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Eastern Hemlock Forests: Guidelines to Minimize the Impacts of Hemlock Woolly Adelgid

Cover photographs (clockwise from upper left): hemlock woolly adelgid (*Adelges tsugae*) ovisacs on hemlock needles (Michael Montgomery, USDA Forest Service), hemlock-shaded stream (Jeff Ward, The Connecticut Agricultural Experiment Station), and black-throated green warbler (©Mike Hopiak, Cornell Laboratory of Ornithology).

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Eastern Hemlock Forests: Guidelines to Minimize the Impacts of Hemlock Woolly Adelgid

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Introduction

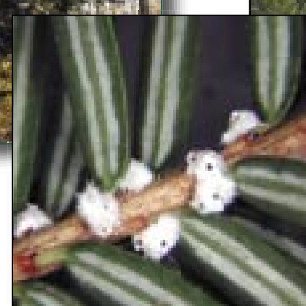
Eastern hemlock (*Tsuga canadensis*) is the most shade-tolerant and long-lived tree species in Eastern North America. Its unsurpassed ability to tolerate low light enables it to form dense canopies and stands that provide a unique habitat for many plant and wildlife species. Carolina hemlock (*Tsuga caroliniana*) is a relic species limited to a small area in the southern range of eastern hemlock. Both species are being threatened by the accidentally introduced hemlock woolly adelgid (*Adelges tsugae*).

Control of the hemlock woolly adelgid is a challenge. An unusual life cycle, presence of susceptible hosts, and a lack of natural enemies contribute to explosive population increases and rapid spread of the adelgid. Until effective controls are discovered, it is anticipated that the adelgid will continue to spread in eastern forests and mortality of hemlock will increase. Decline of eastern hemlock will lead to a loss of habitat diversity and a decrease in the esthetic beauty in many of our forests as hemlock is replaced by hardwood species such as black birch (*Betula lenta*) and red maple (*Acer rubrum*). Because hemlocks can survive for several years after initial infestation by hemlock woolly adelgid, forest managers have time to take steps to minimize its impact.

The primary purpose of this handbook is to help resource managers make informed decisions in preparing management plans and to provide an information bridge between managers with hemlock stands that are, or will be, infested with hemlock woolly adelgid, and the foresters who will implement salvage and rehabilitation activities. This handbook summarizes current scientific knowledge of the impact of hemlock woolly adelgid on eastern hemlock forests and the processes involved in rehabilitating hemlock stands that have been, or will be, damaged by hemlock woolly adelgid.

Healthy hemlock.

Dead hemlock.



Hemlock woolly adelgid ovisacs.

Part 1 of this handbook presents the biology and ecology of eastern hemlock and hemlock woolly adelgid. Part 2 provides guidelines to help managers make decisions regarding the salvage and rehabilitation of damaged hemlock stands in order to recover, to the extent possible, the ecological and esthetic attributes associated with hemlock forests.

Part 1. Biology and Ecology

Hemlock in the Eastern United States

Habitat

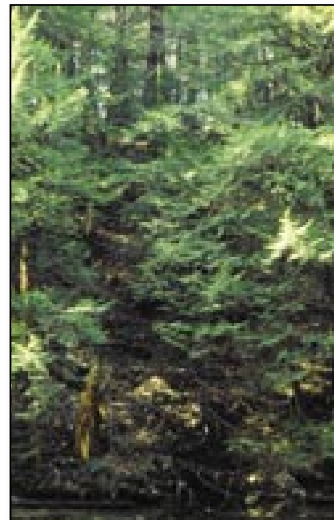
Eastern hemlock is an important component of northeastern and Appalachian forests, often forming nearly pure stands. It grows on almost 19 million acres of forest in the Eastern United States (Schmidt and McWilliams 1996) and is the predominant species on 2.3 million acres (McWilliams and Schmidt 2000). The range of eastern hemlock extends from Nova Scotia to Georgia and westward to Minnesota. The other hemlock growing in the East, Carolina hemlock, is limited to the Blue Ridge Mountains of the Southern Appalachians.

Eastern hemlock is a large, majestic tree that can live for 800 years or more (Godman and Lancaster 1990). A mature tree reaching over 175 feet tall with a diameter of more than 6 feet is among the largest specimens recorded. Although similar in appearance, mature Carolina hemlock is typically smaller, reaching heights of 55 feet and 2 to 3 feet in diameter on larger specimens.

Hemlocks add texture to the landscape.

Eastern hemlock is the most shade-tolerant tree species in the Eastern United States and is able to survive in the understory with as little as 5 percent of full sunlight (Godman and Lancaster 1990). This ability to survive in low light helps explain the deep canopy of hemlock that often extends almost to the forest floor.

Maximum rates of photosynthate storage in hemlocks occur on mild days during the dormant period (winter) when hardwood trees have shed their leaves (Hadley and Schedlbauer 2002). This adaptation enhances the ability of hemlock to develop under deciduous hardwoods.



Hemlock foliage often extends to the ground.

Eastern hemlock can be found on a wide range of sites from ridgetops to swamps. Like all hemlock species, it is intolerant of drought and typically occurs where soil is constantly moist (Farjon 1990). Although its soil requirements are not exacting, it occurs characteristically on moist to very moist, acidic soils with good drainage. Eastern hemlock is found on most topographic positions in the northern part of its range. It is restricted largely to coves and north- and east-facing lower slopes in the Southern Appalachians.

Ecological importance

The dense, evergreen canopy associated with mature hemlock forests creates a unique environment that is a critical habitat for many animal and plant species. The deep, dense canopy of eastern hemlock increases vertical structure heterogeneity in forests, and more than 120 vertebrate species utilize mature stands (DeGraaf and others 1992). Hemlock forests also provide thermal cover and forage for a variety of mammals, including porcupines (*Erethizon dorsatum*) and white-tailed deer (*Odocoileus virginianus*) (Reay and others 1990, Wydeven and Hay 1996). Nearly 90 species of birds can be found in hemlock forests (Benzinger 1994). Several species are significantly associated with hemlock forests (Tingley and others 2002), including the black-throated green warbler (*Dendroica virens*), Blackburnian warbler (*Dendroica fusca*), and Acadian flycatcher (*Empidonax virescens*).

Acadian flycatcher.

A wide variety of aquatic species is more likely to be found in streams sheltered by hemlock than streams sheltered by hardwoods. For example, both brook trout (*Salvelinus fontinalis*) populations and macroinvertebrate diversity were greater in hemlock streams in the Delaware Water Gap National Recreation Area by 300 and 37 percent, respectively (Evans 2002). Hemlock maintains aquatic habitat integrity by regulating streamflow and moderating water temperature (Evans 2002). Hemlock-shaded streams were found to have lower summer temperatures and were less likely to dry up.

Commercial value

Although overshadowed by its importance in augmenting terrestrial habitat diversity, maintaining aquatic habitat integrity, and providing esthetic appeal, the commercial value of hemlock is significant to rural economies. Eastern hemlock comprises 22 percent of the total volume of softwood growing stock in the Northeast (Powell and others 1993, table 18). Harvested trees are used for products as diverse as pulp and paper, lumber, and mulch. Hemlock was estimated to be 7 percent of the sawlog and 12 percent of the annual pulpwood harvest in New England in 1999 (McWilliams and Schmidt 2000, page 9).

Hemlocks are a valuable commodity in some areas.

Hemlock Woolly Adelgid

The hemlock woolly adelgid is tiny, less than 1.5 millimeters (1/16 inch) long, and varies from dark reddish-brown to purplish-black in color. Except for the newly hatched nymphs, it has a covering of wool-like wax filaments that it produces to protect itself and its eggs from desiccation and natural enemies. This "woolly" wax is a characteristic of all adelgids and is most conspicuous when the adelgid is mature and laying eggs. The best time to see these woolly "ovisacs" (see cover) is from late fall to early summer.

The adelgid is an unusual insect that feeds during the cooler part of the year and is inactive during the hot summer months. By feeding during above-freezing periods in late fall, winter, and early spring, the hemlock woolly adelgid has access to photosynthate and other nutrients that are abundant in the hemlock twigs then, and also avoids generalist natural enemies that are inactive at this time. Evidence of the nutritional benefit of feeding during "leaf off" is that this overwintering generation lays about twice as many eggs as the following spring generation.

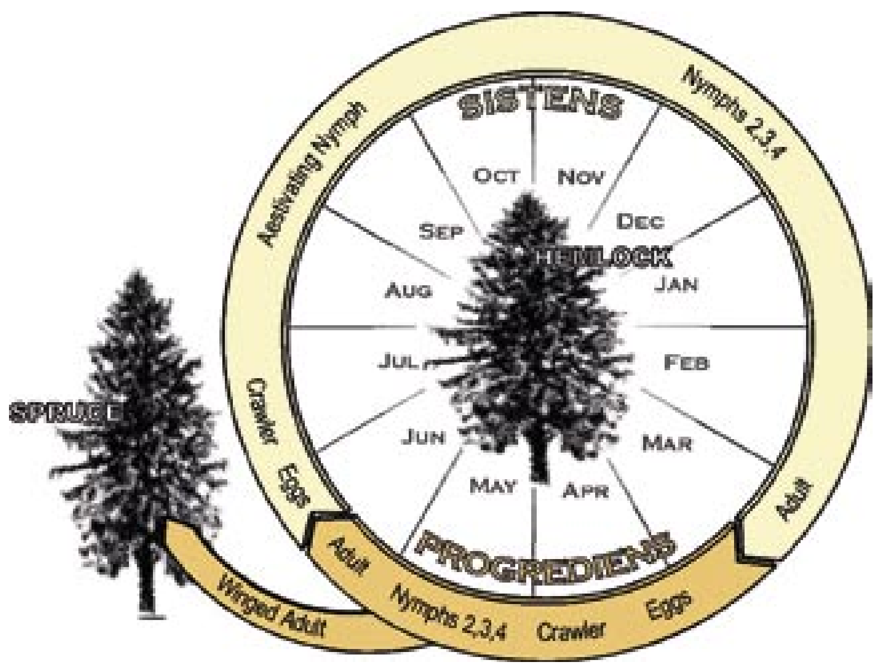
Adult hemlock woolly adelgid and eggs in the ovisac.

generations overlap in middle to late spring (McClure 1989) and the exact time of occurrence of each phase of the life cycle is influenced by local climate. Generally, egg laying is well underway before the first wildflowers appear in early spring.

The egg masses, or ovisacs, produced by the unmated females in late winter/early spring contain up to 300 eggs (McClure and others 2001). These eggs usually start to hatch in April and May into mobile, reddish-brown nymphs that crawl on the branches and can be dispersed between trees by wind and animals. Most of these "crawlers" settle on the twigs produced the previous year, the same twigs that their mothers settled on 9 months earlier. The nymphs have long mouthparts, or stylets, that are inserted at the

Life Cycle

The life cycle of hemlock woolly adelgid in Eastern North America consists of two complete parthenogenetic (all-female) wingless generations on hemlock: the *sistens* (winter generation), whose development spans 9 to 10 months from early summer to midspring of the following year, and the *progrediens* (spring generation), which occurs from spring to early summer. These

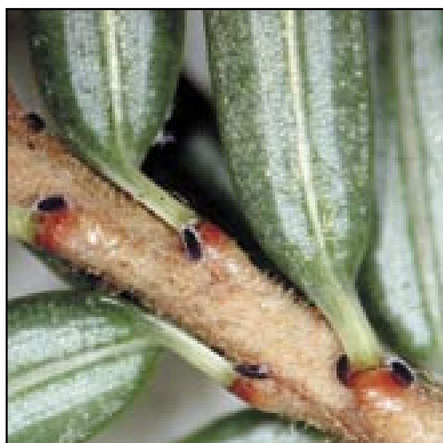


Hemlock woolly adelgid life cycle.

base of the hemlock needles and travel to the xylem ray parenchyma cells in the twig to obtain nutrients (Young and others 1995). They remain at the same feeding site on the hemlock twig, developing through four nymphal stages before they become adults in early June.


Hemlock woolly adelgid crawler nymphs.

These spring generation adults generally lay eggs between mid-June and early July (McClure 1989), although timing is again influenced by temperature, latitude, and elevation. The number of eggs produced (around 20-75 eggs) is smaller than that of the winter generation. The eggs hatch in early July and the emerging crawlers disperse and settle preferentially on the new shoots of hemlock produced in June. However, these nymphs do not feed and instead enter a summer dormancy period called estivation that lasts from July to October. The nymphs are inconspicuous at this time, producing only a tiny halo of woolly wax (above).

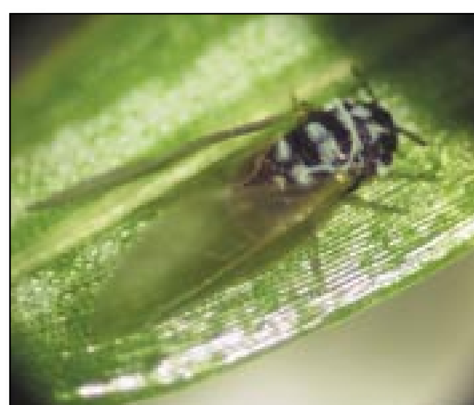

Hemlock woolly adelgid nymphs in summer estivation.

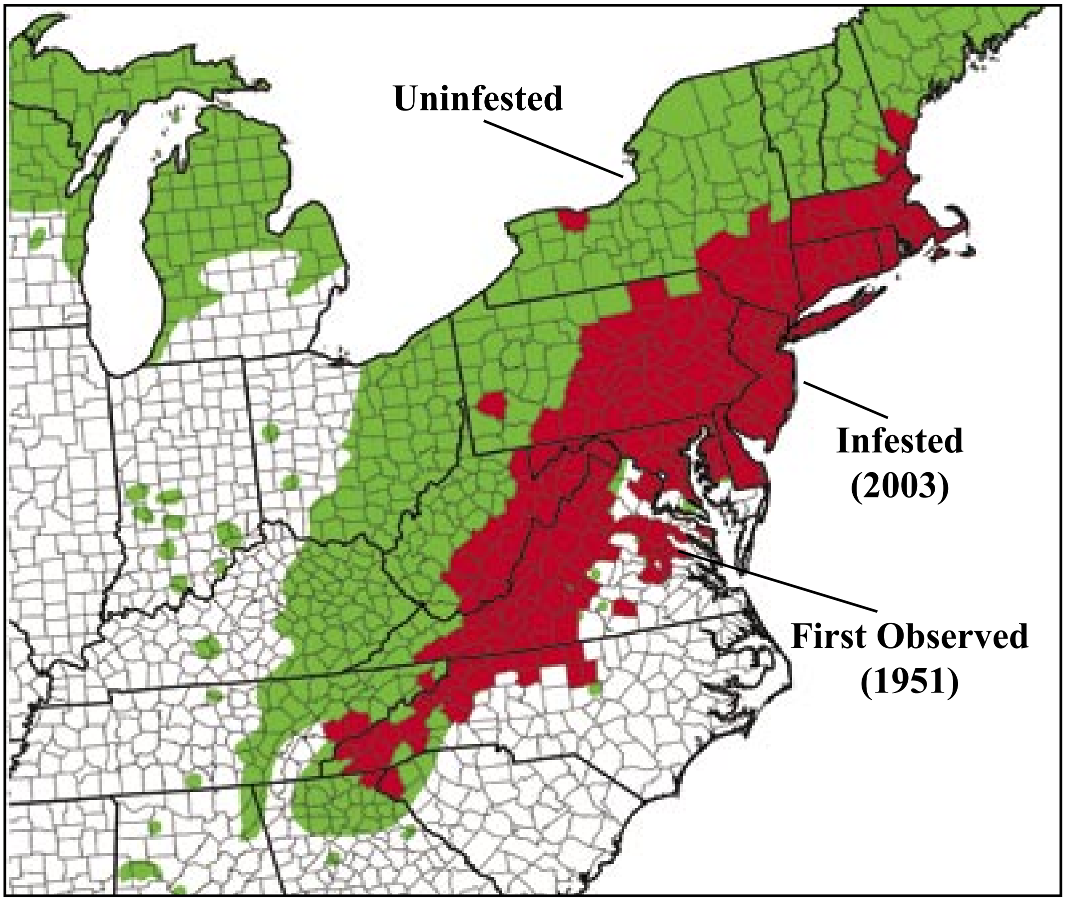
A portion of the spring generation nymphs develops into winged adults (sexuparae) that fly from the hemlock in search of a spruce tree to begin sexual reproduction. In North America, however, a suitable species of spruce does not occur and their offspring do not survive (McClure 1989). The relative abundance of the winged form is density dependent, and a greater proportion is produced when the health of the host tree is declining (McClure 1991a).

When cool temperatures begin to prevail in October, the nymphs of the winter generation break dormancy and swell as they begin feeding. The nymphs develop during the winter; thus, the life cycle on hemlock is completed. This life cycle of two all-female generations each year, timed to avoid periods when predation would be high, makes the hemlock woolly adelgid capable of explosive rates of population increase, especially during the initial stages of infestation on healthy hemlocks.

Dispersal

First discovered and described in Oregon (Annand 1924), hemlock woolly adelgid was initially detected in the Eastern United States in a private plant collection


Winged adult hemlock woolly adelgid.



Distribution of hemlock (green) with area infested by hemlock woolly adelgid (red).

in Richmond, Virginia, in 1951. For several decades, the hemlock woolly adelgid was not considered a significant pest because it had not damaged hemlocks in Japan, Taiwan, and Western North America.

At first, hemlock woolly adelgid spread slowly in the Eastern United States. Its discovery in southeastern Pennsylvania did not occur until 1969. Infestations now range from northeastern Georgia to southeastern Maine and westward to eastern Tennessee. In the last decade, hemlock woolly adelgid populations have been expanding rapidly at the southern, western, and northern fringes of its range. Rates of hemlock woolly adelgid dispersal have been estimated at 20 to 30 km per year (McClure and others 2001, Morin and others in press).

Adelgid eggs and crawlers are easily transported by wind, wildlife (especially birds), humans (McClure 1990), and infested nursery stock (Gibbs 2002, Ouellette 2002). Eggs and crawlers of both generations of hemlock woolly adelgid generally are present from late March through early July in the Northeast; therefore, care should be taken when transporting hemlock products from infested areas through healthy hemlock regions during this period.

The spread of hemlock woolly adelgid northward has been more rapid along larger watercourses and coastal areas. This may reflect the moderating effect of large bodies of water on climate. Another factor favoring the spread along watercourses may be the movement of migratory birds along riparian corridors.

Climate may limit the spread of hemlock woolly adelgid, or at least slow its spread northward. Populations can be dramatically reduced by extreme winter temperatures or sharp downward temperature fluctuations during abnormally mild winters. Laboratory studies of northern field-collected adelgids showed that none survived at -30 to -40 ºF (Parker and others 1999, Skinner and others 2003). In the forest, hemlock woolly adelgid mortality rates greater than 90 percent were observed when temperatures fell below -5 ºF in Connecticut (Cheah and McClure 2002).

Cold may limit the spread of hemlock woolly adelgid.

Research and management efforts to slow the rate of spread and limit the impacts caused by hemlock woolly adelgid are underway, but it is unknown to what extent these efforts will be successful, particularly in the forest environment. Therefore, it is possible that most eastern hemlock stands in the Eastern United States could become infested within several decades, except perhaps for the very coldest regions.

Damage to Hemlock by the Adelgid

Adelgids cause damage by depleting the hemlock's starch reserves, which in turn reduces the tree's ability to grow and produce new shoots. While hemlocks in Western North America and Eastern Asia are believed to be resistant, eastern hemlock and Carolina hemlock are very susceptible and can die within a few years from unchecked, heavy infestations of hemlock woolly adelgid. All age and size classes of hemlock are susceptible to adelgid infestations.

Mortality of eastern hemlock is usually a slow process, occurring over a 2- to 12-year period, or longer, after the initial infestation (McClure 2001, Mayer and others 2002, Orwig 2002). Hemlock decline is characterized by a reduction in new shoot production in infested parts of the crown followed by needle drop, branch tip dieback, thinning of the foliage, lower branch dieback, and finally tree mortality (McClure and others 2001).

Other major factors that influence the rate of hemlock decline are stressors such as drought, poor site conditions, and

Dying hemlock.

insect and disease pests—elongate hemlock scale (*Fiorinia externa*), hemlock looper (*Lambdina fiscellaria fiscellaria*), spruce spider mite (*Oligonychus ununguis*), hemlock borer (*Melanophila fulvogutta*), root rot disease (*Armillaria mellea*), and the needlerust *Melampsora parlowii* (Godman and Lancaster 1990, Souto and Shields 2000). Hemlock mortality has been most severe in parts of Connecticut, New Jersey, Virginia, and parts of Pennsylvania (Orwig and Foster 1998, Bair 2002, Evans 2002, Mayer and others 2002, Orwig and others 2002).

Hemlock borer infestations become evident when woodpeckers remove bark in search of beetles.

As mortality occurs, many hemlock stands will be replaced with deciduous species, such as black birch and red maple (Orwig and Foster 1998, Orwig 2002). The replacement of the hemlock component of the eastern forest by deciduous hardwoods will have long-term ecological and esthetic impacts at both local and regional scales. One important consequence will be the loss of habitat diversity and quality for terrestrial ecosystems.

Loss of eastern hemlock will also impact adjacent riparian habitats. Increased nitrate leaching is possible following extensive hemlock mortality due to increased nitrification rates and inorganic nitrogen availability (Jenkins and others 1999). These changes have potential ramifications for both stream productivity and deterioration of water quality in watersheds that provide public drinking water.

Another insidious threat, especially in forest preserves, is the steadily increasing deer herd. Eastern hemlock is a preferred browse species of white-tailed deer (Alverson and others 1988). Survival and growth of seedlings are greatly reduced by deer browsing (Ward 2002). In areas with large deer herds, hemlock seedlings may be sparse or almost absent (Frelich and Lorimer 1985). Thus, dying hemlocks are not replaced by hemlock seedlings, but by other species such as black birch and red maple.

Hemlock regeneration is limited by deer browsing.

Part 2. Guidelines for Managers

Planning and Monitoring

One of the concerns of forest managers is predicting when stands infested with hemlock woolly adelgid will experience damage and mortality. Until effective biological controls, tree resistance, or practical chemical pesticides can be developed (see the section on controlling hemlock woolly adelgid), managers should anticipate damage to hemlock stands within several years of the initial infestation. Fortunately, steps can be taken to speed recovery and minimize the impact that the loss of hemlock will have on ecosystem functions and esthetic values. To avoid crisis management, these steps should be initiated before the onset of widespread hemlock decline and mortality. As noted above, there are several years between initial infestation and marked stand mortality. Thus, there is usually ample time for thorough planning.

Management decisions are generally driven by 1) resource management objectives, 2) site and stand conditions, and 3) economic resources available to implement a course of action. The decision of which option to follow will take careful consideration and planning. Management options include harvesting stands before notable decline, salvage harvesting (removal of dead and dying trees), felling trees without removing them, protecting individual trees using biological controls or insecticides, and doing nothing.

Development of a management plan that will establish priorities, standards, and practices will facilitate objective decisions and allocation of limited resources. Engaging local input during the planning stages will provide an opportunity to educate concerned citizens about the potential negative consequences of "letting nature take its course" (such as hazard trees, lower esthetic values, and spread of alien plants) and about the financial considerations of alternative methods of dealing with stands damaged by hemlock woolly adelgid. Local public officials should be included in the planning process to identify regulatory issues and remedies, if needed, before implementing any management activities.

Obtain public input during field tours.

This section provides information not only for prioritizing the location of management operations (e.g., salvage cutting) and reestablishment of an evergreen conifer component, but also for monitoring the progression of an adelgid infestation.

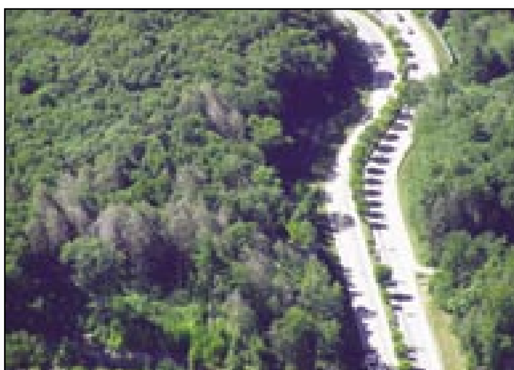
Prioritizing hemlock stands

Criteria for determining management priorities should include economic, ecological, and esthetic factors:

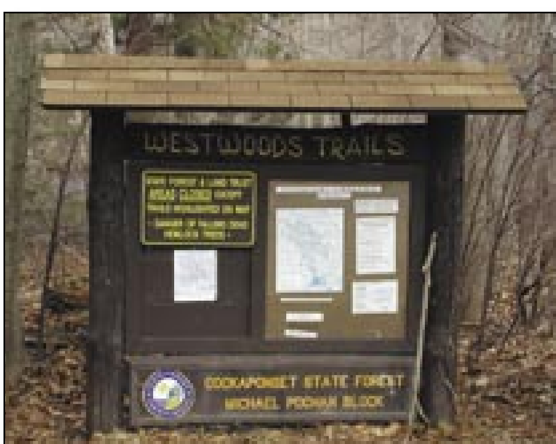
- *Economic criteria* for determining priorities should include public safety (hazard tree management), restoration costs, hemlock woolly adelgid control costs, public water supply quality, wildfire potential, and potential for viable salvage harvest (accessibility and merchantability).

- *Ecological criteria* should include habitat protection of endangered and threatened species, regeneration potential, current condition of hemlock and rate of potential decline, streambank and water quality protection, vulnerability to invasive species, and availability of alternative evergreen cover for wildlife.

- *Esthetic criteria* (visual impact) should include declines in tourism and visitors due to decreased quality of the recreational experience, trail or facility closure, and the presence of standing dead trees or significant logging slash. Slash is the residue (twigs, branches, and unmerchantable logs) left after logging (Helms 1998).



Consider visual impacts.



Trails may be closed by hemlock woolly adelgid.

Locating all stands with a significant hemlock component, in most cases, is easily done using existing aerial photography. Other useful sources for locating hemlock stands include infrared digital orthophotographs and Landsat (satellite) images. Some States and Federal units have GIS maps of hemlock stands. For each stand with a significant hemlock component, consider stand characteristics, site quality, tree characteristics, and the potential for rehabilitation.

Stand characteristics

Each stand should be examined for relevant stand characteristics, such as age, diameter, volume, and accessibility. In addition to the usual forest stand inventory measurements, stands should be ranked (or rated) by the esthetic, cultural, and ecological values provided by their existing hemlock component. Ecological values should include water quality (riparian buffer integrity) and wildlife habitat, especially for species of special concern, such as the Blackburnian warbler and brook trout.

Site quality

An important component for prioritizing stands should be site quality. Hemlocks growing in better moisture regimes generally survive a hemlock woolly adelgid infestation better than those on drought-prone or waterlogged sites (Mayer and others 2002). Generally, hemlocks on southwest-facing slopes experience more rapid mortality than those on northeast-facing slopes (Orwig and others 2002). Stands deep in ravines seem more tolerant of the adelgid than those stands on benches at the top of a ravine.

Tree characteristics

Selection criteria should also consider predominant tree characteristics within the stand. Desirable attributes include healthy trees with medium to large crowns and trees with good stem form. When genetic preservation is important, a local hemlock population with adaptations to regional differences in climate, soil, and photoperiod (Olson and others 1959) should be protected from hemlock woolly adelgid to provide a seed source for reintroducing hemlock. Chemical control will be required to maintain the health and vigor of trees in these stands until an effective biological control is developed. Therefore, stands should be selected that have good accessibility to facilitate chemical treatments and future seed collection. These stands will also provide a reminder of the importance and grandeur of hemlock forests.

Rehabilitation planning

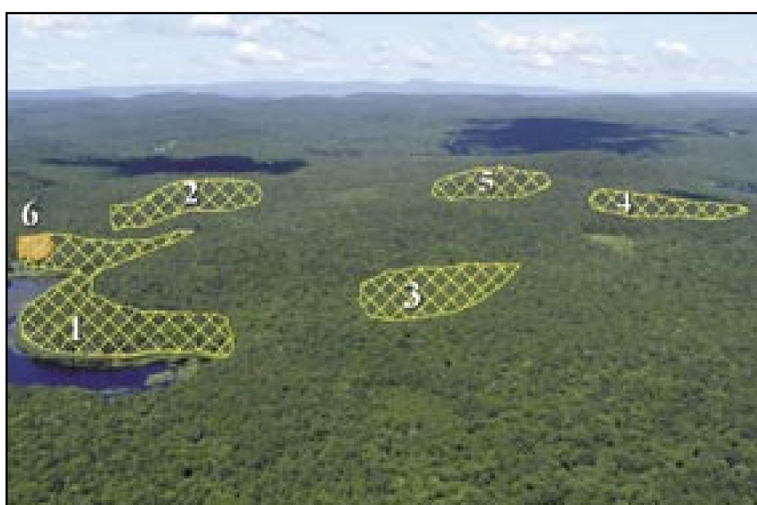
The goal of rehabilitation is to speed recovery of at least some of the unique ecological and esthetic attributes of the hemlock forest. Because of the cost associated with rehabilitation activities, it may be necessary to have a protocol established for prioritizing hemlock stands as part of the planning process. Unique stand characteristics and the relative importance of factors, such as riparian buffer integrity (water quality), wildlife habitat, and esthetic and recreational values, should be considered. Accessibility and the presence (or lack) of regeneration might also serve as criteria for prioritizing hemlock stands.

Control of alien invasive species, such as burning bush (*Euonymus alatus*) and Japanese barberry (*Berberis thunbergii*), should be considered because they may crowd out native shrubs and herbaceous species. Where alien invasive species are a potential problem, monitoring and eradication will be necessary in the rehabilitation process.

Ideally, selection of replacement species will also be made during the planning phase. Unfortunately, no native conifer species has the combination of unique attributes (evergreen, shade tolerant, soft foliage texture) of eastern hemlock. Therefore, forest managers will have to select a species that best achieves management objectives for each particular site (e.g., stream shading). Selection criteria should consider the importance of 1) using species native to Eastern North America, 2) growth rate, 3) response to competition, 4) resistance to browse damage, 5) site limitations, and 6) availability.

Monitoring adelgid populations

Monitoring is an integral part of the process to determine when hemlock woolly adelgid populations have increased to the level that hemlock trees will be impacted. Monitoring



Prioritize hemlock stands for treatment and restoration.

hemlock woolly adelgid in a stand need not be time consuming. It is helpful to know when the stand was first infested and when the infestation became generally distributed on most of the trees in a stand. Once a tree is infested, it takes several years before the tree becomes generally infested and damage is visible. The lag between initial infestation and widespread mortality usually provides the forest manager with ample time for developing a rehabilitation plan.

Yearly inspection of hemlocks for the presence or absence of the hemlock woolly adelgid will be sufficient for many management plans. The objective of this inspection is to determine if the adelgid is present in the stand, and if so, to what extent. Initially, the distribution of the adelgid is patchy, occurring only on a few trees and limited to small areas on those trees. Although the adelgid density can be sufficiently high on one or two branches on a tree to cause needle loss and twig death, the stand will show little sign of damage until the adelgid becomes more widely distributed.

Inspect hemlocks yearly for hemlock woolly adelgid.

An inspection may consist of simply walking through the stand and looking closely at a few branches on several trees. November through early July is the best time to inspect because the adelgid is easier to detect by the presence of its woolly masses. A good sample size for a grove of a few acres is 10 to 25 trees and 2 to 4 branches per tree. The criteria for determining when to treat will depend on a local cost-benefit analysis. Earlier reports noted that hemlock growth dramatically slowed or stopped when the proportion of twigs infested was greater than 45 percent (Evans 2002) or there were at least 30 hemlock woolly adelgid per 100 needles (Mayer and others 2002). At these infestation levels, the decline in overall appearance and health of the tree becomes visible.

Monitoring infested stands

When no chemical control will be conducted, it may be more effective to monitor tree condition rather than hemlock woolly adelgid populations. In stands where chemical treatments will be implemented, monitoring pest densities and tree condition is absolutely vital to ensure treatments will be conducted before noticeable decline in the health and vigor of individual hemlock trees. Examples of such areas include exemplary groves of mature hemlock, campgrounds, green belts along scenic parkways and streams, specimen trees, and areas that will be conserved as a local seed source. Monitoring tree condition is essential in stands that will have a commercial, or break-even, salvage cutting. Although hemlock trees generally survive years after the initial infestation, sudden mortality is not uncommon for visibly declining trees during a period of extended drought. To offset costs, it is important to harvest trees before they die and become unmarketable.

Controlling Hemlock Woolly Adelgid

Research and practical experience have shown that it is possible to control hemlock woolly adelgid in small hemlock groves or on individual trees. Treatments are most effective if they are initiated before hemlock woolly adelgid populations have reached detrimental levels and tree health has been compromised. The challenge is to develop cost-effective methods of controlling hemlock woolly adelgid in hemlock stands and across the landscape. In the interim, the following measures can be followed to maximize the survival of trees in high-priority areas.

Light hemlock woolly adelgid infestation.

Cultural controls

Healthy hemlock trees can tolerate higher densities of hemlock woolly adelgid better than can trees with low vigor. Therefore, it is imperative to maintain the health of threatened trees (McClure 1995). Prophylactic steps can be as simple as mulching to maintain soil moisture and irrigating during periods of extended drought. Quarantines must be observed to limit movement of hemlock products such as logs, firewood, and seedlings from infested areas into areas that are not yet infested. States with hemlock woolly adelgid quarantines include Maine, New Hampshire, Vermont, and Michigan at this time.

Bird feeders should be removed near hemlocks because birds are known to transport both egg masses and crawlers for long distances. Removing isolated infested trees may also help to slow the spread of hemlock woolly adelgid. Nitrogen fertilizer should **not** be applied because this enhances adelgid survival and reproduction (McClure 1995). Recovery of trees treated with insecticides may be assisted with moderate applications of fertilizers that address specific nutrient deficiencies.

Chemical controls

While a number of insecticides can be effective in controlling hemlock woolly adelgid on individual trees (McClure 1991b), the high cost of treatment limits insecticide use to protecting individual high-value trees. Chemical treatment is not a permanent solution and applications have to be repeated at intervals ranging from several months to a few years. Insecticides should be chosen that have the least impact on beneficial insect and mite predators. Pyrethroids are effective against hemlock woolly adelgid (Cowles and Cheah 2002a) but are toxic to predatory mites and could prevent establishment of specialist predatory beetles being released for biological control of hemlock woolly adelgid. It is important to read and follow the instructions on the pesticide label before using any treatment to ensure compliance with all laws to protect the environment. Many pesticides can only be applied by a licensed pesticide applicator.

Horticultural oil or insecticidal soap sprays have been found to be effective in controlling hemlock woolly adelgid on accessible trees (McClure 1995, Cowles and Cheah 2002a). Oil has special value because it is also effective against rust mites, spider mites, and armored scales while being relatively nontoxic to certain predators (Cowles and Abbey 1999). However, the need to thoroughly coat the insect renders these products impractical for tall trees or large areas.

Systemic treatments, such as the use of imidacloprid, are increasingly used by arborists to control hemlock woolly adelgid. Unlike oil sprays, imidacloprid has little value in controlling armored scales or mites, and may temporarily lead to greater populations of these pests (James and Price 2002). Various formulations of this chemical are labeled for soil and trunk injection. Soil application can provide multiple years' benefit for hemlock woolly adelgid control (Cowles and Cheah 2002b, Webb and others 2003, Cowles and others 2004), but there is a paucity of information on the impact on aquatic and soil organisms. Trunk injection may be better suited for locations where there is special concern for minimizing the release of imidacloprid in these environments. While trunk injection may provide protection for several months (McClure 1991b, Doccola and others 2003), soil injection provides longer protection and does not wound the tree (Cowles and Cheah 2002b).

Some insecticides can be injected into the soil.

Biological controls

The hemlock woolly adelgid is not a native species and consequently has few natural enemies in Eastern North America. Restoring and maintaining hemlock as an important component of eastern forests will ultimately depend on development of effective biological controls. Predators already established or native to Eastern North America are generally not effective in reducing populations to nondamaging levels (Montgomery and Lyon 1996, Wallace and Hain 2000). Several predators known to feed exclusively on adelgids have been imported and are being investigated for biological control (McClure 2001, Reardon and Onken 2004). It is likely that a complex of natural enemies (introduced predatory insects and diseases), rather than a single "magic bullet," will be needed to maintain hemlock woolly adelgid below damaging levels.

The first predator to be imported and released for biological control in infested Eastern States is a tiny, black lady beetle (*Sasajiscymnus tsugae*) from Japan (McClure and others 2000). To date, nearly a million *S. tsugae* have been released in over 100 sites in 15 Eastern States from Georgia to Maine.

Several species of lady beetles (*Scymnus* sp.) from China and a derodontid beetle (*Laricobius nigrinus*) from British Columbia have been imported and the establishment of these predators is just beginning. Efforts

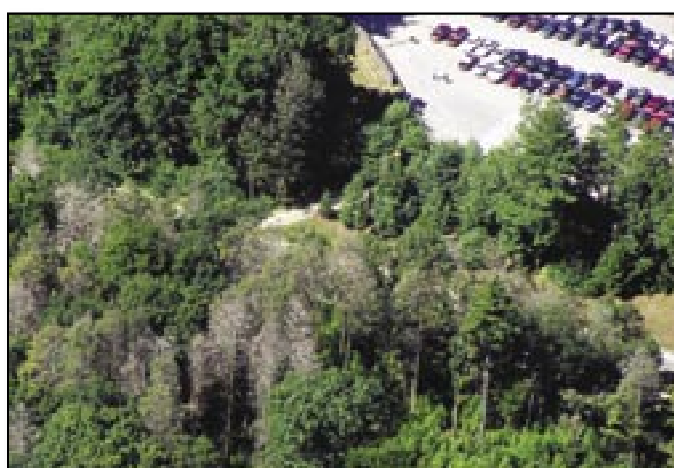
Beetles released for biological control (left to right: *Sasajiscymnus tsugae* from Japan, *Scymnus ningshanensis* from China, and *Laricobius nigrinus* from British Columbia).

to locate, evaluate, and establish additional natural enemies will continue to be a high priority for research and forest health practitioners in the coming years (Reardon and Onken 2004).

Managing Salvage Harvests

Harvesting trees that are dead or dying to recover their economic value is classified as salvage cutting (Helms 1998). Salvage cutting in hemlock stands, especially before complete mortality, has sparked public controversy in some areas. As mentioned under the section on management planning, objective salvage standards that have included public input will help allay concern over cutting “old-growth forests.” Failure to salvage hemlocks dying from hemlock woolly adelgid has lead to park closures in New Jersey (Mayer and others 2002) and Connecticut. Such parks may remain closed for 10 years or more until the slowly rotting hemlock snags are no longer a public safety hazard.

Although it may be tempting to retain hemlocks with some green foliage during the salvage operation, it should be recognized that hemlock mortality increases sharply when more than 80 percent of needles are lost due to defoliation (Stephens 1988). Studies in Connecticut found that up to 80 percent of hemlocks left after the initial harvest died within several years (Orwig and Kizlinski 2002). Hemlocks killed by hemlock woolly adelgid near roads and trails must be removed to ensure public safety. This removal will require additional expenditures that could have been avoided if the trees were harvested in the



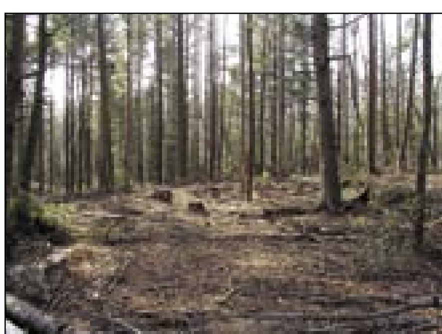
Dead hemlocks should be removed near roads.

initial salvage operation. Any hemlocks left in the hope that they will recover should be at least 200 feet (or twice their height) from roads and trails.

Special care must be taken to protect residual evergreen trees and shrubs during the salvage operation for several reasons. First, residual evergreens can preserve some of the esthetic and ecological values that had been provided by hemlock. The presence of established evergreens will also help speed recovery. Studies have shown that smaller trees and shrubs can grow quite rapidly when exposed to the increased sunlight that occurs after a harvest such as a hemlock salvage operation. Finally, remediation costs will be lower if residual evergreens are protected. Planting and nurturing new trees is expensive. It is much more cost effective, and ecologically sensitive, to protect those plants that are already growing on the site.

Evergreen shrubs should be protected during harvesting.

Slash standards (height and amount) will vary depending on proximity to streams, public viewpoints, and whether the area will be replanted. Although high slash may protect regeneration from browse damage, low slash is preferable in areas with high public visitation and where new conifers will be planted. Salvage cutting standards should also include the number of residual snags (standing dead trees) for raptors and species such as woodpeckers. Residual snags should be set back from trails and roads to minimize risk to the public from falling trees and branches.



Light slash left after logging.

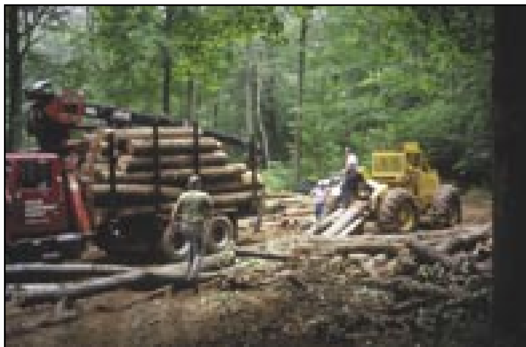
Best management practices

Salvage cutting, indeed any harvesting, requires careful planning before the harvest, monitoring during the harvest, and control measures after the harvest to protect forest soils and water quality. These practices are commonly called Best Management Practices, or BMPs. The intent of BMPs is to minimize movement of soil from a harvested area to adjacent wetlands and riparian zones.

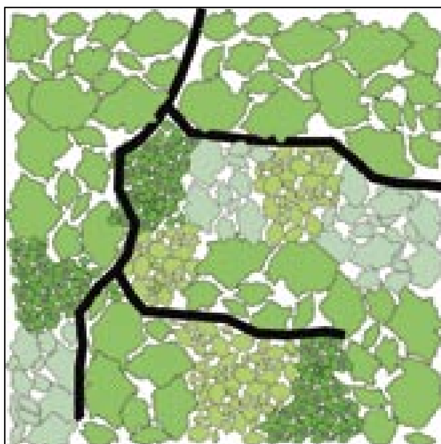
This section is intended to be an introduction to BMPs for land managers who are unfamiliar with forest harvesting operations, including salvage cutting. This section is not meant as a detailed technical guide, but rather a starting point for communication between land managers and practicing foresters who are familiar with local forests, soils, and regulations. More detailed guidelines and pertinent State and local regulations can be obtained from the State Forester's office, Cooperative Extension Service, or the Internet (http://www.stateforesters.org—follow links to Best Management Practices). Because hemlock often occurs near riparian areas, it is especially important to be aware of State regulations regarding activities near watercourses.

Before the harvest

Skidding is the hauling of logs from the forest to a collection point (landing) where they can be loaded onto a truck (Helms 1998). Wiest (1998) provides a detailed guide for forest road construction. The network of skid roads and trails by which harvested trees are removed from the forest is the largest source of soil erosion. Erosion on this network can be greatly reduced by carefully locating all skid roads and trails before harvesting. Where practical, skid roads should be located on gentle slopes with well-drained soils. Road grades should be kept as low as possible, and sediment-control structures should be installed before the road is used, especially on steep grades.



Loading logs at the landing.



A well-designed road system can provide a trail network.

Another key to reducing sedimentation is to minimize the number of stream and wetland crossings. Never allow skidding (hauling logs) down or directly across a streambed. A bridge or culvert must be used to cross perennial streams. In many instances, a corduroy road (small trees and culls) may be placed on one, or both, approaches to the crossing. A corduroy crossing may also be appropriate for intermittent streams that do not have running water. Placement and construction of these structures is beyond the scope of this handbook and should be discussed with a professional forester.

The landing is where harvested logs are stored before being loaded onto trucks for shipment to a mill. The landing should be located on level ground with excellent drainage to minimize soil erosion. Sediment-control systems, such as hay bales, may be appropriate to control soil loss for landings on gently sloping land. Locating the landing where it is not immediately visible from public roads may reduce public criticism. Lastly, require a barrel on the landing for oil cans and trash.

Buffer zones around wetland and riparian areas should be delineated and clearly marked (Welsch 1991, Welsch and others 1995). Use of heavy equipment in these zones may be fully or partly restricted depending on soil

Temporary bridges protect streams.

type and the amount of saturation. Whenever possible, trees should be felled away from streams to minimize damage to streambanks and prevent debris dams. Many States also require that a minimal level of residual trees (expressed as number of trees or basal area per acre) be left near watercourses to protect streambanks. Felling and leaving trees parallel to the slope (along the contour) on steep slopes may also help reduce erosion.

Before the salvage cutting operation, accessible trails should be rerouted to maintain public safety from falling branches and trees. It is also important to keep all-terrain vehicle, motorbike, and mountain bike traffic off skid trails in salvage areas. These stands are already vulnerable to erosion because of dead root systems.

During the harvest

The primary focus during the salvage harvest is to ensure that the cutting plan and all BMPs are followed. Doing this will require periodic inspections during the harvest operation. A primary concern during these site visits will include ensuring that skidding stays on designated roads and trails to minimize sediment movement. During periods of extended rainfall or a thaw during the winter, it may be necessary to halt skidding in some sections with saturated soils. Inspection will determine that equipment entrance into the buffer zones is in accordance with the cutting plan. The skidder and other equipment should be examined for leaks that would contaminate wetlands and streams.

Professional loggers cause little damage to live trees.

Inspection will also determine that those trees marked for cutting, and only those trees, are harvested. This part of the inspection will examine the residual trees (those left after cutting) to determine that reasonable care is being taken to protect them from damage during felling and skidding operations. Because existing evergreen trees and shrubs will help speed recovery of the unique attributes that had been provided by hemlock, special attention should be paid to their protection. Lastly, the inspection will ensure that slash and stump heights are within the guidelines of the cutting plan to speed esthetic recovery of the forest. This is especially crucial for those areas with public access.

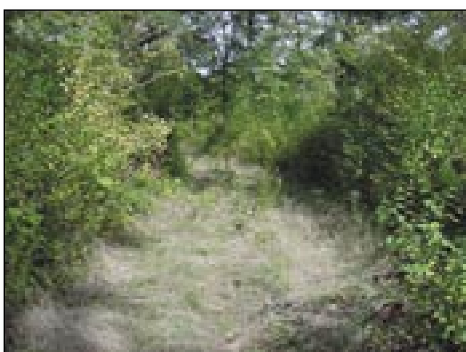
Trees should be protected from logging damage.

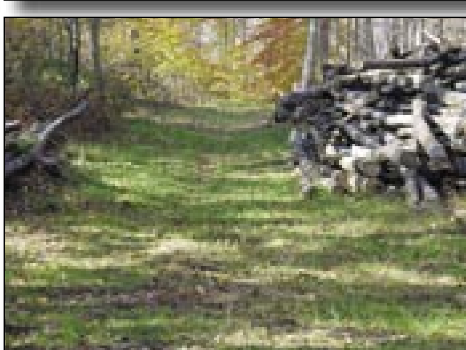
After the harvest

The primary focus after the harvest has been completed is to minimize sediment movement by stabilizing exposed soil. This involves smoothing the skid roads, installing water bars (if needed) to divert water, and then seeding the roads. Brush can also be placed on skid roads to slow waterflow and discourage their use by motorized vehicles and mountain bikes. In areas with soils that are susceptible to erosion, it may be advisable to use additional sediment-control measures, such as staked hay bales or silt fences.

All temporary stream- and wetland-crossing structures should be removed and the approaches should be graded to nearly the original condition. All graded areas should be quickly reseeded. Planting shrubs native to the area can also help stabilize the soil. Because these areas are of special concern, it is important to err on the side of caution and install sediment-control measures immediately after the crossing is no longer needed. It may be necessary to fence off streambanks adjacent to parks, picnic areas, and trails with high visitor use to protect the site from trampling until new vegetation has become established.

The landing should be smoothed, seeded, and have sediment-control structures installed where needed. The landing also provides an excellent opportunity to install a wildflower meadow, thus increasing local habitat diversity and beauty (Jones 1993). It is important to keep motorized vehicles and mountain bikes off the landing and road network at least until the new vegetation has become established.





Seeded skid trail (above) and log landing (below).

Rehabilitation

Rehabilitation is the restoration of some of the ecological or esthetic attributes associated with hemlock forests before they were damaged by hemlock woolly adelgid. As noted earlier, hemlock forests destroyed by hemlock woolly adelgid will often be replaced by hardwood species, such as maple and birch. The resulting forest will have quite different ecological attributes and habitat diversity. In some cases, it may be possible to begin restoration before salvage operations by encouraging regeneration of desirable species, such as white pine (below). Prescriptions for increasing regeneration could include thinning, prescribed burning, or underplanting with seedlings from a tree nursery. Fencing may be required where seedlings may be damaged by deer browsing. Destruction of new seedlings by trampling in parks and along trails with high public use can be reduced by a combination of fencing, improved trail delineation, and educational signs. More detailed information

White pine regeneration after hemlock mortality.

on regenerating forests can be obtained from the State Forester's office, the Cooperative Extension Service, or Ward and Worthley (2003).

New seedlings can be obtained from tree nurseries.

An important step in restoring damaged stands is to limit the spread of alien invasive species. A combination of an ability to grow in shade and high resistance to browse damage allows several alien species to form dense patches that can exclude native shrubs and wildflowers. Controlling alien invasive species is best done by eradicating established plants before hemlock mortality to limit vegetative growth and seed production. Continual monitoring and eradication may be necessary to eliminate new seedlings.

Prevent alien invasive species from becoming established.

In the forest, two alien invasive species are especially common in areas of high deer density: burning bush and Japanese barberry. Both species have been listed as widespread and invasive throughout much of the Eastern United States. Other alien invasive species of concern include Asiatic bittersweet (*Celastrus orbiculatus*), Japanese stiltgrass (*Microstegium vimineum*), Norway maple (*Acer platanoides*), and various honeysuckles (*Lonicera* sp.).

Species selection

Planting alternative evergreen species to replace hemlocks that were killed by hemlock woolly adelgid can restore some of the ecological or esthetic attributes that were lost. Do **not** replace hemlocks with single species plantations. The unfortunate reality is that other exotic insects and diseases will probably be introduced. Replacing eastern hemlock with a monoculture may well create a similar problem

Plant mixed species where hemlock was lost.

for future resource managers. A properly planned planting with a diversity of species will look like and function as a natural stand. Using evergreen shrubs during the initial planting will increase their survival and growth, and have the additional benefit of increasing habitat diversity.

Irregular planting, as opposed to planting on a grid, will also enhance the natural appearance of the stand as it develops.

Potential native species for planting include eastern white pine (*Pinus strobus*), red pine (*P. resinosa*), pitch pine (*P. rigida*), eastern redcedar (*Juniperus virginiana*), northern white-cedar (*Thuja occidentalis*), balsam fir (*Abies balsamea*), Fraser fir (*A. fraseri*), Atlantic white-cedar (*Chamaecyparis thyoides*), red spruce (*Picea rubens*), and white spruce (*Picea glauca*). Several native broadleaf species could be used to provide low evergreen cover. These include American holly (*Ilex opaca*), inkberry (*Ilex glabra*), rhododendron (*Rhododendron maximum*, *R. catawba*), and mountain laurel (*Kalmia latifolia*).

Non-native conifer species that may be planted include Norway spruce (*Picea abies*), Colorado spruce (*Picea pungens*), Douglas-fir (*Pseudotsuga menziesii*), sawara (*Chamaecyparis pisifera*), cedar of Lebanon (*Cedrus libani*), English yew (*Taxus baccata*), and western hemlock (*Tsuga heterophylla*). There are also three Asian hemlock species that are resistant to hemlock woolly adelgid and have been grown in arboreta and ornamental settings in the Eastern United States: northern Japanese hemlock (*Tsuga diversifolia*), southern Japanese hemlock (*Tsuga sieboldii*), and Chinese hemlock (*Tsuga chinensis*).

Studies are underway to develop hemlocks with resistance to hemlock woolly adelgid that are suitable for eastern climates. Hybrid crosses between the Asian species and *T. canadensis* have not been successful, but hybrid crosses between *T. caroliniana* and *T. chinensis* have provided viable hybrids (Bentz and others 2002). Other studies seek to identify the chemical nature of resistance to hemlock woolly adelgid in hemlocks (Lagalante and Montgomery 2003). Hopefully, hemlock with characteristics of the eastern species that are resistant to the adelgid will be available in the future.

Norway spruce (left) and eastern white pine (right) are evergreen species that can be planted following hemlock mortality.

Planting operations

Planting operations require careful orchestration of personnel, planting stock, planting equipment, and browse protection (if needed). Seedlings are perishable and should be planted as soon as possible after they are delivered from the nursery. Ensure that the planting site is accessible and that the amount of slash will not impede operations prior to receiving planting stock. Volunteers used to assist in planting should have appropriate training. Unless the planting will be contracted, it will be necessary to provide sufficient planting bars, shovels, and planting bags for all personnel.

Reestablishing an evergreen component in forests that were once dominated by eastern hemlock will be especially difficult in areas with large deer herds. Eastern hemlock and other conifers are preferred browse species (Alverson and others 1988). Deer browse damage on nursery seedlings is higher than on naturally established seedlings.

Rigid mesh tubing can reduce browse damage.

Planting evergreens, especially white pine and hemlock seedlings, in areas with high deer populations is a waste of material and labor unless deer browse protection is provided (Ward 2002). The decision to use browse protection, and the type of browse protection used, should only be made after a careful analysis of the costs. In some circumstances, it may be more cost effective to use larger seedlings; however, the cost effectiveness of using larger hemlock seedlings should be fully examined.

Planted eastern white pines protected from deer browsing.

Lastly, a plan should be developed to monitor and control hardwood competition. Conifer seedlings are often overtopped by hardwood regeneration. These competitors can limit the amount of available light (Salonius and Beaton 1997). Height growth and survival of overtopped seedlings will be greatly reduced. A machete or brush hook can be used to remove larger hardwoods until the conifer seedlings have become well established with vigorous crowns.

Reintroducing hemlock

In the short term, the reintroduction of eastern hemlock should only be considered if the trees will be monitored and protected from future adelgid infestations. Controlling adelgids on small trees can be easily accomplished using horticultural oils applied with backpack sprayers, but annual inspections should be conducted to ensure timely applications.

Once effective biological controls have been developed, the need for continued chemical applications should be minimal or unnecessary. Seed could be collected from those hemlock trees that were protected to produce seedlings adapted to the region. The expertise gained from planting other conifer species can then be applied to reintroduce eastern hemlock. In areas where deer densities are high, the experience gained in establishing other evergreens will be especially crucial in deciding on effective barriers to prevent browse damage.

Summary

- Develop a management plan before adelgid infestations and hemlock damage occur.

- Identify those stands that are at risk and prioritize them for treatment according to ecological, esthetic, and economic values.

- Monitor the prevalence of hemlock woolly adelgid and hemlock health.

- Preserve valuable hemlocks with appropriate cultural and chemical controls and encourage the establishment of biological controls where possible.

- Protect public safety by removing dead and dying hemlocks near roads and trails.

- Conduct harvest operations using Best Management Practices to protect forest soils and water quality in adjacent wetlands and riparian areas.

- Establish evergreen cover, where possible, with mixed species plantings to restore some of the ecological and esthetic characteristics that had been provided by hemlock.

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