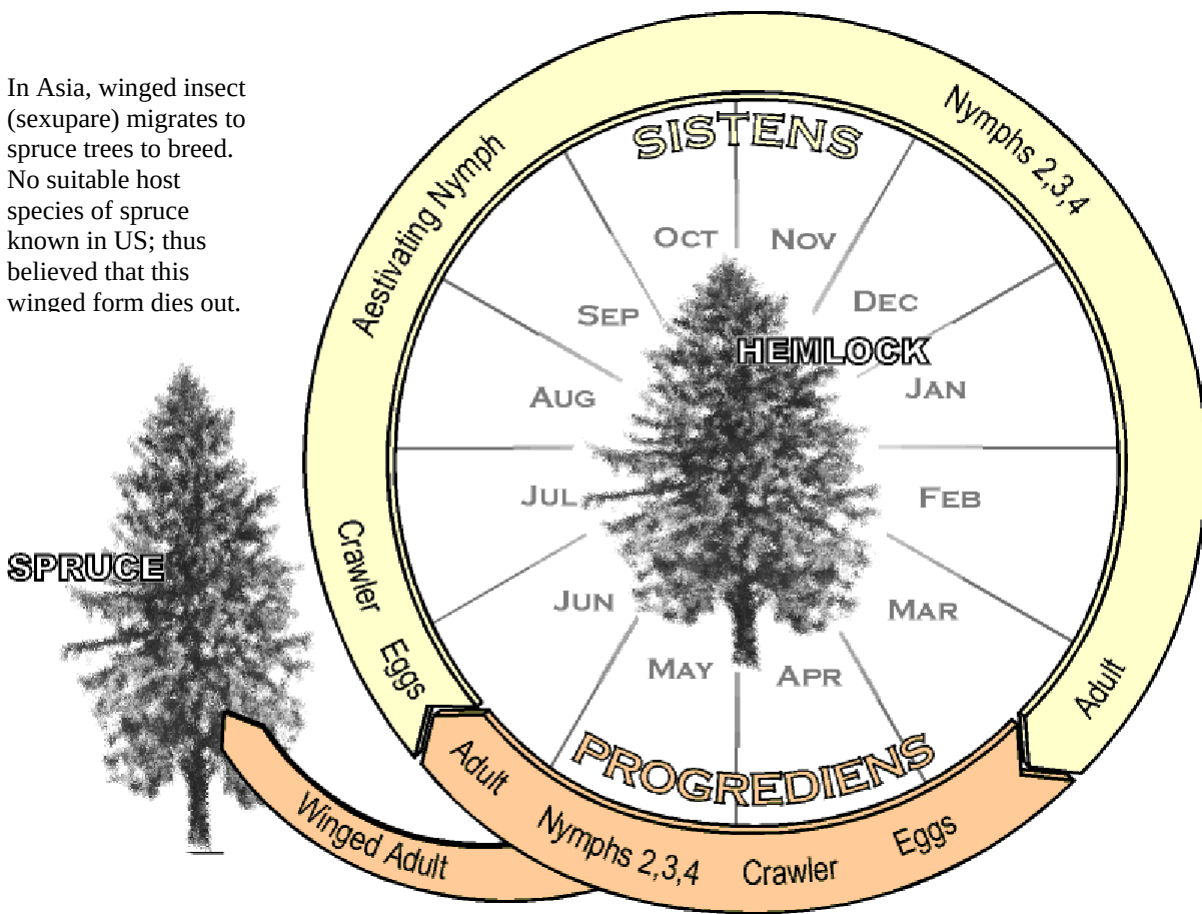


Figure 5. MABI location, HWA progression, and hemlock range in the eastern U.S. (USFS 2004).

In Asia, winged insect (sexupare) migrates to spruce trees to breed. No suitable host species of spruce known in US; thus believed that this winged form dies out.



Note: timing of this cycle may vary according to location of the population.

Figure 6. HWA annual life cycle (Vince D'Amico and Mike Montgomery; PDCNR 2004).

Parks, and Recreation, but the event increased awareness and concern about the potential threat of HWA introduction in Vermont. Efforts to track the trees from this shipment turned up an additional 17 infested hemlocks in Vermont, imported from a New Hampshire nursery. A total of 843 trees were associated with these two shipments; 98.3% of these were removed and destroyed, with only 14 trees (1.7%) unaccounted for.

In areas where the pest has become established, HWA impacts across the landscape have varied considerably. Research at National Parks includes assessment of variation in these impacts at Shenandoah, Delaware Water Gap, and Great Smoky Mountains National Parks (Young et al. 2004). Remotely sensed data with GIS-based analysis suggest that clustering of areas with heavier HWA damage indicates a connection to site conditions, although these factors tend to even out with increasing duration of infestation (Royle and Lathrop 2002; Young and Morton 2002). Additional assessments of HWA-induced hemlock decline have identified three key site factors as likely contributors to this variability: soil moisture (Onken 1995; Scudder et al. 2000; Orwig et al. 2002), aspect (Bonneau et al. 1999; Orwig et al. 2002), and site quality (Sivaramakrishnan and Berlyn 1999; Royle and Lathrop 2002). There is growing evidence that soil moisture is the most important site factor influencing HWA damage (Sivaramakrishnan and Berlyn 1999; Scudder et al. 2000; Orwig et al. 2002), with increasing levels of soil moisture (given adequate drainage) favoring resistance to HWA. Preliminary research has also indicated, however, that HWA damage levels can be associated with proximity to streams and other waterways; suspicions are that this may be due to thermal buffering and/or other factors such as corridor use for bird travel (and, hence, HWA transport) (Young et al. 1999; Kimple and Schuster 2002; McClure and Cheah 2002).

Low winter temperatures appear to be a primary factor limiting range expansion of HWA in the northeastern US (Souto and Shields 1999; Scudder et al. 2000). Laboratory experiments have confirmed that low temperatures have a distinct effect on HWA survival, with complete mortality after exposure to temperatures of -35°C (-31°F) or lower, regardless of duration of exposure (Parker et al. 1999). Infestations have been documented into USDA cold hardiness Zone 5A (characterized by average annual minimum temperatures that range from -26.1 to -28.9°C [-15 to -20°F]), but questions have arisen over the insect's ability to adapt to colder temperatures (Parker et al. 1999; Parker et al. 2002).

II. Develop and Implement Exotic Species Management Plans

A. Integrated Pest Management and HWA

Since 1979, federal agencies including NPS have utilized integrated pest management (IPM) as the basis of planning procedures for pests, including non-native invasives. IPM strategies emphasize strong inventory and monitoring programs as a means to direct prevention activities and utilize early detection and treatment as an effective and ecologically sound management approach (NPS 2004d). There are compelling biological and economic reasons to manage NNIS when population levels are low. Research on the “Allee effect” in population dynamics indicates that there are thresholds generated for probability of establishment as a function of introduced population size or density; below these thresholds, a population is much more prone to extinction (Drake 2004). This effect implies that eradication efforts may likely succeed at less than 100% mortality (Liebhold and Bascompte 2003). Cost-benefit analysis indicates economic benefits to slowing the spread of pests even if a relatively small area remains uninfested (Sharov 2004). Biological controls have proven ineffective in hemlock stands already significantly damaged by infestation (Ward et al. 2004).

A GIS-based HWA risk assessment was developed in Vermont specifically to assist in prioritizing monitoring and detection efforts, and to help with educational efforts (Machin 2003). This assessment was designed to be comprehensive enough to translate ongoing research findings into practical applications for resource managers while having flexibility to adapt to new information (consistent with adaptive management strategies integral to IPM). Since no persistent populations of HWA had become established in Vermont as of 2004, HWA risk assessment at MABI focuses on the monitoring, prevention and early detection aspects of IPM. Geographic areas less fortunate, however, have employed numerous methods in attempts to control HWA, ranging from fertilization and pesticide use to rearing and release of biological control agents (McClure et al. 2003; Ward et al. 2004).

B. Vermont HWA Risk Assessment Methodology

In modeling the risk posed to Vermont hemlocks by HWA, we differentiated between the potential for attack (susceptibility), and the potential impact of attack (vulnerability) (Luther et al. 1997). In this case, the term susceptibility is used in reference to factors that influence *introduction and establishment* of the pest. The *potential impact* of HWA infestation on hemlocks is described by the term vulnerability. The work described herein modeled values based on the inverse of vulnerability, designated as *resistance* (i.e. resistance of the trees if infested with HWA).

1. Modeling Susceptibility

The first step in modeling both susceptibility and resistance was to synthesize existing HWA research and consolidate it into meaningful trends that could be translated to a GIS-based model. Some susceptibility factors were difficult to quantify and model in a spatially explicit manner

(e.g. dissemination by wind, birds, and deer), but low winter temperatures, nurseries, and seasonal residences are important factors that were more easily modeled.

Cold: Because low winter temperatures appear to significantly reduce HWA populations, we sought a more refined data layer than conventional maps representing USDA cold hardiness zones (Cathey 1990). The revision is an extrapolation of climate station data to a landscape level, based on 30-year normal monthly average minimum temperatures for 377 National Oceanic and Atmospheric Administration - National Weather Service (NOAA-NWS) cooperative observer stations in the northeastern US as a function of latitude and elevation (Miller 2003b).

Nurseries: The Vermont Agency of Agriculture provided a database of registered Vermont nurseries and plant dealers. These nurseries were spatially located using an address matching system. Attribute data corresponding to contact information for all nurseries and landscaping businesses was built into the GIS.

Seasonal Residences: Risk of potential introduction from seasonal residences (a known historical vector due to transport of plants from infested areas [Bofinger 2002; Ouellette 2002; Vermont Department of Forests, Parks, and Recreation, Barbara Burns, Protection Forester, phone conversation, Feb. 6, 2003]) was addressed in a three-tiered manner with increasing specificity:

- a. Data from the 2000 US Census provided the number of total residences and number of seasonal residences on a per- town basis.
- b. Data from the E911 system allowed the isolation of seasonal residences (VCGI 2004b); these data were overlaid and analyzed in conjunction with various combinations of the other data layers.
- c. The digital town parcel map was joined to the town grand list, which includes home addresses of landowners. Landowners listing primary addresses in states with documented occurrences of HWA were isolated from this data layer.

Cover Type: As discussed in the HWA section of “Evaluation of Potential Impacts to the Park” (above), continuity or proximity of host material is an important factor influencing risk of introduction. Forest stands at MABI were analyzed using data from the 2004 MABI Forest Management Plan, which included information on stand species composition as a percentage of basal area (Fig. 1) (NPS 2004c). Hemlock cover at MABI was placed in a landscape-scale context with the use of USFS Forest Inventory Analysis (FIA) data, which mapped hemlock distribution based on interpolation from region-wide monitoring plot data. FIA data included an adjustment of hemlock basal area estimates based on land cover/ land use to account for factors such as forested and non-forested areas (Morin et al. 2005).

2. Modeling Resistance

A synthesis of HWA research showed that soil moisture, site productivity, and aspect appear to be key factors affecting the varying impact of HWA across the landscape. GIS layers to address these factors were developed from attributes within the Vermont soils database (Soil Survey Geographic (SSURGO) data from the USDA Natural Resources Conservation Service)(VCGI

2004c) and a 30m cell resolution United States Geological Survey (USGS) Digital Elevation Model (DEM) of Vermont (VCGI 2004d).

Soil Moisture: An “Integrated Moisture Index” (IMI) was created for southern Vermont based on a model developed as a generalized index for applications where moisture is a key driving variable to an ecological pattern or process (Iverson et al. 1997). This index was developed, via a grid-based system, to incorporate factors including hillshade (differential solar radiation), flow accumulation, curvature (landscape forms such as ridges and depressions), and soil water-holding capacity (Figure 6). Each of these computations was scaled to assign higher values to factors contributing to higher moisture content, and then incorporated into a cumulative IMI ranging from 0 (dry) to 1 (moist).

Site Productivity: Site productivity was based on Vermont’s Current Use Advisory Board classification, which uses site index value as an indicator of site quality (Vermont Department of Property Valuation and Review 1980). This is stored as an attribute in the soils database (VCGI 2004c) on a categorical basis (four classes). These classes were assigned a numerical value (1-4) and rescaled to a 0 to 1 index, with values closest to 1 representing the most productive soils and those closest to 0 the least productive.

Aspect: Research has indicated that hemlocks on north and east aspects exhibit higher resistance to HWA and hemlocks on south and west aspects exhibit lower resistance, though the mechanisms are not clearly understood (Bonneau et al. 1999; Orwig et al. 2002). Slope aspect was calculated from the Vermont DEM (VCGI 2004d). An aspect transformation calculation was then applied (Beers et al. 1966) to yield an aspect grid with values closest to 1 on northeast slopes and values closest to 0 on southwest slopes.

Once these three layers were processed, they were weighted using the raster calculator in ArcGIS™ 8.X (ESRI 2003). Based on input from researchers and State of Vermont forest protection specialists consulted, soil moisture, site productivity, and aspect were given a weighting value of 0.70, 0.20, and 0.10 respectively. These values were based on institutional knowledge as best available information, but can be re-evaluated with the results of emerging research and field data. Because each of these factors (as computed) contributes to increased resistance (decreased vulnerability) of hemlocks to HWA, the process created a spatially explicit resistance grid with embedded values for each pixel ranging from 0 to 1 based on the three weighted layers. Classification (using the Jenks system for identifying natural breaks in the data set) indicated 0 to 0.375 as low, 0.376 to 0.609 as medium, and 0.610 to 1.0 as high resistance index values.

The resistance index was then used to analyze the forest stands with hemlock components at MABI through the use of zonal statistics, which yielded mean resistance index values for each of the stands (the “zones”).

Integrated Moisture Index (“IMI”)

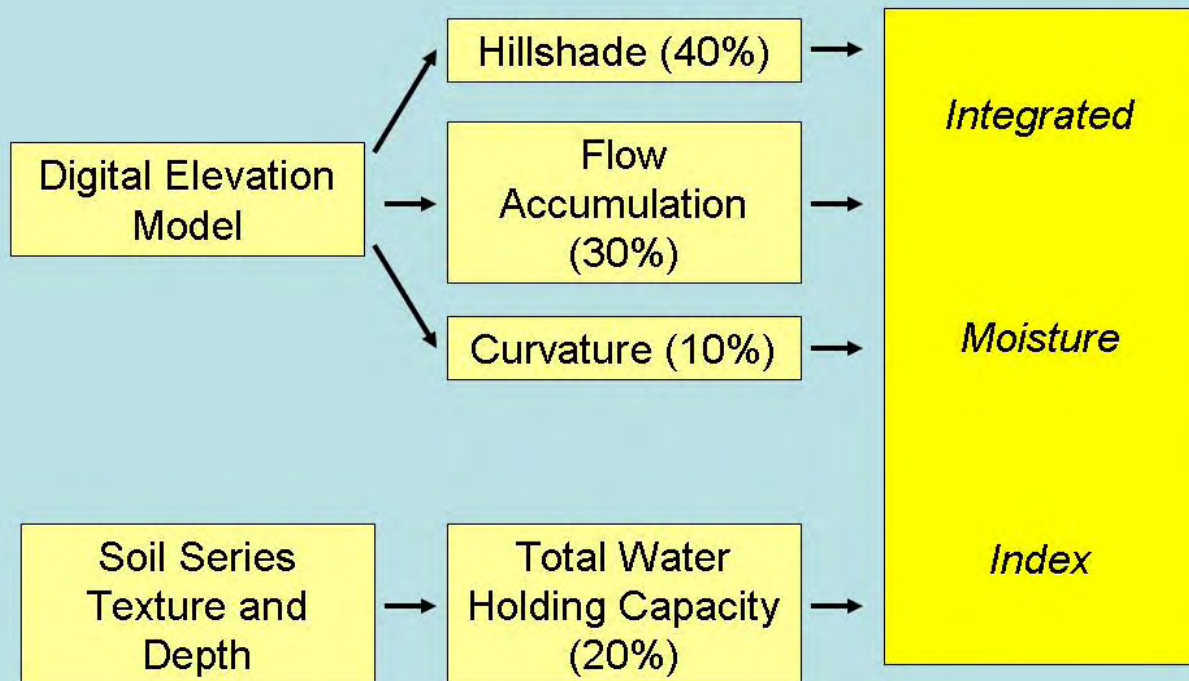


Figure 7. Integrated Moisture Index model (Iverson et al. 1997) applied to southern VT as one component of the HWA resistance index.

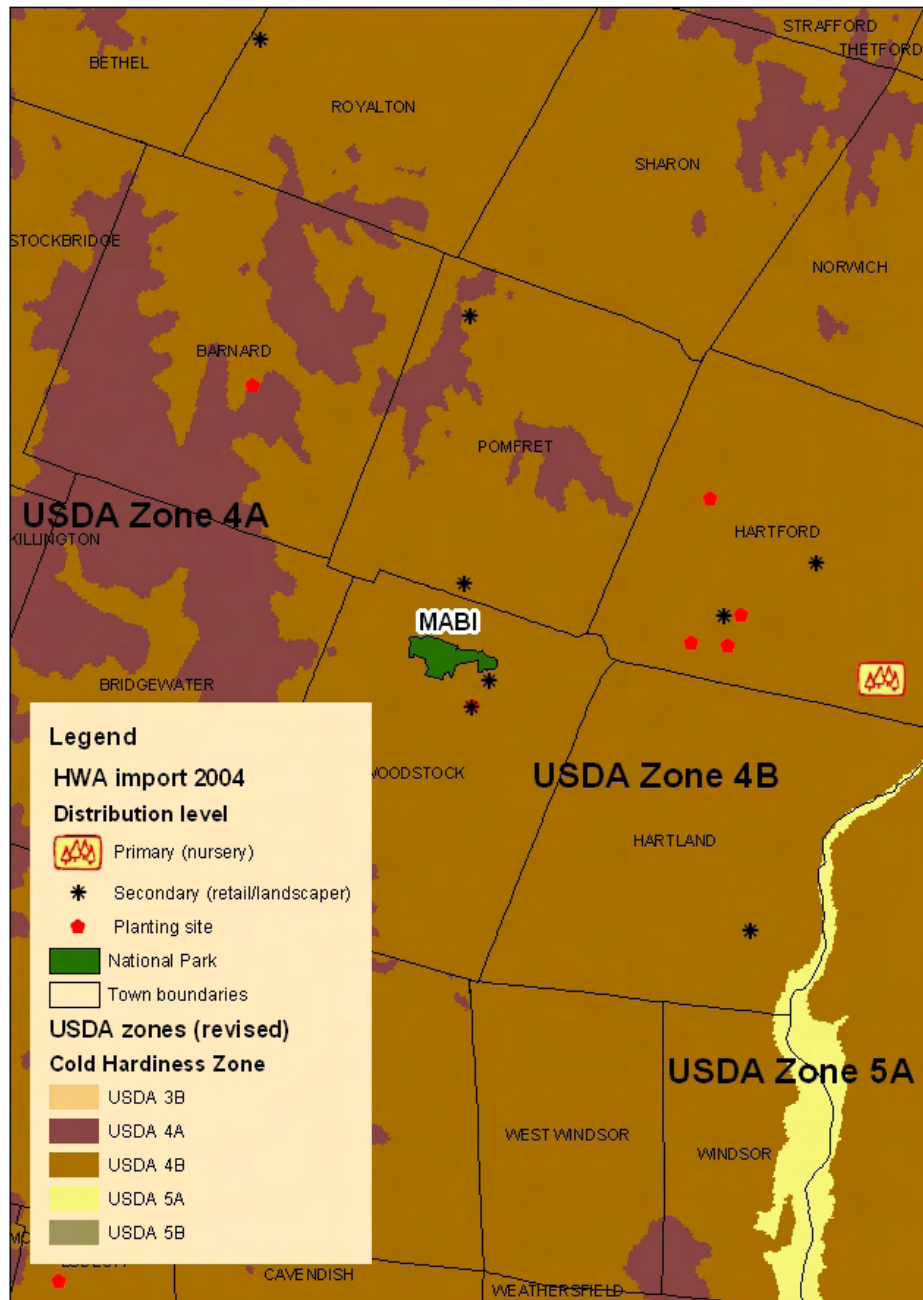


Figure 8. Revised USDA cold hardiness zones and distribution of nursery stock associated with an HWA import during summer 2004.

C. Results

1. Susceptibility

Cold: MABI is situated in revised USDA cold hardiness Zone 4B, but lies approximately 10 miles west of the northern extremes of Zone 5A (Fig. 6). As of 2004, Zone 5A marked the coldest zone of documented HWA infestations (Parker et al. 1999). Average annual minimum temperatures of -26.1 to -28.9°C (-15 to -20°F) characterize Zone 5A, while the range for Zone 4B, including MABI, is -28.9 to -31.6°C (-20 to -25°F).

Nurseries: Thirty-nine nurseries licensed by the Vermont Agency of Agriculture lie within 15 miles of MABI; five of these are within 5 miles. Contact information for these nurseries is stored in the MABI Forest Management GIS database. Licensing surveys are annually conducted by the Vermont Agency of Agriculture; in 2004-2005 these surveys will include questions regarding volume of sales and whether nurseries carry hemlock stock as well as several other plant species associated with other NNIS of special concern (e.g. emerald ash borer, Asian long horned beetle, and sudden oak death). This information will be entered into the GIS database and joined to the nurseries data layer developed for licensed Vermont nurseries. As of 2004, hemlocks were permitted to be imported in Vermont if certified as disease and pest free by authorities from the state of export (VAAFm 2004). An emergency rule with updated quarantine regulations went into effect February 18, 2005, including requirements for origination of stock only from non-quarantined areas and areas surveyed for HWA annually if adjacent to quarantined areas (VAAFm 2005).

During the summer of 2004, infested hemlock stock was imported into Vermont and distributed by nurseries and landscapers in Vermont and New Hampshire. The Vermont Agency of Agriculture and Department of Forests, Parks, and Recreation rapidly addressed the importation and subsequent distribution of that nursery stock, evaluated several options, and chose to respond with an eradication effort (with cooperation from involved nurseries and numerous others). The dissemination of infested stock was mapped as part of the response strategy, with detailing of primary, secondary, and tertiary distribution levels (Figure 8). One of the primary distribution points was a wholesale nursery in White River Junction, just 16 km (10 mi) east of MABI, and several secondary distributors and outplanting sites were located within 8 km (5 mi) of the Park (Figure 9).

Mapping of the distribution of hemlocks associated with HWA-infested shipments received by the two primary distributors indicated that 20 out of 39 (51.3%) secondary level distributors (retail nurseries, landscapers, and similar businesses or individuals) were not licensed or registered with the state (this is not required for landscapers and individuals). Registration or licensing in all these sectors is not likely to occur and there will clearly remain gaps. This can potentially cause time lags and information gaps for recall, tracking, and monitoring efforts (14 trees from the summer 2004 shipment were sold for cash by secondary level distributors and were not recovered in subsequent tracking/eradication efforts). Of particular note for MABI was a tree and land care business located less than 2 miles north of the Park. Should HWA establish in the area, removal and handling of infested materials by such businesses might warrant attention.

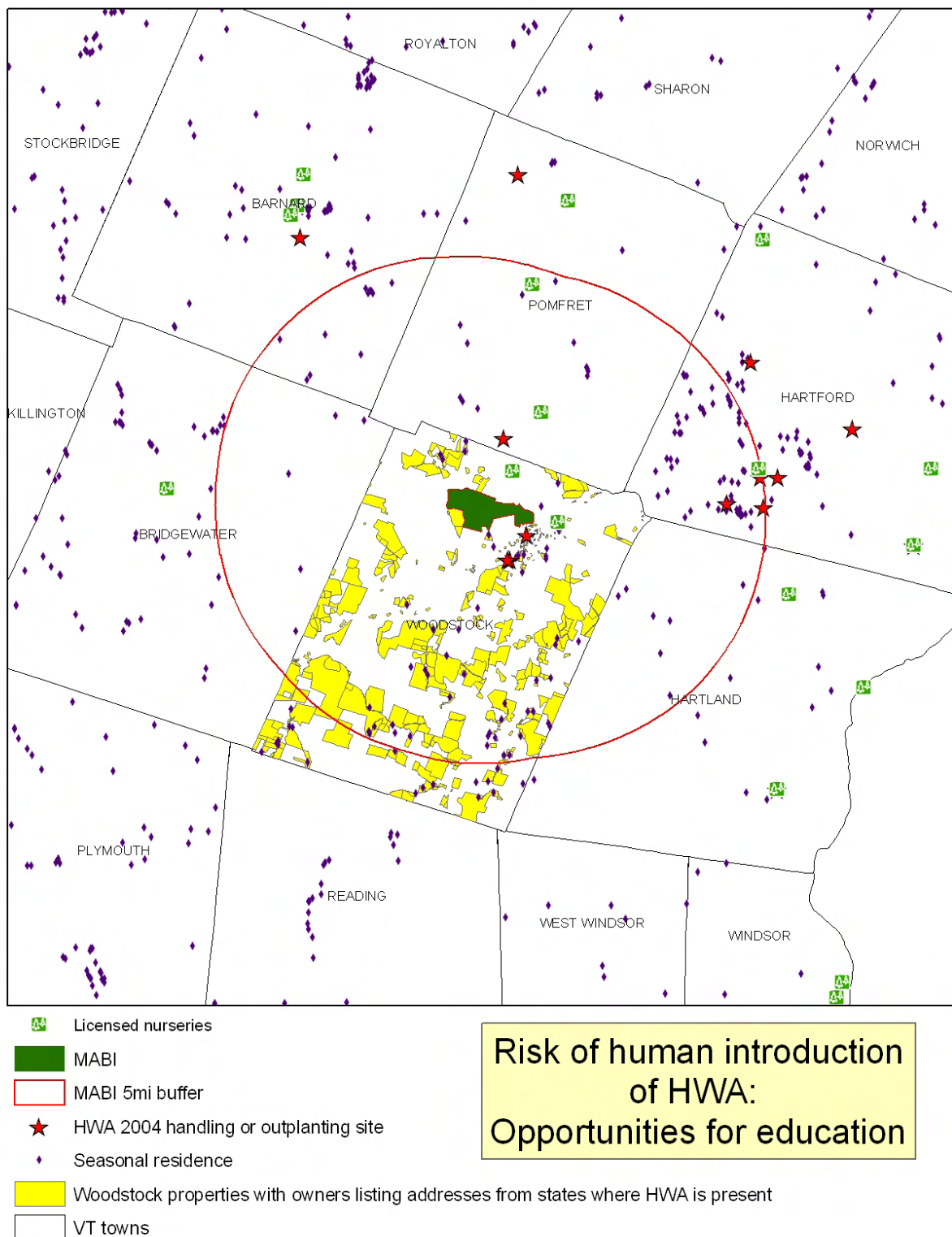


Figure 9. Risks for human introduction of HWA within 5 mi. of MABI.

Seasonal Residences: As of 2004, 143 seasonal residences were listed within a 5-mile radius of MABI (Figure 9). Additionally, contact information for Woodstock landowners indicates that 17.5% of property owners list addresses in states with documented HWA infestations, and these owners account for 27.8% of the property in Woodstock. Similar figures for surrounding towns were not available at the time of this report. The primary concern with seasonal residences and other out-of-state property owners is potential risk of introduction via transport of stock from infested areas, (Bofinger 2002; Ouellette 2002; Vermont Department of Forests, Parks, and Recreation, Barbara Burns, Protection Forester, phone conversation, Feb. 6, 2003). This issue may need to be evaluated more thoroughly if hemlock becomes difficult to obtain through the nursery trade.

Cover Type: Ample host material is provided by dense stands of hemlock (hemlock component 88% or more of stand basal area) in the southern and northwestern portions of MABI, with additional stands including hemlock components of 40% or more located in the northeast and northwest portions of the Park (Fig. 1). Hemlock is also a significant component of the northern hardwoods/hemlock complex through much of MABI, with hemlock components of 14% or more extant in several portions of the Park (Fig. 1). In a wider landscape context, hemlock distribution maps derived from USFS Forest Inventory Analysis plot data indicate estimated hemlock basal areas ranging from 1 to 10 m²/ha in the area surrounding MABI, presenting sufficient opportunity for spread of the insect (Fig. 10; Morin et al. 2005).

2. Resistance

Application of the HWA resistance index showed a wide range of values within the confines of MABI, with mean resistance index by stand ranging from a low of 0.324 ± 0.075 (sd) in stand 7 to a high of 0.874 ± 0.034 in stand 40 and a mean for all stands with hemlock components of 0.634 ± 0.178 (Table 1). A GIS-based format permits rapid visual assessment of additional risk factors such as the density of hemlock in these stands and the presence of legacy hemlocks, as well as the distribution of risk class areas within the stands (Fig. 11). Of particular note was the conjunction of low resistance index and high percentage of hemlock (RI 0.324 ± 0.075 , hemlock 93%) in stand 7, a dense hemlock stand that has grown up on the south edge of the Park and was recommended as important habitat for salamanders in the area (Faccio 2001). Stand 37b, a mixed hardwood-hemlock stand on the southeast side of the Park, showed a smaller 20% hemlock component but also had a low mean resistance index (RI 0.400 ± 0.164). Also of concern was stand 34. The resistance index for this stand was somewhat higher (0.563 ± 0.165), but the stand had a 26% hemlock component and some additional risk factors. This stand also included half of the legacy hemlocks present at MABI, and was identified as important habitat for amphibians, including a breeding population of the rare Jefferson's salamander (Faccio 2001).

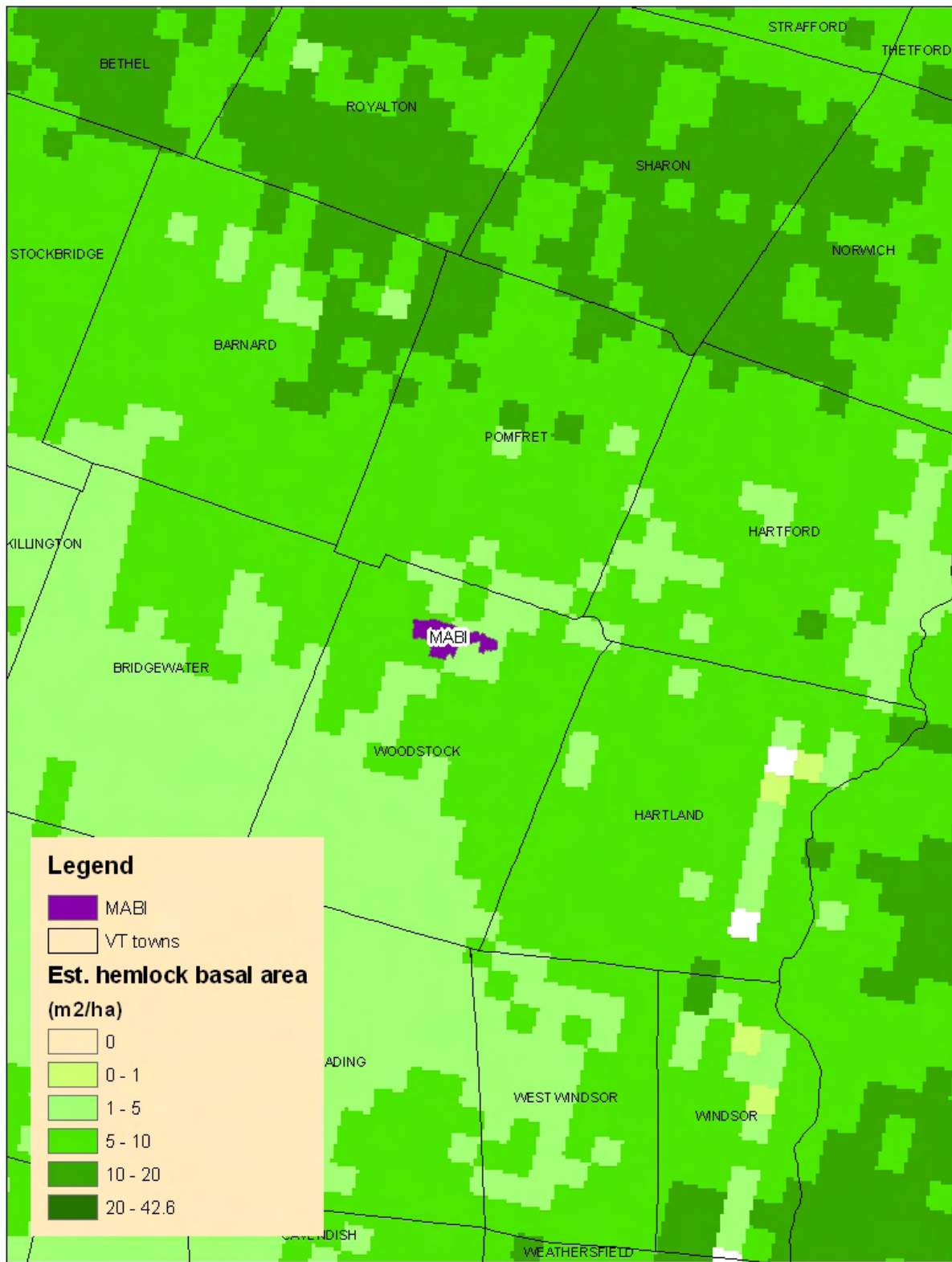


Figure 10. Landscape-scale estimates of hemlock basal area in area surrounding MABI indicate opportunities for HWA spread (FIA data, Morin et al. 2005).

Table 1. HWA resistance index values, acreage, percent hemlock, and age for forest stands with hemlock components, MABI 2004.

Stand ID	Mean	Stand Dev	Min	Max	Acres ¹	Pct Hemlock ²	Age
2	0.550	0.121	0.335	0.745	10.5	7	1887 and 1910-11
7	0.324	0.075	0.227	0.482	2.4	93	1900 and 1930s
10	0.562	0.173	0.241	0.771	7.1	3	1940s to 1960s
11	0.482	0.159	0.235	0.758	4.0	3	1800s and 1940s-50s
20	0.737	0.141	0.241	0.881	14.9	2	1900
21	0.686	0.144	0.299	0.855	32.0	40	late 1800s and 1920
25	0.502	0.048	0.413	0.547	1.6	13	1917
27	0.405	0.139	0.221	0.679	4.0	2	1896
30	0.518	0.190	0.219	0.877	15.3	14	1900 and before
31	0.552	0.182	0.281	0.815	15.8	17	late 1800s to early 1900s
34	0.563	0.165	0.230	0.817	30.0	26	late 1800s
37a	0.865	0.013	0.839	0.875	2.0	20	before 1900
37b	0.400	0.164	0.138	0.732	7.3	20	before 1900
38a	0.730	0.155	0.357	0.944	7.3	88	before 1900
38b	0.843	0.003	0.840	0.846	1.1	88	before 1900
39	0.798	0.119	0.298	0.945	84.1	12	1920s
40	0.874	0.034	0.824	0.946	5.6	43	1897
43	0.856	0.010	0.846	0.873	2.2	10	1880s
44	0.841	0.066	0.604	0.954	28.7	2	before 1900
45	0.471	0.101	0.249	0.722	15.8	8	1880s
46a	0.865	0.007	0.857	0.876	1.3	6	1880s and various
46b	0.528	0.128	0.364	0.832	5.8	6	1880s and various
All	0.634	0.178	0.138	0.954	298.9	24	

¹ Acreage calculations shown are based on cell resolution used for the resistance index model and may vary slightly from stand acreages indicated in the Forest Management Plan.

² Hemlock component as percentage of stand basal area.

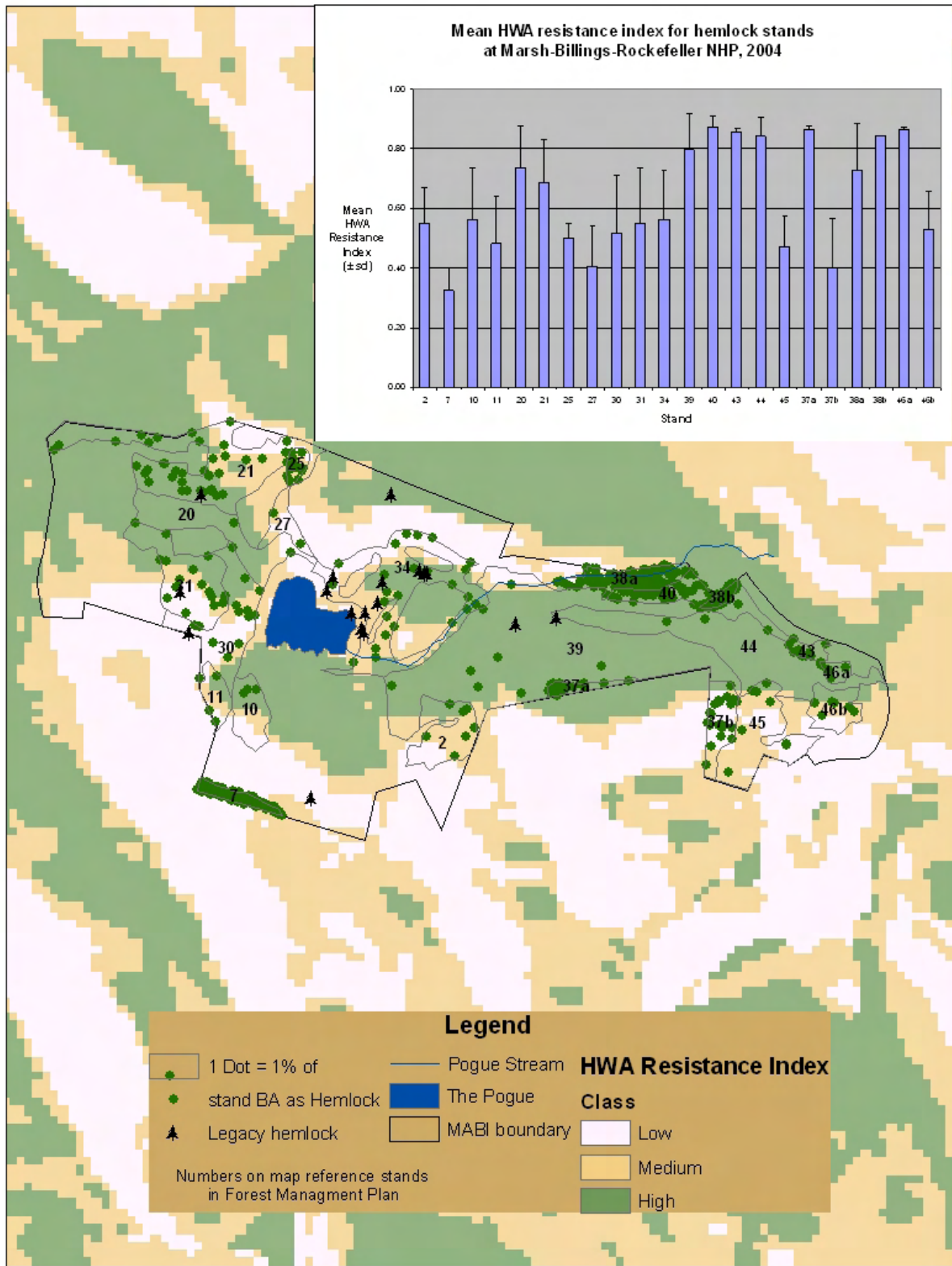


Figure 11. Resistance index mapping for stands with hemlock components, MABI 2004.

D. Discussion

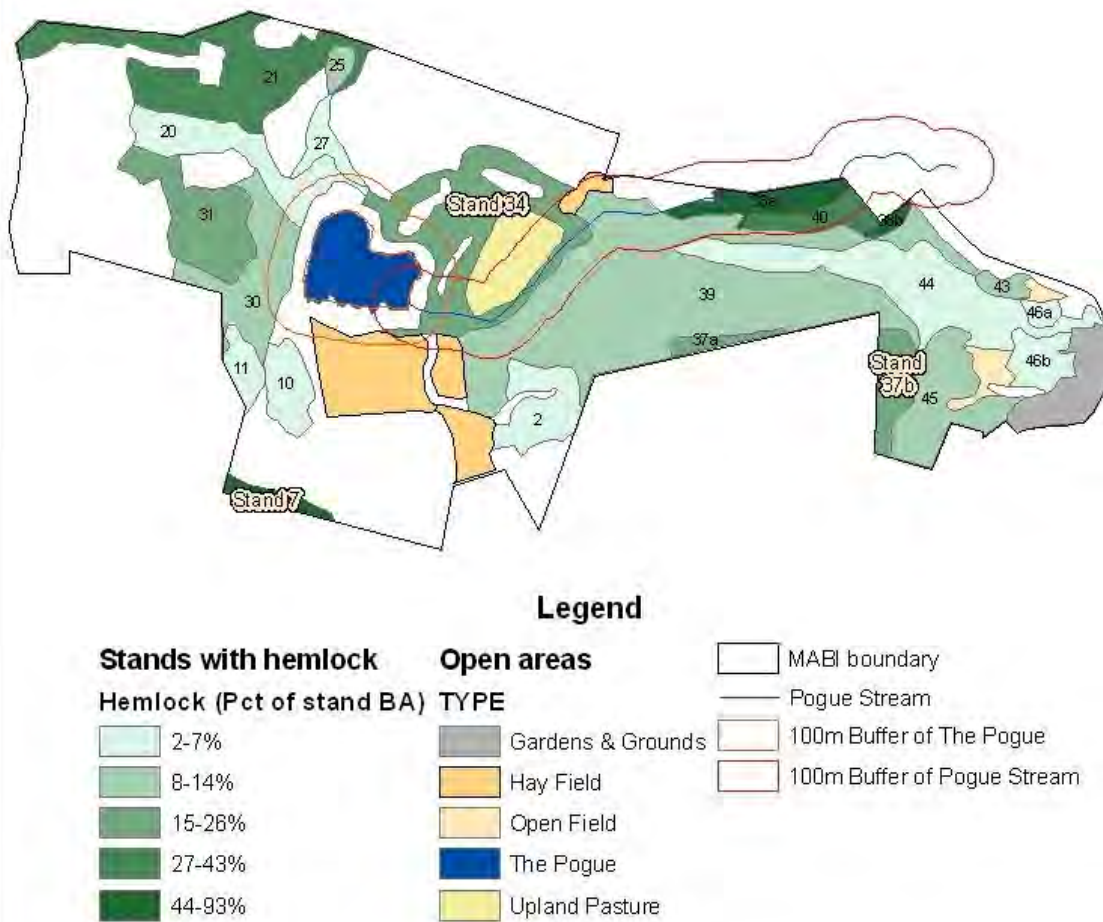
Analysis conducted for this risk assessment indicates several factors that warrant concern. MABI is located within 10 miles of the northern reaches of revised USDA cold hardiness zone 5a, the current limit of known persistent populations of HWA. Nurseries and seasonal residences dealing with hemlocks exist in close proximity to the Park, and nursery stock associated with infested shipments was recently either planted (though subsequently removed and destroyed) or handled at some of these locations. Hemlock is common in the surrounding area, allowing ample opportunity for natural dissemination of the pest. Some stands at MABI show low or moderate resistance index values in conjunction with additional risk factors such as open edges and proximity to streams.

Although MABI is located outside the current northern limits of HWA's range, concerns have been expressed that the insect may have the ability to adapt to lower temperatures (Parker et al. 1999). What appear critical for the survival of HWA are extreme minimum temperatures. The insect has the ability to rapidly expand populations, and unusually warm winters could conceivably favor HWA survival.

Additionally, some researchers have noted strong positive correlations between HWA damage and proximity to streams and open water. Though the dynamics of this relationship are not well understood, suspicions are that the relationship is at least partly due to thermal buffering. Overwintering insects may also be buffered against cold by snow cover on lower branches (Young et al. 1999; Kimple and Schuster 2002; McClure and Cheah 2002). Figure 12 indicates a 100-meter (the extent of positive correlations with HWA damage noted by this research) buffer surrounding the stream in the northeast portion of the park, which flows through one of the more dense stands of hemlock on the property, as well as a similar buffer surrounding the Pogue. These areas would be the only likely possibilities (given a warm winter) for the type of open water conditions researchers suspect may contribute to buffering of the insect against cold temperatures (though the Pogue freezes over during the winter months). The overlap of these buffers in stand 34 adds more considerations to the moderate resistance index, substantial hemlock component, numerous legacy hemlocks, and important amphibian habitat present in this stand. HWA infestations tend to progress most rapidly when there are numerous, healthy hemlocks present (McClure et al. 2001; Ward et al. 2004), and questions have also arisen concerning escalated dispersal of HWA in stream corridors due to use of these areas as travel corridors for birds in particular (Ward et al. 2004).

Further concerns arise for stand 34 regarding its proximity to a number of open areas (Fig. 12). Research on HWA impacts in hemlock stands of southern New York suggests that "edge effects" negatively correlate distance from the edge of the forest stand with HWA impacts on the stand, at least in early stages of infestation (McClure 1990; Kimple and Schuster 2002). Suggestions are that the pest subsequently proceeds in a relatively linear fashion through stands, but such factors even out over time (Kimple and Schuster 2002; Young and Morton 2002). Such research suggests possibilities of introduction in situations similar to the road, hayfield and pasture edges at MABI, but also implies that early detection in such areas might allow time for control strategies before progression to stand interiors (Kimple and Schuster 2002).

**Monitoring priorities:
Forest stands with hemlock components
in relation to open areas and
buffers of open water areas,
MABI 2004**



Numbers on map reference stands in Forest Management Plan

Figure 12. Factors affecting HWA monitoring priorities, MABI 2004.

The HWA life cycle (Fig. 6) suggests that detection and monitoring efforts could be focused in the fall and winter after aestivating nymphs become active again. Alternatively, spring monitoring could occur before deciduous leaf-out (and after potential impacts of winter HWA mortality). Since the pest population can increase quickly and damage tends to be heaviest in the initial year of an infestation, however, the trick would be to monitor early enough in the spring to permit effective control measures while population levels are low. The mean resistance values for the stands containing hemlock at MABI, along with the relative density of hemlock in those stands, suggest that stands 7 and 37b would be priority monitoring locations. Additionally, the edge effect noted above suggests that particular attention be focused on the exteriors of stands where boundaries occur with hayfields and roads, and contributes to the addition of stand 34 as a priority area.

The substantial component of hemlock in landscaping around the historic mansion grounds at MABI also warrants monitoring. For the extensive hemlock hedges in this area, this may simply involve HWA education and reminders for personnel maintaining these plantings. Larger specimen trees may need to be monitored for tree health (thinning foliage in particular), as foliage may be difficult to access for inspections. Branch inspections might be warranted should the insect be detected elsewhere in the Park, however, as these trees might be candidates for focused control strategies best launched at lower levels of infestation than foliage impacts would be apparent. Branch inspections would also be desirable for hedge plantings, as these trees are of a size that makes them prime candidates for focused control strategies (such as horticultural oil sprays) that would be greatly aided by close monitoring of insect populations (McClure et al. 2003; Ward et al. 2004).

If cold does not continue as a limiting factor in the northward spread of HWA, the prevalence and widespread distribution of hemlock in Vermont present ample host material for dispersal of the insect as well as a significant target for potentially substantial ecological and economic impacts. Vermont authorities charged with responsibility for managing forest pests (Vermont Agency of Agriculture and Vermont Agency of Natural Resources-Forests, Parks, and Recreation) have been proactive and effective in rapidly addressing previous introductions of HWA in Vermont. Tracking of the distribution of nursery stock associated with the 2004 importation of infested hemlocks, however, identified difficulties associated with detection and monitoring of HWA. Phytosanitary measures to eliminate, reduce, or limit the spread of plant pests are maintained by all states (NPB 2005; VSO 2005), and the infested hemlocks imported to Vermont were compliant with quarantine regulations in effect at the time (VFAAM 2004; these regulations were revised in January 2005 [VFAAM 2005]). However, the insects that came in with these shipments were not detected during required inspections before shipping. Additionally, numerous distributors in Vermont were not licensed with the state, complicating tracking and removal associated with eradication efforts (only nurseries require such licensing (VSO 2005) and it is debatable whether this is desirable in other sectors). Fourteen trees out of 843 initially imported to Vermont through two nurseries were eventually sold to private individuals for cash and have not been located.

Previous importations into the state had occurred both through nurseries and through seasonal residents who planted stock brought to Vermont from infested areas. Movement of stock by

seasonal residents or other individuals is difficult to monitor and could become more of an issue if hemlocks become more difficult to obtain through the nursery trade. The serious nature of this pest and potential implications for forest health suggest that focused educational efforts may well be warranted. It is our hope that the nurseries and seasonal residences information presented here offer an effective tool in assisting such efforts. Additionally, the Park's commitment to forestry education activities presents an ideal avenue for education efforts.

E. Management Recommendations

Given the assessment of HWA risk conducted for MABI, the following management recommendations are proposed:

1. *Continue to offer on-going prevention and education efforts.*
 - a. Distribute literature, including information conveying the concerns of the Park regarding HWA, to nurseries, seasonal residents in the area, and Park visitors.
 - b. Utilize forestry education activities conducted at MABI as an avenue to educate participants; consider including literature with workshop materials.
 - c. Set up a display at the visitor center to help visitors appreciate the hemlock resource at the Park and encourage closer attention to these trees, thereby engaging visitors as additional monitors. Make particular use of the legacy hemlocks.
 - d. Work with other local organizations (e.g., Woodstock Conservation Commission, Vermont Woodlands Association, etc.) to increase community and visitor awareness and involvement in HWA monitoring and prevention strategies.
2. *Conduct annual detection and monitoring efforts.*
 - a. A sampling methodology and monitoring sheets are currently available from the University of Vermont (Scott Costa, Department of Plant and Soil Science Entomology Lab, (802)656-5441, Scott.Costa@uvm.edu). Websites maintained by NPS (NPS 2004e) and the Pennsylvania Department of Conservation and Natural Resources (PDCNR 2004) have excellent information for monitoring strategies. These monitoring efforts can be coordinated with similar proposals for an overall IPM plan at MABI, which include annual visual assessments of all stands and more extensive tree health monitoring as part of regular five-year inventories (MABI, Christina Marts, Natural Resource Manager, phone conversation, Feb. 27, 2005).
 - b. Focus efforts in stands 34, 7, and 37b; also along The Pogue, Pogue Stream, and edges abutting open areas.
 - c. Consider Pogue and Pogue Stream detection efforts in the fall and winter because of the potential for higher survival of overwintering insects due to thermal buffering from the stream.
 - d. Conduct late winter or early spring efforts for other stands, focusing in particular on stand edges where adjacent to openings.

3. *Evaluate possible control strategies should the insect be detected.*

- a. Evaluations of many potential controls have been conducted, and the HWA bibliography database maintained on the USFS HWA website (USFS 2004) is an outstanding source for information and downloadable abstracts for many of these evaluations and research efforts. Additionally, the proceedings of the Third Symposium on Hemlock Woolly Adelgid in the Eastern United States (USFS 2005) contain up-to-date information on HWA control strategies. Broadly, potential control efforts include cultural, chemical, and biological controls as well as silvicultural management options (McClure et al. 2003; Ward et al. 2004). It is recommended that these options be more closely examined and that a response plan be developed for MABI.
- b. Cultural controls (mulching, irrigation during droughts, and avoiding nitrogen fertilizers) aim to aid resistance to HWA by maintaining the health and vigor of trees. Removing bird feeders near infested trees can help prevent spread of the insect by birds. (Ward et al. 2004).
- c. Chemical controls can only be considered a short-term, stop-gap measure for high-value trees. Horticultural oils and insecticidal soaps appear as effective as chemicals but require complete coating of the foliage. Soil-based applications of Imidacloprid appear effective but have associated water-quality risks, so less-effective stem injections of Imidacloprid have been recommended in areas where water quality is an issue (McClure et al. 2003; Ward et al. 2004). It is important to note that amphibian and reptile management recommendations presented for the Park (Faccio 2001) stress restriction of pesticide use for protection of these species.
- d. Cultural and chemical controls may be worth in-depth evaluation for hemlocks in the historic mansion grounds area at MABI in particular. Education and reminders concerning HWA for personnel maintaining these areas appear a cost-effective and worthwhile investment. Additionally, continued discussions by Park personnel (MABI, Christina Marts, Natural Resource Manager, phone conversation, Feb. 24, 2005) concerning careful consideration of sources for planting stock and possible in-house nursery production should be encouraged.
- e. Biological control efforts will likely require a complex of introduced organisms for long-term protection, rather than a “magic bullet” organism; rearing of these organisms has so far proved labor-intensive and costly, though introductions appear to be having success in some areas (Ward et al. 2004; USFS 2005). It is important to consider that biological controls have not been effective on stands that are already heavily damaged (predators need prey, and the prey needs food; no foliage means few insects as prey) (USFS 2005).
- f. Silvicultural options appear to favor “doing nothing” for ecologic reasons such as soil conservation, successional trends, and reduction of invasive plant incursions (USFS 2005). Safety, economic, and aesthetic considerations may figure prominently, however, and this would certainly be the case at MABI considering the network of trails in particular. In such cases, a number of options and Best Management Practices have been explored (Ward et al. 2004).
- g. The most effective long-term approach may be identification and conservation of resistant hemlock, if genetic resistance indeed exists (Ward et al. 2004; USFS 2005).
- h. Stands containing hemlock at MABI are not extensive in area, suggesting possibilities for focused control strategies, but these actions may not be effective if HWA is widely

established on adjoining parcels. Researchers and land managers currently dealing with these issues strongly recommend extensive communication and engagement of the public concerning evaluation and selection of chemical, biological, and silvicultural options in particular, including informational signs where management options are being implemented (Ward et al. 2004; USFS 2005).

4. *Develop a comprehensive NNIS risk assessment for MABI.*

- a. As part of the development of an Integrated Pest Management Plan for the Park, identify NNIS that present a risk and prioritize them to focus assessment efforts. Develop response plans and management recommendations that identify appropriate actions, actors, and support resources.
- b. Create a unified GIS based system that incorporates data and analysis applicable to current high priority NNIS, has the flexibility to be expanded in response to new threats, and incorporates invasive plant management as well as forest pests and pathogens to consolidate efforts and allow for long term tracking.

F. Adaptive Management

Adaptive management, a central operating tenet of MABI management philosophies, requires reassessment and revision of management as new information becomes available (Cortner 2000). Information on HWA is growing as continuing research is conducted, and should be periodically assessed for pertinent concerns. Research on fertilization of hemlocks indicated that nitrogen fertilization can increase HWA susceptibility and damage to hemlocks (McClure 1991b), and more recent research has indicated that high foliar nitrogen levels in hemlock are correlated with HWA damage (though it is not clear if this is cause, effect, or both) (Pontius et al. 2002). Our resistance model incorporates forest site productivity class (though not weighted heavily) as a factor contributing to hemlock resistance to HWA; research on these nitrogen factors may affect such an evaluation. Similarly, knowledge of the relationship between HWA and stream corridors needs further elucidation to clarify site, temperature, and other factors such as bird and animal transport of HWA. These factors may need to be incorporated into the model and the associated methodology to increase its effectiveness. Prescriptions for HWA control and silvicultural management options would also require monitoring and assessment for adaptive management if the insect becomes established in Vermont (Sharov 2004; Ward et al. 2004).

III. Consultation with Federal and State Agencies

NPS personnel are actively engaged in addressing mounting problems with NNIS, HWA among them. As such, websites maintained by NPS offer an excellent means for information and referral that is frequently updated (NPS 2004d; NPS 2004e; NPS 2004f). Similarly, the USFS HWA website has been mentioned previously as a central clearinghouse for information regarding this pest (USFS 2004).

HWA risk assessment in Vermont has been funded by the US Department of Agriculture Forest Service State and Private Forestry. The assessment has been conducted by Redstart Forestry and the University of Vermont, in cooperation with the Vermont Agency of Natural Resources Forests, Parks, and Recreation and the Vermont Agency of Agriculture and the Cooperative Agricultural Pest Survey (CAPS) program. All of these organizations are actively engaged in addressing HWA and represent valuable resources for the Park.

Conclusion

Although HWA has not established any persistent populations in Vermont as of 2004, concern and caution seem well warranted. Cold temperatures appear to be limiting the northward advance of the pest at this time, but historical progressions of other non-native invasive species (e.g., Chestnut blight, Dutch elm disease, beech bark disease, gypsy moth, emerald ash borer) have evidenced advancing fronts over time (Liebhold et al. 1995; Morin et al. 2005). Hemlock is a widespread and ubiquitous species in the New England landscape, presenting ample opportunity and corridors of movement for the pest. In addition, the long history of human movement of infested material should not be overlooked. Hemlocks are well-loved landscape plants, and lack of information concerning risks of transport can easily contribute to accidental introductions of HWA, as historical incidences confirm.

The hemlock woolly adelgid risk assessment conducted at Marsh-Billings-Rockefeller National Historical Park indicates significant risk factors present in the area. Hemlock plays a unique and particularly vital ecological role in the Vermont landscape. The active role of federal and state agencies in dealing with HWA indicates a fortunate opportunity for a high level of cooperation in continuing a proactive stance that can potentially limit HWA efforts in Vermont to prevention, early detection, and rapid response. MABI stands uniquely poised to take a key role in education concerning efforts to address HWA in particular. The presence of the legacy hemlocks at the Park, the support of the NPS Inventory and Monitoring Program, the Park's commitment to IPM, and the conservation and forestry interpretation and education that are part of the Park's mission provide exceptional opportunities for important work in addressing the challenge of HWA and other non-native invasive species.

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