Framework for Genetic Conservation of Eastern (*Tsuga canadensis*) and Carolina (*T. caroliniana*) Hemlock

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Background

Native hemlock in eastern US are threatened by a number of biotic and abiotic stressors, but hemlock woolly adelgid is the most severe. Global trade and travel have accelerated the pace of introduction of invasive forest insects and pathogens to an unprecedented level. Carolina hemlock, which has a very limited range, could face extinction within the next decade. Eastern hemlock populations are expected to be drastically reduced and some populations may be completely eliminated. The genetic resources of these species will be irreversibly lost if these drastic reductions in population size occur without careful preparation. Changing climates have resulted in increased risks from drought, fire, and native forest insects and pathogens. Some of our native tree species face the threat of local or range-wide extinctions, along with subsequent negative impacts on the ecosystems within which they reside. Strategies and action plans are needed to guide national gene conservation efforts for the most threatened species. To address these concerns, a workshop was held at the USFS Dorena Genetic Resource Center on October 11-12, 2007. One outcome of the workshop was a General Framework for Genetic Conservation. The framework outlines the steps needed to develop genetic conservation plans for these threatened species or groups of species.

Overview

Hemlocks are critical components of eastern forests. Their genetic resources are irreplaceable and critical to the maintenance of the species and the ecosystems that depend on them. These genetic resources can be conserved though a variety of approaches, including *in situ* methods in which plants are protected in their native habitats subject to natural evolutionary processes, and *ex situ* methods in which genetic material is stored at off-site locations such as in seed banks, genetic resource plantations (*e.g.* provenance and progeny tests), and seed orchards. A robust gene conservation strategy is being developed for eastern and Carolina hemlocks that combines elements of both approaches based on knowledge of species genetic structure, and the perceived threat to individual species whether from natural disturbance processes, introduced insect and pathogens, or sensitivity to changing climate. These should be supported by effective management policies and strategies to conserve and ultimately restore the species.

Strategic Rationale

This framework assumes that a forest tree species (or closely related groups of tree species) has been previously identified as needing immediate attention to conserve genetic resources due to imminent local or range-wide extinction, and that prompt action is needed to conserve genetic resources. Applying this general framework will help ensure that all facets of genetic conservation are considered in the development of species-specific plans.

Organizing Framework

The following steps are a general framework for genetic conservation of the hemlock species that are native to eastern US. Swift action on these items is needed to protect the genetic resources of these species. Some additional analyses may continue after initial actions have begun and serve to refine efforts as the work progresses.

1. Organize working group

The eminent threat posed by the hemlock woolly adelgid across the eastern United State has lead to the formation of a National Working Group to address this threat in a concerted manner. This working group is composed of partners from numerous State and Federal agencies from Maine to Georgia as well many other non-government organizations. These partners have help develop direction and set priorities within the hemlock adelgid arena. The working group has several technical committees one of which deals with hemlock genetics. This technical committee provides overall direction as well as oversight within the realm of hemlock genetics. Within this technical committee is a subgroup whose focus is the conservation of hemlock genetics. The coordination of this effort will fall upon representatives within the US Forest Service along with other partners. This group will take the lead role in the project to develop the conservation plan as well as gather and secure the genetic resources of the two eastern hemlock species. This effort will be cooperative in nature and involve numerous stakeholders from both the public and private sector. For the Forest Service (FS), the Regional Geneticists, Area Geneticists, Research Geneticists and Genetic Resource Centers are key contacts in developing and implementing this plan. Collaboration with other genetic conservation efforts such as the National Genetic Resources Program of USDA Agricultural Research Service (http://www.ars-grin.gov/) and the Center for Plant Conservation at the Missouri Botanical Garden (http://www.centerforplantconservation.org/) will also be pivotal in this process. Rare plant program managers will become involved if either hemlock species is listed (or could potentially be listed) as Threatened or Endangered under the Endangered Species Act.

2. Identification of threats

Risk assessment and evaluation of current and future threats to the long-term sustainability of hemlock species and ecosystems.

- Threats include:
  - o **Invasive Insects** Hemlock Woolly Adelgid (HWA, *Adelges tsugae*) is the single greatest threat to eastern (*Tsuga canadensis*) and Carolina (*T. carolin-*

iana) hemlock genetic resources in the Eastern US and is the primary focus of this conservation framework. The adelgid has the potential to cause local and range-wide extinctions of both hemlock species.

The Elongate Hemlock Scale (EHS, *Fiorinia externa*) is also an exotic insect that attacks eastern hemlock. It is not nearly as damaging to hemlocks on its own, but its co-occurrence with HWA can hasten tree decline and death.

- o **Climate** Severe drought across the southeastern US during 2007 and 2008 has exacerbated adelgid related mortality in the region. Additionally, drought is one of major factors that limits the establishment and long-term survival of hemlock seedlings and can eliminate the majority of advance regeneration in impacted stands (Godman and Lancaster 1990).
- o **Disturbance Events** Severe drought increases the risk of widespread wildfires. While mature hemlocks are reasonably tolerant of fire, seedlings are not. Similar to drought, this can significantly reduce the amount of advance regeneration present in a stand (Godman and Lancaster 1990).
- o **Salvage Harvests** Salvage harvests are often recommended to landowners who wish to recover some monetary value from mature stands of hemlocks prior to significant HWA infestation or decline. These may result in the loss of important hemlock genetic resources (Ward et al. 2004).
- o **Climate Change** Several climate change scenarios suggest significant reductions in the amount of suitable habitat for hemlock species in the eastern US. McKenney *et.al*. 2007 predict that potential eastern hemlock habitat will be eliminated in the southeastern US and drastically reduced in the northeastern United States by 2100. Iverson and others predict hemlock forest type reductions of up to 40% in the northeastern portion of the country (Iverson et al. 1999, Iverson and Prasad 2002).

  The changes in climate that are predicted will require unprecedented rates of migration by hemlocks. The ability of these species to migrate will be severely compromised by the drastically reduced populations, cone production and rates of natural regeneration caused by HWA.

- Evaluation and status of current, imminent, and future threats
  - o Hemlock Woolly Adelgid:
    - – **HWA Distribution and Population Levels** As of December 2007, the hemlock woolly adelgid could be found infesting native hemlock stands in 17 eastern US states from Maine to Georgia (Figure 1). Infested counties are noted in brown, but this does not indicate the severity of the infestation. HWA population levels are highly variable from year to year and are impacted by weather patterns (*e.g.* in the Northeast extreme cold winter temperatures typically reduce adelgid density) and host tree health.
    - – HWA Genetic Variation and Virulence Mitochondrial DNA analysis indicates that the adelgids that occur in the eastern US have very limited genetic

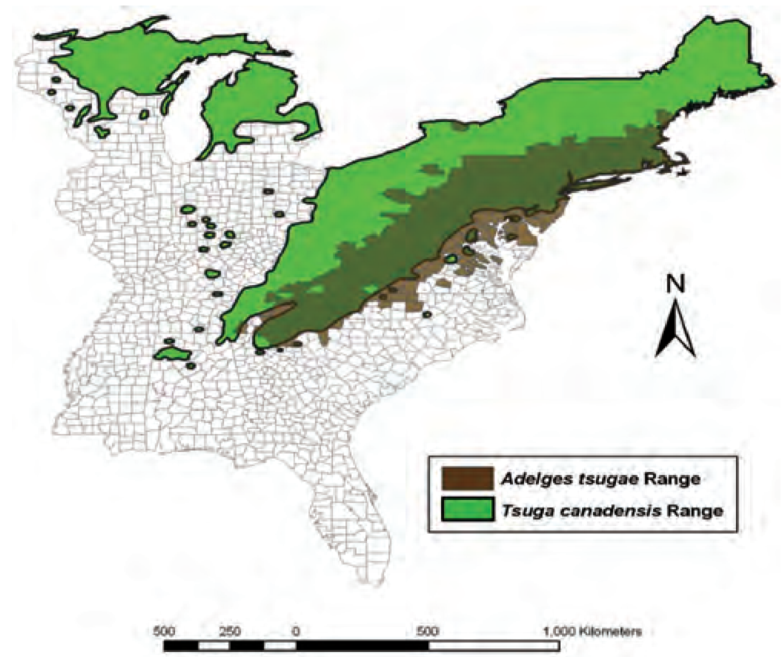

Figure 1. The distribution of hemlock woolly adelgid in the eastern United States as of December 2007. This map was produced by Camcore using USDA Forest Service data found http://www.na.fs.fed.us/fhp/hwa/hwatable_web/hwatable6.pdf.

variation (Havill *et.al*. 2006). This is probably because the current infestation resulted from a single introduction of the pest in Virginia and because adelgid reproduction is 100% parthenogenetic.

Adelgids occur naturally on hemlock species native to East Asia and western North America, but do not cause significant damage or tree decline. Significant HWA related mortality is only an issue on eastern and Carolina hemlocks in the eastern US where the adelgid is an invasive pest (McClure et al. 2001). The source of the US infestation is most likely an adelgid population in southern Japan that infests *T. sieboldii* (Havill et al. 2006).

– **HWA Rate of Spread** The current rate of spread of HWA into uninfested hemlock stands is very difficult to predict. Spread into northern New England has been very slow and is likely related to significant over wintering mortality among adelgids. Spread to the south (North and South Carolina, Tennessee, Georgia) where winter temperatures are warmer and, presumably, HWA over wintering mortality is much less, has been much more rapid. General consensus is that HWA spreads to uninfested areas at an average rate of 10-15 miles per year (Souto et al. 1996).

– **Host Species Silvics, Geographical Distribution, and Known Levels of Resistance or Tolerance** The somewhat rare Carolina hemlock is endemic to the southeastern US where it grows in a small number of isolated populations in Virginia, Tennessee, Georgia, and North and South Carolina

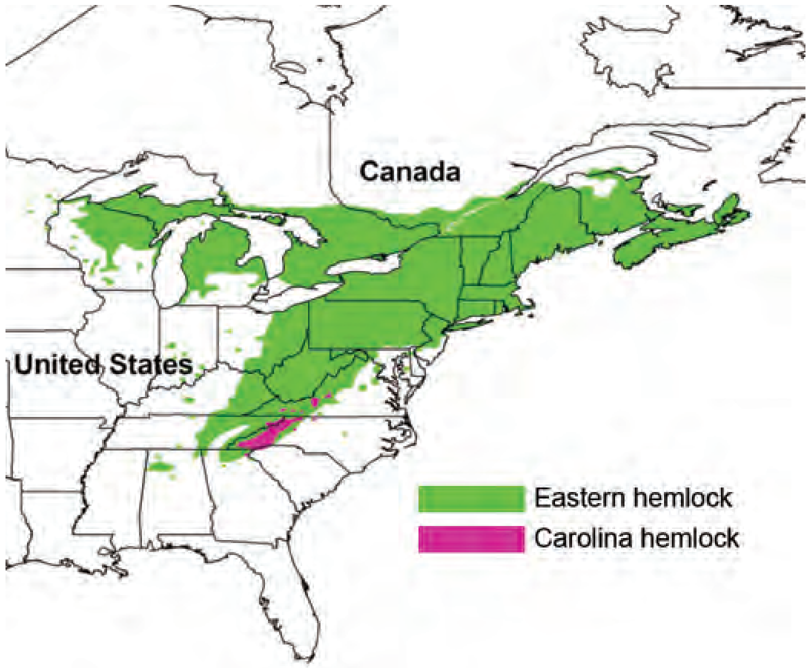

Figure 2. Geographic distribution of eastern and Carolina hemlock in the eastern U.S.

(Figure 2, above). It is typically found growing along exposed ridges and bluffs of the southern Appalachians, but a few populations can be found in higher elevation regions of the Virginia and North Carolina Piedmont. The species is usually described as growing on dry, sandy, nutrient poor soils but recent field reconnaissance and soil analysis indicates that Carolina hemlock occupies a greater diversity of site types than originally thought (Jetton et al. 2008a).

Eastern hemlock is found in eastern North America from Nova Scotia west to Wisconsin and Minnesota, and south along the Appalachian Mountains into Alabama, Georgia, Tennessee, South Carolina, and North Carolina with scattered populations in the western portions of Kentucky, Indiana, and Ohio (Figure 2). It covers a range of elevations from sea level to 1000 meters and displays a high level of phenotypic variation across this range. Eastern hemlock typically grows in moist cool ravines, valleys, and riparian strips and occupies moist, acidic, nutrient rich soils (Godman and Lancaster 1990).

Although there is evidence that Carolina hemlock may harbor some tolerance to HWA, particularly during the early stages of an infestation (Jetton et al. 2008b), there is little indication that either species harbors natural adelgid resistance. In time, both Carolina and eastern hemlocks succumb to HWA infestation.

– **Host/Pest/Environment Interaction** Hemlock woolly adelgid population cycles are driven by a density-dependent feedback cycle that is related to the health of the hemlock host (McClure 1991). Newly infested healthy hemlocks typically support adelgid populations that increase very rapidly and reach maximum densities within one or two years. Once these high HWA densities are reached, the host tree begins to experience twig dieback and very little new growth is produced. This causes a decline in adelgid populations for a one or two year period during which trees experience some recovery. This recovery is associated with the production of stunted new growth, which is quickly colonized by HWA. At this point, trees typically decline to a point where recovery, even in the absence of the adelgid, is unlikely and mortality soon follows.

This feedback between the adelgid and its hemlock host is almost certainly affected by environmental conditions, but this has not been well studied. One theory to explain the reported tolerance of Carolina hemlock during the initial phases of HWA infestation (Jetton et al. 2008b) is that the nutrient and water limited sites that this hemlock species typically occupies make it a poor host, leading to very slow adelgid population growth.

The hemlock woolly adelgid threatens to eliminate both eastern and Carolina hemlocks from large portions of their geographic range. If this were to happen, two ecologically vital tree species would be removed from eastern forests. Similar conifer species that might fill the ecological niche of hemlocks do not exist, and research has demonstrated that openings created by dead or dying trees are filled by black birch in the north and *Rhododendron* in the south (Orwig and Foster 1998). This would have important consequences for other species that inhabit hemlock ecosystems. Hemlocks provide an important source of cover and forage for a number of mammalian and avian species, some that are recognized as hemlock obligates. Eastern hemlock is also an important riparian species throughout much of its geographic range where it stabilizes soils and moderates stream temperatures and habitat conditions for a number of aquatic organisms including amphibians, insects, and fish. Of particular concern is the native brook trout (*Salvenlinus fontinalis*) that is most prevalent in headwater streams draining hemlock forests. The increases in stream temperature and light intensity that would result from the loss of hemlock could eliminate this native fish whose habitat is also impacted due to competition with the introduced brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) (Evans et al. 1996).

Hemlock woolly adelgid infestations are not restricted to forest hemlocks. Landscape trees and ornamental varieties derived from the native trees are also highly susceptible to the adelgid. Well over 200 cultivated varieties of eastern hemlock have been developed for horticultural use (Swartley 1984), and prior to HWA's widespread dispersal throughout the eastern US, these were worth millions of dollars annually to nursery growers and landscape centers.

The economic impact of HWA should also be viewed from the standpoint of adelgid management. Stem and soil injections of the systemic insecticide Imidacloprid are highly effective at reducing adelgid impacts on individual trees. However, application costs can be as high as $25 to $50 per tree, limiting their use to high value trees in residential landscapes, recreation areas, or easily assessable forest locations. Biological control agents (adelgid predators) are the most promising long-term solution for reducing HWA impacts in the forest environment. Mass rearing programs for many of these predator species have been established throughout the Southeast. They can produce hundreds of thousands of these beneficial insects annually.

Hemlocks are an important component of many federal, state, and municipal parks that occur within their geographic range. The enjoyment that many people derive from visits to these areas is at least partially related to the scenery and environmental conditions created by hemlock forests. Reduced aesthetic values and dangers associated with dead and dying trees as a result of HWA infestation negatively affect this enjoyment and the spiritual connection that some have to these environments. This could lead to indirect economic consequences for the parks themselves or surrounding towns due to reduced tourist dollars.

Concerns about the spread of HWA into currently uninfested areas could also lead to political repercussions associated with the institution of quarantines by individual states to restrict the transport of timber, firewood, and hemlock nursery stock from neighboring states.

3. Summary of genetics knowledge for eastern and Carolina hemlock

- **Hemlock Phylogenetics** Phylogenetic analysis of chloroplast DNA sequences among the nine naturally occurring hemlock species resolved two clades within the genus (Vining 1999; Havill et al. 2008). The two western North America species (*T. heterophylla* and *T. mertensiana*) form one clade and the second includes the Asian species (*T. chinensis*, *T. dumosa*, *T. forrestii*, *T. sieboldii*, and *T. diversifolia*) and Carolina hemlock (*T. caroliniana*) from eastern North American. Eastern Hemlock (*T. canadensis*) is sister to the Asian clade.
- **Carolina Hemlock** The genetic diversity in 15 natural populations of Carolina hemlock has been assessed using amplified fragment length polymorphisms (AFLP). Results suggest that despite its small, disjunct natural distribution, Carolina hemlock has moderate levels of genetic diversity and high amounts of genetic differentiation among populations (Camcore 2006). It appears that populations in the eastern part of the natural distribution are more genetically diverse than those on the western fringes, possibly indicating that these are close to the center of the species' glacial refuge more than 12,000 years ago.
- **Eastern Hemlock** There have been two important studies that assessed levels of genetic diversity in Eastern hemlock using isozymes, one by Zabinski (1992) that

focused on Midwestern populations and a second by Potter et al. (2008) that studied southeastern populations. Both studies found that eastern hemlock exhibited considerably less genetic diversity than most other conifers in the region, but that a greater portion of this small amount of variation is distributed among populations. Potter et al. (2008) found that, among hemlocks in the southeastern US, populations along the eastern periphery and Appalachian interior exhibited higher levels of diversity that those on the western periphery of the geographic range. Both studies support paleobotanical evidence that the refuge area for eastern hemlock during the peak of the Wisconsinian glaciation was located in the Southeast, specifically, to the east of the southern Appalachians. The spatial arrangement of some populations is also likely to influence genetic diversity in this species, particularly when one considers populations that are outliers from the main geographic range and those that occur at different elevations that exhibit phenotype variation. However, these have not been studied in detail.

Genetic variation in adaptively neutral traits such as those that were discussed above often differs from genetic variation in adaptively important traits such as the dates on which growth is initiated or stopped. Relatively little is known about variation in adaptively important traits in eastern hemlock, although a few small studies indicate that at least some exists. Stearns and Olson (1958) reported that hemlock seed collected in Tennessee germinated under different conditions than hemlock seed collected in Indiana or Maine. Nienstaedt and Olson (1961) reported that hemlock seedlings from southern sources tended to continue growing later in the fall than seedlings from northern sources. Eickmeier and others (1974) reported that hemlock grown from seed collected in northeastern Wisconsin were not as tolerant of warm, dry conditions as hemlock grown from seed collected less than 200 miles away in a warmer, drier part of the state.

- **Gaps in Knowledge of Hemlock Genetics** Almost nothing is known about genetic variation in adaptively important traits for either species. This information will be essential for planning hemlock restoration efforts.

Eastern hemlock population structure and patterns of genetic diversity within the northeastern portion of its US range have not been assessed. Research in this area will be key in developing effective *in situ* and *ex situ* conservation strategies.

4. Planning

A. Goals

- o Maintain portions of a relatively small number of populations of mature hemlock *in situ* using insecticides until biological control is feasible.
- o Explore the possibility of maintaining portions of a relatively small number of populations *ex situ* using plantations outside the range of hemlock.
- o Capture enough genetic resources from a relatively large number of populations and individuals in *ex situ* seed collections for use in restoration efforts.

- o Develop biological control methods in order to facilitate reestablish of hemlock populations and maintain them without the use of insecticides.

- o If biological control of hemlock woolly adelgid is not practical, the transfer genes for resistance to HWA to eastern hemlocks may be required.

B. Current Conservation Activities   There are currently limited *in situ* conservation activities underway on the Cherokee, Pisgah, Nantahala, Chattahoochee National Forests, and within the Great Smoky Mountains National Park. These NF have selected areas within the native range of hemlock and implemented chemical and biological controls for HWA. These areas have been located in such a manner so that they may exchange pollen and maintain maximum population diversity.

Ex situ gene conservation activities, including identification of existing *ex situ* genetic resources, collection and storage of new populations via seeds or other propagules, and establishment of new gene resource plantations.

- o Identify known domestic and international genetic resources:

Domestic and international *ex situ* genetic resources exist for Carolina hemlock (Camcore 2007). Since 2003, Camcore (NC State University) in cooperation with the USDA Forest Service has been conducting seed collections from all known populations of the species. To date, approximately 22 different populations have been identified and checked in the field. Seeds have been collected from 13 of these and represent samples from 84 mother trees across the geographic range (Figure 3). Populations where seeds have not been collected will be sampled when seed is available. Portions of the collected seed have been sent to cooperators in Chile and Brazil where seedlings are currently be-

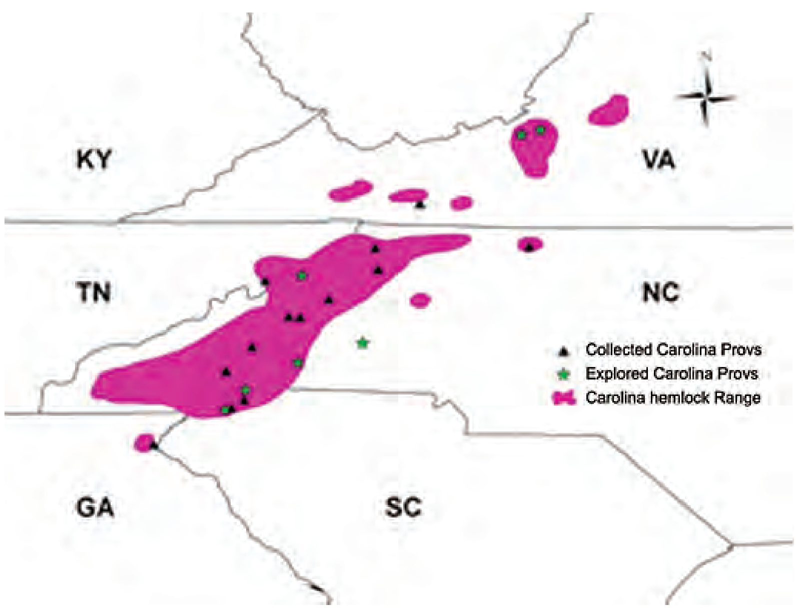

Figure 3. Camcore Carolina hemlock site explorations (shown as stars on map) and seed collections (triangles) 2003 – 2007.

ing cultivated in nurseries for eventual establishment in *ex situ* seed production areas. Seed has also been sent to the University of Arkansas where seedlings are being grown for *ex situ* plantings on the Ozark National Forest. Conservation seed reserves are being held in the Camcore seed bank in Raleigh, North Carolina, and a small working collection of provenance bulks from 3 populations resides at the National Seed Laboratory (NSL) in Dry Branch, Georgia.

In 2005, Camcore began collecting representative genetic material of eastern hemlock for *ex situ* conservation in the 7 state area (Alabama, Georgia, Virginia, Kentucky, Tennessee, North and South Carolina) that comprises the southern portion of the geographic range (Camcore 2007). Priority areas for seed collection to capture the maximum levels of diversity were determined based on a chemical marker analysis from vegetative samples collected from across this 7 state area (Potter et al. 2008). The results from this study were described above in the section on genetics knowledge for species of concern. Restated briefly, this study determined that eastern hemlock exhibits low levels of genetic diversity across the southern portion of its range. Previous *ex situ* conservation efforts by Camcore with other conifers indicate that, for species with low to moderate levels of genetic diversity, a sample size of 6 to 8 populations throughout a species' geographic range and 10 to 20 trees per population will conserve most alleles with frequencies of 5% or greater (Dvorak et al. 1999). Given the large distribution of eastern hemlock across the Southeast, the existence of satellite populations that may contain rare alleles, unique adaptations, and phenotypes that vary with elevation, Camcore has decided that sampling seed from 10 mother trees in each of 60 populations (600 trees total) will be sufficient to represent the genetic diversity of the species in the region. Priority will be given to areas of high diversity indicated by Potter et al. (2008) and satellite populations, and seed collections will be stratified by elevation in the Appalachian interior. To date, seed has been collected from 69 mother trees in 14 populations, all located in the eastern portion of the geographic range where high levels of diversity exist (Figure 4). Seed production has been lacking in other parts of the range, most likely due to high HWA impact and severe drought (Camcore 2007). This seed currently resides in the Camcore seed bank where it awaits shipment to Arkansas, Chile, and Brazil for *ex situ* conservation.

Camcore plans to expand its gene conservation work with eastern hemlock to include populations in the northern portion of the geographic range beginning in 2009. Although genetic diversity analyses and population structure have not yet been evaluated, it is assumed that a similar 600 tree strategy will be a good starting point for planning germplasm collections in the 16 state area of Connecticut, Delaware, Indiana, Maine, Maryland, Massachusetts, Michigan, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, West Virginia, and Wisconsin. The exact number and distribution of mother trees and populations targeted for seed collection can be adjusted to reflect pockets of high diversity and the importance of satellite populations

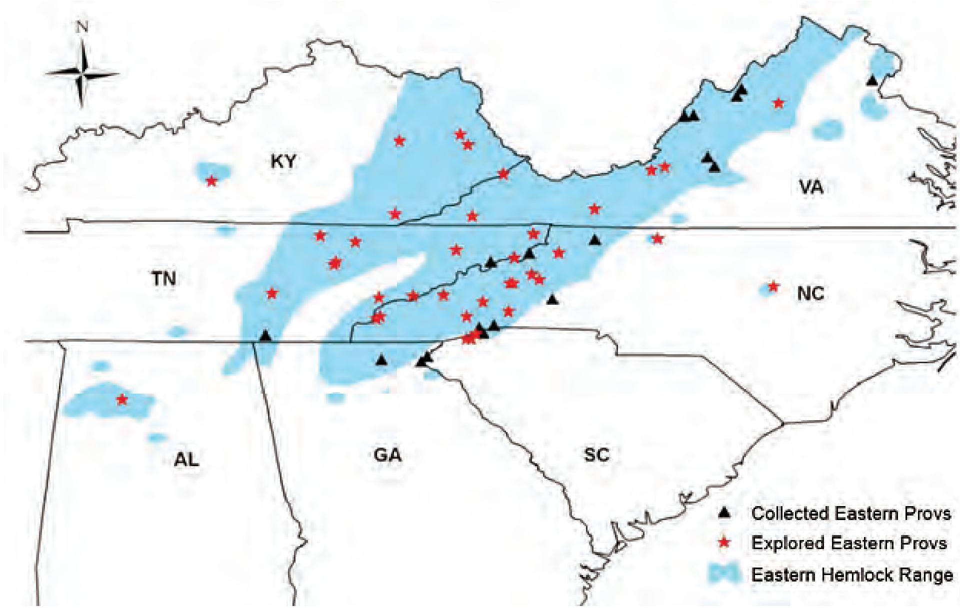

Figure 4. Camcore eastern hemlock site explorations (shown as stars on map) and seed collections (triangles) 2005– 2007.

and elevational variation following initial field surveys and completion of diversity studies.

- Establish seed collections within the National Plant Germplasm System through the USFS National Seed Lab (NSL).

Working collections will be maintained at the NSL, whereas long-term collections will be maintained at the National Center for Genetic Resources Preservation in Fort Collins, CO.

Camcore plans to submit both working and conservation collections of hemlock seed to the National Plant Germplasm System when seed is available. Small amounts of Carolina hemlock seed have already been sent to the National Seed Laboratory, and these collections will be expanded now that seedlings for the *ex situ* plantings are established. The small amounts of eastern hemlock seed that have been collected to date are prioritized for the establishment of *ex situ* populations. Camcore anticipates that future improvements in tree health associated with relief from current drought conditions and *in situ* conservation efforts (see above) should increase the level of seed production across the range and the availability of eastern hemlock seed for long-term storage in the National Plant Germplasm System.

- Where possible, establish *ex situ* populations (provenance trials, progeny tests, etc.) of living trees at sites not currently under threat.

Using the FloraMap™ climatic model, Camcore has identified areas in southern Chile and Brazil and the Ozark Mountains of Arkansas that have climates similar to those in populations where Carolina and eastern hemlock seed has already been collected (Jetton et al. 2008a,c). Because hemlocks do not occur naturally in these areas they are ideal for *ex situ* conservation plantations and protecting hemlock genetic resources from HWA. To further refine site selections within these regions that have been identified by FloraMap™, extensive soil sampling and analysis has been conducted in these same hemlock stands to determine optimum soil conditions for seedling establishment (Jetton et al. 2008a). These areas have been targeted for the conservation of Carolina hemlock and southern seed sources of eastern hemlock. Carolina hemlock seedlings are already being grown in forest nurseries at all three locations and the first conservation bank will be planted in Chile in 2008. Additional predictive models from FloraMap™ using data from eastern hemlock populations in the Northeast and Midwest will be necessary to determine if these same regions or others will be most suitable for *ex situ* conservation of northern seed sources.

- Where practical, develop a breeding program to produce locally-adapted, resistant stock through: traditional recurrent selection, interspecific hybridization with backcrossing, and/or genetically engineered resistance or tolerance.

There is little indication that natural HWA resistance exists in either eastern or Carolina hemlock, although there is some indication that the latter is more tolerant of the adelgid (Jetton et al. 2008b) and that this trait may vary among provenances (Camcore 2006). Provenance progeny tests planted within the generally infested region can be used to evaluate this and determine if selection for adelgid tolerance will be possible.

The most promising approach for breeding locally adapted HWA resistant stock might be through interspecific hybridization of eastern and Carolina hemlocks with adelgid resistant hemlock species from the Pacific Northwest and Asia and then backcrossing to the pure species. An approach similar to the American chestnut program would be appropriate. Attempts to hybridize hemlock species have been successful for *T. caroliniana* x *T. chinensis* crosses and the F1 offspring are highly adelgid resistant (Bentz et al. 2002). To date, attempts at other hemlock hybrid combinations have been less successful, but might improve with the use of the broad genetic base made available by current germplasm conservation efforts.

- Establish needed reforestation stock using seed orchards, somatic embryogenesis, or other appropriate technology

When HWA resistant genotypes are available seed orchards and breeding facilities will be developed to produce reforestation stock. Multiple facilities distributed throughout the range of hemlock will be necessary to breed and multiply hemlocks locally adapted to the surrounding areas. Again, a design similar to the research farm system utilized by the American chestnut program is a good guide. However, given the cost of HWA management and the very long breeding cycle of hemlocks (20-30 years per generation), an effort should be made to establish indoor (greenhouse) accelerated breeding houses similar to those used for breeding western hemlock in the Pacific Northwest (Ross et al. 1986; Eastham and Ross 1988).

C. Research and Development Needs

- Studies of genetic variation in adaptively important traits to guide species restoration work, particularly in conjunction with climate change.
- Climatic modeling to better understand of how climate change will affect the current distribution of eastern and Carolina hemlocks in the southeastern US.
- Additional studies on the genetic diversity of HWA in the eastern US to further pinpoint sources of introduction and if the current infestation resulted from a single or multiple introductions.
- Conduct field and greenhouse studies to understand the influence of environmental conditions on the density-dependent feedback between HWA and the host tree.
- Field reconnaissance to evaluate population structures and soil conditions in eastern hemlock stands throughout the northern portion of the geographic range.
- Evaluation of molecular markers within eastern hemlock throughout the northern portion of the geographic range and in disjunct populations such as Hemlock Bluffs in Cary, NC and Mammoth Cave National Park in Kentucky for the presence of rare alleles. This will be critical to identifying pockets of diversity and rare alleles for *ex situ* seed collections.
- Develop breeding techniques for indoor orchards for eastern and Carolina hemlocks. Accelerated breeding could be a key component to the production of HWA resistant stock of reforestation.

C. Rehabilitation and restoration

- Implement strategies to rehabilitate damaged ecosystems:
- Utilize hazard rating systems to prioritize where efforts are most needed and would be most successful;
- Utilize silvicultural methods that enhance natural regeneration opportunities, manage competing vegetation, and create planting opportunities;
- Plant locally-adapted resistant stock (if available);
- Reforest denuded areas;
- Assess efficacy of rehabilitation and restoration strategies over time and adjust activities as need to ensure sustainability;
- Plant diverse species mixes to maintain species diversity and ecological buffering capacity.

D. Policy actions

- o Develop and implement appropriate policies to institutionalize genetic conservation. Include:
  - – Networking – coordinate planning and actions with partners;
  - – Governance – implement effective policies and procedures;
  - – Organization – develop efficient organizational structures;
  - – Advisory groups – engage stakeholders in developing solutions;
  - – Legal considerations and compliance - NEPA, cooperative agreements, intellectual property issues, Executive Orders, ESA, etc.;
  - – Rule-making for management activities – develop and implement appropriate rules and regulations.
- o Consider what needs to be achieved in protection status and establish benchmarks to measure progress.

E. Communication

- o Develop communication plans for effective outreach and information dissemination:
  - – Products – publications, brochures, websites to provide information on genetic conservation programs;
  - – Roll-outs – plan effective public and Congressional information campaigns;
  - – Database(s) – insure that information is available and accessible in information systems such as the Germplasm Resources Information Network (GRIN);
  - – Awareness – build awareness through effective outreach and education efforts.

F. Resources

- o Determine resources need to implement effective conservation plans:
  - – Funding
    - – Consider opportunities for cost-sharing with partners,
    - – Frame high, medium, and low funding level options with clear descriptions of benefits and consequences of each level;
- o Human resources
  - – Identify staffing needs,
  - – Identify volunteer opportunities;
- o Facilities/equipment.

5. Monitoring and Assessment

- Develop a Quality Assurance/Quality Control Plan (QA/QC) to monitor and assess progress of genetic conservation plans:
    - o Internal review – develop procedures for internal monitoring and assessment of progress towards achieving goals and objectives of genetic conservation plans.
    - o External review – develop plans for external reviews of genetic conservation plans.
    - o Adaptive management – plan for re-evaluating plans through feedback loops to account for new threats or changes in climate or technologies;
    - o Accountability – develop appropriate reporting and accounting procedures.

Conclusion

Genetic resources are critical to the maintenance of ecosystems that are productive, sustainable, and resilient to new stresses such as insects, pathogens, and climate change. Developing effective genetic conservation plans for threatened species requires coordinated, consistent approaches to planning and implementation of effective strategies and actions. This general framework will help ensure that all facets of genetic conservation are considered in the development of species-specific plans. The USDA Forest Service will work with partners to implement these plans.

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Hemlock Woolly Adelgid

Fifth Symposium on Hemlock Woolly Adelgid in the Eastern United States

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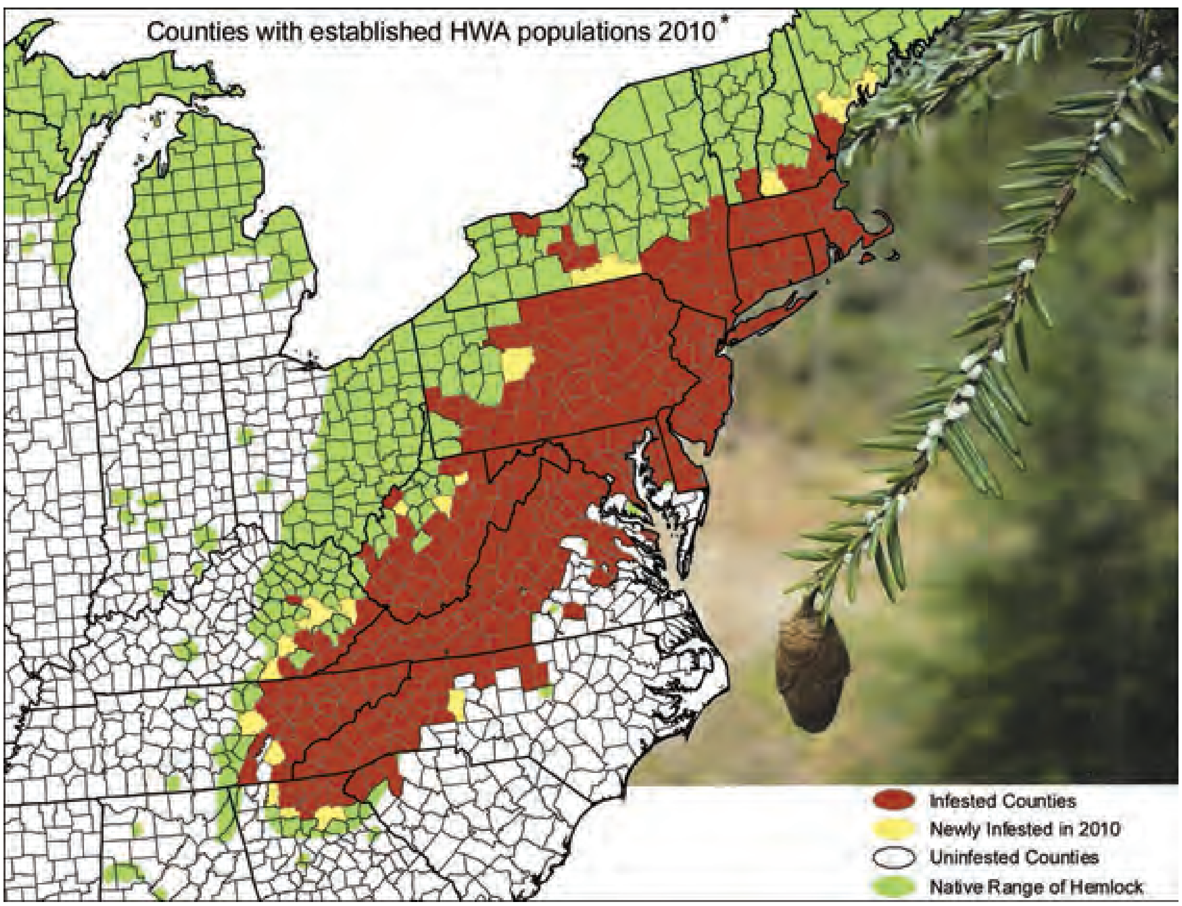

*See inside cover.

Compiled by Brad Onken and Richard Reardon

FHTET-2010-07
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*__Cover map__: Produced by USDA Forest Service, 2010. The map depicts counties with established populations of hemlock woolly adelgid (HWA) that have been confirmed by state forest-health officials. The coarse nature (scale) of the map does not provide information below the county level; highlighted counties are not necessarily entirely infested with HWA.

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