Special Technology Development Program

New Project Proposal

PROJECT NUMBER (Region-year-sequential number/priority)**:** NA-2002-01

PROJECT TITLE: Assessing Hemlock Woolly Adelgid Infestation, Hemlock Health and Susceptibility Using Hyperspectral Remote Sensing Technologies

PROJECT STATUS (select one by deleting inapplicable option)**:** New

EXPECTED PROJECT DURATION (total years for project including current fiscal year)**:** 3

EXPECTED COMPLETION DATE OF THE PROJECT (fiscal year)**:** 2004

SUBJECT (This is a hierarchical table that helps us understand our financial investment.):

1. Total Suppression/Prevention Technology	%		2. Survey and Monitoring Technology	%	
a. Total Biological Control i. Microbial % ii. Parasitoides % iii. Synthetic hormones/pheromones % iv. Other %		%	a. Advancements in Detection Technology		%
			b. Landscape Level Assessment Technology i. Data Visualization	20	%
b. Total Modeling i. Pesticide (Insecticide) Application % ii. Disturbance % iii. Growth and Yield % iv. Organism % v. Population % vi. Terrain %		%	c. Remote Sensing i. Aerial % ii. Hyperspectral % iii. Satellite %	60	% ii
			d. Other		%
c. Genetic, Cultural and Silvicultural Innovations For Controlling Pest Species i. Fire % ii. Methyl Bromide Alternatives % iii. Thinning/Regeneration Techniques and other Silvicultural Guidelines % iv. Resistance, Screening, and Breeding %		%	3. Assessment Technology	%	
			a. GIS % b. Spatial Analysis % c. Landscape Analysis % d. Decision Support % Risk and Hazard % Expert Systems %	10 10	a d
d. Pesticide Application (Spray) Technology i. Equipment innovations % ii. Methods and Guidelines %		%	4. Social Values	%	
			5. Technology Transfer Innovations	%	
e. Other		%	6. Other	%	

STATUS OF SUBJECT SPECIES (select one by deleting inapplicable options)**:** non-native invasive

PROJECT OBJECTIVES (question to be answered by the project)**:**

1. Develop and validate a rating system that will predict eastern hemlock susceptibility to hemlock woolly adelgid infestation.
2. Develop NIR spectroscopy techniques to directly assess adelgid infestation levels and hemlock decline.

3. Utilize hyperspectral remote sensing technologies to map hemlock decline, infestation and susceptibility to hemlock woolly adelgid infestation on a landscape scale.

BRIEF DESCRIPTION OF PROJECT:

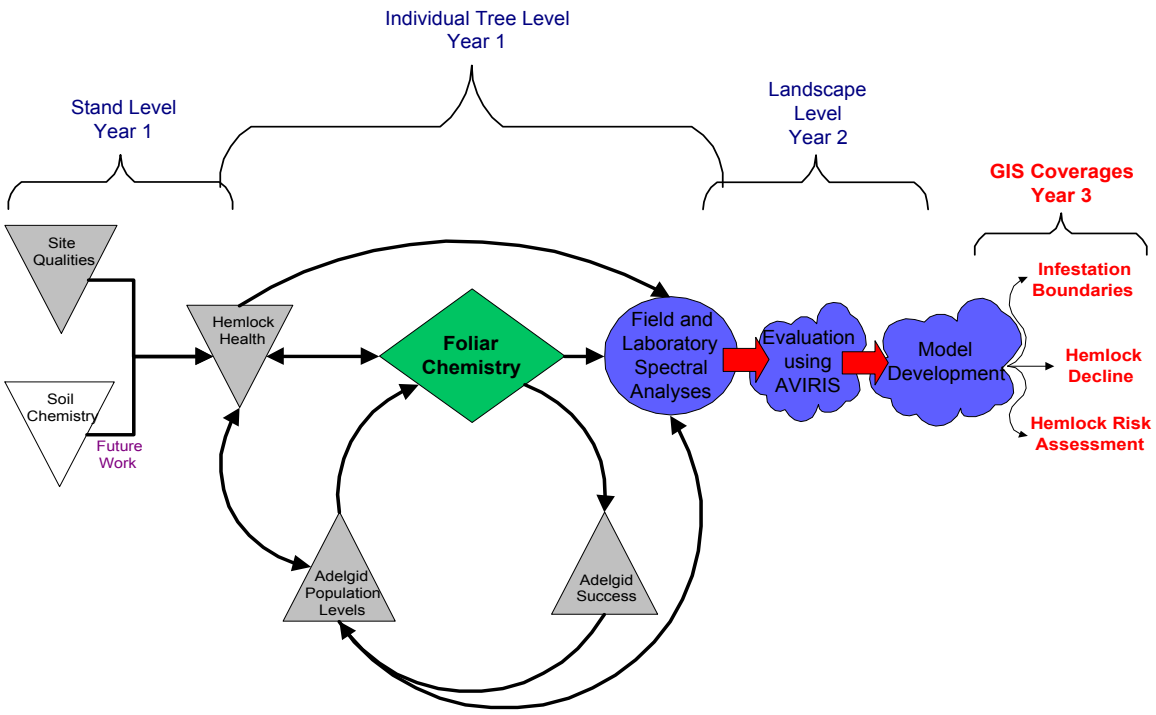
The hemlock woolly adelgid (HWA), an invasive insect pest native to Asia, is causing decline and mortality in hemlock forests across the eastern U.S. It appears that the pattern of mortality will continue with devastating effects on eastern forest ecosystem function and aesthetic value. This project will allow us to develop hyperspectral remote sensing techniques to directly assess HWA infestation levels, hemlock decline and stand vulnerability with greater accuracy and detail than previously demonstrated. These tools will facilitate the successful development and application of an integrated pest management program aimed at ultimately controlling the hemlock woolly adelgid.

The primary goals for each year are as follows:

Year 1: Use chemical and spectrometry data at the tree level in conjunction with adelgid infestation, health, and susceptibility data to create predictive equations that will be used at the stand and landscape scale.

Year 2: Create GIS data layers of foliar chemistry and hemlock species maps that will be used to predict HWA infestation status, decline symptoms and hemlock stand vulnerability from the equations developed in Year 1.

Year 3: Create and validate maps of HWA infestation, hemlock decline and stand vulnerability. Disseminate technologies via workshops, professional meetings and peer reviewed journal articles.



FHP LEAD CONTACT (FHP person submitting proposal)**:**

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Dennis Souto	NA	(603) 868-7717, dsouto@fs.fed.us, (603) 868-7604

FHP LEAD INVOLVEMENT (add lines as necessary)**:**

Role	Time Commitment
Facilitate dissemination of information	0.5 mo./yr.

PRINCIPAL INVESTIGATOR(S) (add lines as necessary)**:**

Name	Affiliation (Office or Dept.)	Phone, E-mail, Fax
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Mary Martin	UNH, CSRC	(603) 862-4508, mem@gromit.unh.edu, (603) 862-0188

PRINCIPAL INVESTIGATOR(S) INVOLVEMENT (add lines as necessary)**:**

Name	Role	Time Commitment
Jennifer Pontius	Project Coordination, Data Management, Spectroscopic Analyses	12 mo./yr.
Richard Hallett	Project Design, Laboratory Management	1mo./yr.
Mary Martin	Remote Sensing Analyses, NASA Liaison	1mo./yr.

COOPERATORS (contributing to, but not leading, the project) (add lines as necessary)**:**

Name	Affiliation (Office or Dept.)	Phone, E-mail, Fax
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Jason Denham	NY DEC	(518)402-9425, jpdenham@gw.dec.state.ny.us (518)402-9028

COOPERATOR INVOLVEMENT (add lines as necessary)**:**

Name	Role	Time Commitment
Michael Montgomery	Adelgid Counts/Health Rating, Plot Locations	0.5mo./yr.
Kathleen Shields	Histology Studies	0.5mo./yr.
Starling Childs	Plot location and monitoring.	0.25mo./yr.
Richard Evans	Plot location and monitoring, Health Ratings	0.25mo./yr.
Jason Denham	Validation plot location and monitoring	0.25mo./yr.

JUSTIFICATION:

This research will provide the scientific basis and prototype for a regional scale remote sensing effort with the levels of accuracy necessary to enable forest land managers to focus HWA management actions where and when they are most needed. This work will also lead to a better understanding of HWA infestation patterns and the subsequent decline of hemlock stands as they relate to foliar nutrient status and landscape variables in the northeastern United States. These relationships can then be used to assess and map hemlock stands with respect to their infestation status, relative susceptibility to infestation and expected rates of decline. The development of such new technologies is essential in order to develop an effective integrated pest management program and to identify strategic areas for its implementation.

URGENCY (Does the project address a crisis situation? Would delay result in irreversible loss?)**:**

HWA is currently causing severe hemlock decline and mortality across eleven states in the eastern United States. HWA continues to spread and is predicted to cause the demise of eastern hemlock across its entire range. The adverse long-term impacts of such extirpation include the loss of ecosystem diversity, function and sustainability. Once lost from the ecosystem, it may take thousands of years for hemlock to return to dominance in our eastern forests.

NATIONAL FHP TECHNOLOGY DEVELOPMENT PRIORITY:

Priority 1: __ Priority 2: __ Priority 3: __ Priority 4: _X_

This project will develop new technologies to detect incipient adelgid infestation and assess hemlock decline. Because decline following infestation can be rapid, any successful biological control plan must be implemented where HWA populations are low and trees are uninjured. Therefore, developing the ability to detect and map early infestation and decline on a landscape scale will help to insure the success of an integrated pest management program.

TECHNICAL COMMITTEE DEVELOPMENT PRIORITY:

Priority 1: _X_ Priority 2: _X_ Priority 3: __ Priority 4: __
Priority 5: __ Priority 6: _X_ Priority 7: _X_ Priority 8: __

Using state of the art, hyperspectral field and airborne instruments, this project will develop new technologies to detect HWA, monitor hemlock decline and predict relative stand susceptibility. Combined in a GIS platform, these data tools will allow us to visually display HWA parameters on a landscape scale.

SCOPE OF APPLICATION:

HWA now occurs in parts of eleven states along the eastern seaboard from North Carolina to Massachusetts (McClure et al. 1996; Souto et al. 1995). Current rates of spread are estimated at 10-15 miles per year into uninfested areas with all indications that it will be able to penetrate hemlock's entire range (Orwig & Foster 1998).

This project provides a unique opportunity to combine field and remote sensing techniques to study the patterns and dynamics of an exotic pest across the landscape. The airborne technologies developed with the proposed research will act as a bridge to the next class of spaceborne remote sensing instruments, which

will allow us to assess hemlock and HWA across eastern hemlock's entire geographic range. General relationships between infestation dynamics and foliar chemistry established for HWA with the proposed project may also be applicable to other insects like aphids and scales (McClure 1980; Stark 1965).

RESEARCH BASIS (strength of research basis, including publication citations)**:**

Since the 1980's when HWA first surfaced in the northeast, it has spread rapidly, leading to decline and mortality in over eleven states, from North Carolina to Massachusetts (Souto et al. 1995). Current estimates are that HWA is moving 10 – 15 miles a year into uninfested areas (Orwig & Foster 1998; Souto et al. 1995). Once settled on young hemlock twigs, HWA causes needle loss, bud mortality, and finally branch and tree mortality, sometimes within several years (McClure 1991; Young et al. 1995).

Although HWA introduction, biology and ecosystem response have all been documented over the past decade (Castello et al. 1995; McClure 1987; Young et al. 1995; Evans et al. 1995; Jenkins et al. 1999; Onken 1995; Orwig & Foster 1998), important observations remain unexplained. Perhaps the most critical findings are that the impact of HWA varies significantly with site conditions and the presence of other stressors (Orwig & Foster 1998). In both field and greenhouse studies, individual hemlock trees and adjacent stands have often responded very differently to attack (Sivaramakrishnan & Berlyn 1999).

To date, no one has addressed how foliar nutrient status relates to HWA infestation and hemlock decline. In fact, many studies cite the need for further exploration of the role of additional variables in HWA infestation and hemlock decline (Royle & Lathrop 1999; Young et al. 1999). It is understood that herbivory is usually positively correlated with foliar nitrogen concentrations and that low nitrogen concentrations in foliage can limit insect populations (McClure 1980; Schowalter et al. 1986; White 1984). However, no attention has been paid to the role of other essential macronutrient foliar concentrations in insect population patterns. Of particular interest are Ca and Mg, which are linked to pathogen-induced sugar maple decline on the Allegheny Plateau (Horsley et al. 2000).

Our own pilot study, conducted in 1999, showed significant differences in foliar N ($p=0.031$), lignin ($p=0.003$), Ca ($p=0.0001$) and Mg ($p=0.023$) concentrations between heavily infested, declining stands and very recently infested, healthy stands. We also compared chemical data from several adelgid resistant hemlock species (http://www-eosdis.ornl.gov) to our own extensive database of eastern hemlock foliar chemistry. Analyses show a clear and significant distinction between the chemistry of the resistant and non-resistant species (nitrogen $p=0.009$). Additional samples of resistant (*Tsuga chinensis* (TSCH), *T. sieboldii* (TSSI), *T. mertensiana* (TSME) *and T. diversifolia* (TSDI)) species and eastern hemlock (TSCA) were collected from the Arnold Arboretum in Massachusetts. Comparison of foliar chemistry from this localized area also shows a clear distinction in the chemistry between the resistant and non-resistant groups (lignin $p<0.001$).

In addition to foliar elements that relate directly to leaf nutrition, phytochemical compounds such as terpenoids, have been used widely to characterize host resistance to herbivores (McClure & Hare 1984; Cates & Alexander 1982). Studies of other *Tsuga* herbivores suggest that terpenoids are an important deterrent (McClure & Hare 1984; Gutierrez et al. 1997). Our own preliminary histological data suggest that levels of some terpenes may be associated with the health of adelgid populations. We believe that these data are compelling enough to warrant investigation into the potential role of foliar chemical concentrations in HWA infestation.

The researchers involved in this project have used Landsat TM data to classify hemlock tree vigor with an overall accuracy of 65.8% (Bonneau et al. 1999). However, with only seven bands, the spectral resolution of TM data limits the ability to accurately map incipient adelgid infestation or early signs of hemlock decline. Hyperspectral spectrometers differ from the more commonly used remote sensing instruments, such as Landsat TM, in that they measure many contiguous narrow spectral bands. The instruments currently available to us are: NIRSystems Benchtop Spectrometer, ASD FieldSpec Spectrometer, NASA's Airborne Infrared Imaging Spectrometer (AVIRIS), and NASA's Hyperion instrument recently launched on the New Millennium EO-1 platform. These instruments measure more than 200 contiguous channels in the range of .4μm – 2.5 μm with a spatial resolution of 4-17m (AVIRIS) and 30m (Hyperion). This combination of spectral and spatial detail will allow us to evaluate reflectance of hemlock sites at the tree and stand scale.

Using the laboratory spectrometers and the AVIRIS instrument, the principal investigators in this proposal have developed and applied techniques to map species distribution (Martin et al. 1998) and to quantify leaf- and canopy-level foliar chemistry with hyperspectral reflectance data ((Martin & Aber 1997); (Smith 2000); (Hallett et al. 1997); (Bolster et al. 1996); (Ollinger et al. In press)). AVIRIS derived maps of foliar chemistry have been used to estimate forest productivity, soil characteristics, nutrient cycling and

species classification on a landscape scale ((Martin et al. 1998); (Ollinger et al. In press); (Smith 2000)). We anticipate that these image analysis techniques will also be useful for the direct identification of HWA infestation and susceptibility to infestation.

METHODS (project design, hypothesis, statistical approach, and QA/QC procedures)**:**

In conjunction with research scientists across the northeast, we have established 45 adelgid study plots encompassing a range of HWA population levels, hemlock decline symptoms and site characteristics. From these plots, we will collect multiple samples from each of the five dominant hemlocks and analyze for foliar chemistry (N, lignin, cellulose, Ca, Mg, K, P, Fe, Al, Mn, and terpenoids, determine tree vigor categories, site characteristics and HWA population levels. Near-infrared and visible spectral characteristics will also be measured for each tree in the field and in the laboratory.

We propose three primary tasks addressing HWA infestation in the northeastern U.S.:

A. Develop and validate a rating system that will predict eastern hemlock vulnerability to hemlock woolly adelgid: By comparing the foliar chemistry and site characteristics across our 45 plots, we will determine which characteristics are most closely associated with apparent resistance in selected uninfested and non-declining stands. Data analyses will include logistic regression, multiple analysis of variance and principal components analysis.

B. **Develop NIR spectroscopy techniques to directly assess adelgid infestation levels and hemlock decline:** By directly examining the spectral signatures of hemlocks on our 45 plots, we will create calibration equations to characterize field and laboratory measured spectra as they directly relate to adelgid population levels and hemlock decline symptoms. Calibration equations will be developed using a partial least square regression approach and validated on independent samples. These relationships will be used to help calibrate the hyperspectral remote sensing imagery that has been collected over a portion of the study area.

C. Utilize hyperspectral remote sensing technology to map hemlock decline, infestation and vulnerability to hemlock woolly adelgid infestation: AVIRIS imagery was collected in July 2001 over 16 of our plots (Neversink (NY), Harvard Forest (MA) and White Mountain (NH) locations) All of these areas have had AVIRIS imagery collected in the past as well as flights scheduled over the next several years. This will enable us to develop techniques to map hemlock decline, infestation and vulnerability at the landscape scale.

Pre-processing of image data will include atmospheric corrections using the Atmospheric REMoval (ATREM) program (Gao et al. 1993), topographic corrections (Colby 1991), and geographic registration to a standard projection(Smith 1996). Image analysis will focus on (1) identification of hemlock stands, (2) derivation of canopy chemistry coverages from hyperspectral image data, and (3) direct assessment of infestation and decline categories. These data products will be combined with data on adelgid population levels and hemlock health assessments to develop and validate prediction equations (as described above) at the stand level. Using these equations, we will create maps of HWA infestation boundaries and varying levels of hemlock decline across our flight lines.

In a GIS platform we will then combine all necessary data layers to run our prediction model for stand vulnerability. Data layers may include: our AVIRIS derived foliar chemistry maps, digital elevation models, hydrology and stream data layers. Output for each pixel will include a predicted relative susceptibility class that describes how likely a stand is to become infested and suffer fatal decline symptoms as a result of HWA. This GIS model will be applied across our entire flight line and will be validated by yearly visits to independent validation plots to track their progress.

Field Sampling and Laboratory Analyses: The 5 dominant hemlocks will be sampled in each 50m x 50m plot by shooting off small branches with a 12-gauge shotgun (#4 steel shot). Needles will be separated from the branch, oven dried at 70° C, and ground to pass a 1 mm mesh screen. Reflectance measurements will be made in the field using an ASD Field-Spec spectrometer with an artificial light source. Foliar N, lignin and cellulose concentrations will be determined using a NIRSystems model 6500 near infrared spectrometer (McLellan et al. 1991; Bolster et al. 1996). The dried and ground foliage will be digested using a modified TKN digestion with a selenium catalyst (Isaac & Johnson 1976). Analysis of the digestate for Al, Ca, Mg, K, and Mn will take place on a Varian, VISTA AX, Axial ICP. Foliar terpene levels will be analyzed using fresh-frozen tissue and the techniques described by Muzika (1990).

Crown rating: Tree health will be assessed using crown ratings, which specifically tracks the physiological changes resulting from adelgid infestation. This involves the combination of several parameters including: the percentage of terminals with new growth, live crown ratio, foliar density

(measured with a concave spherical densiometer), and crown dieback. Each health parameter will be assessed individually and as a combined decline category.

Mortality: Hemlock mortality (as percent basal area) will be calculated for each plot, based upon measurements of all hemlock greater than 5 cm diameter at breast height.

HWA infestation levels: Four branches from each of our hemlock dominants will, have every terminal examined for the presence or absence of adelgid using a 10X hand lens. Percent infestation will be calculated as the percent of terminals with current generation adelgid present.

Site characteristics: Measurements for slope, elevation, aspect, landscape position, stand composition and infestation history will be recorded for each plot.

MEASURES OF SUCCESS:

Standard of Success: The development of NIRS calibration equations will be subject to rigorous independent validation. For prediction equations, the data sets will be divided into calibration samples (75%) and validation samples (25%), allowing for the calculation of an independent standard error of calibration (SEC) and prediction (SEP). In the third year we will also establish independent validation plots for our AVIRIS derived coverages.

Expected Outcomes: We expect to have maps of adelgid infestation boundaries, hemlock decline categories and relative stand susceptibility over our AVIRIS flight lines for dissemination by the end of the third year. Additionally, prediction equations will be made available for application with other hyperspectral imagery.

Implementation of Products/methods: These technologies will be directly applicable to AVIRIS imagery across the range of eastern hemlock. In addition, this work acts as a bridge to spaceborne hyperspectral instruments, which will soon be available to the general research community.

PRODUCTS AND DUE DATES:

Year 1: Model to assess the susceptibility of hemlock stands.
Equations using benchtop and field spectral technologies to predict adelgid infestation and decline at the tree level.

Year 2: An image showing the extent and location of hemlock stands within the flight lines.
Foliar chemistry (nitrogen, calcium, etc.) coverages of the identified hemlock stands.

Year 3: Maps of the extent of hemlock infestation, hemlock decline categories and stand vulnerability

PUBLICATIONS (how results will be reported: journals, reports)**:**

These results will be presented through peer-reviewed journals as well as public forums so that this vital information will reach scientific audiences, the general public and land managers. We anticipate one dissertation, as well as several papers in refereed journals such as: Journal of Near Infrared Spectroscopy, Canadian Journal of Forest Research and Environmental Entomology. In addition, results will be presented at regional and national conferences and society meetings.

TECHNOLOGY TRANSFER:

A collaborative agreement with the FHP program at the Forest Service Northeastern Research Station in Durham will allow us to present this information to forest land managers. During the third year of this study, we plan to present the relationships we establish here, GIS coverages, along with expected management implications to private landowners and forest managers at local and regional meetings.

PRODUCT LEVERAGING:

Although other projects have used Landsat TM data to monitor HWA, no one has used the finer resolution remote sensing instruments currently available. This project differs from currently funded STDP projects, which propose some component of hyperspectral analyses, in that we have in hand, current hyperspectral imagery over our monitoring plots at the leading edge of HWA's front. Our collaborative group also has priority from NASA for future hyperspectral airborne flights (AVIRIS) over this same area as well as priority access to hyperspectral spaceborne imagery (Hyperion), which we plan to utilize in subsequent phases of this project.

LONG-TERM BUDGET REQUEST:

	Item	Requested FHP STDP Funding	Other-Source Funding	Source
FY 2002				

Administration	Salary	$13,208	$37,200	$3200 USDA Directors Initiative $28500 USDA For. Serv. NE $5500 UNH
	Overhead			
	Travel	$3,300	$7,590	$7590 USDA Directors Initiative
Procurements	Contracting		$60,000	NASA AVIRIS Imagery
	Equipment	$950	$250	$250 USDA Directors Initiative
	Supplies	$3,580	$3,580	$3580 USDA Directors Initiative
Year Totals		**$21,038**	**$108,620**	
FY 2003				
Administration	Salary	$14,558	$35,360	$29640 UDSA For. Serv. NE $5720 UNH
	Overhead			
	Travel	$3,300		
Procurements	Contracting	$6,105		
	Equipment			
	Supplies	$2,580		
Year Totals		**$26,543**	**$35,360**	
FY 2004				
Administration	Salary	$10,070	$36,776	$30826 USDA For. Serv. NE $5950 UNH
	Overhead			
	Travel	$3,863		
Procurements	Contracting			
	Equipment			
	Supplies	$895		
Year Totals		**$14,828**	**$36,776**	
Project Totals:		**$62,409**	**$180,756**	

LONG-TERM BUDGET REQUEST EXPLANATION: (add lines as necessary):

Salary is requested for hourly field and laboratory help as well as three months time per year for a remote sensing technician to assist in image processing and GIS applications. The travel budget includes fieldwork in six states for sample collection and health assessments. Additionally, this budget includes PI travel to two professional meetings or conferences to present the results from this work. Funds for sample analysis and field supplies includes supplies for field sampling, preparation, storage and analysis of samples. This also includes the purchase of a light source and power supply for the ASD field spectrometer in year 1. In year 2, funds will be transferred to the USDA Northeastern Research Lab at Hamden, CT for terpene analysis and histology work.

BENEFITS (What are the proposed benefits of this project):

For minimal cost, this project allows us to assess the ability of hyperspectral remote sensing technologies to detect and monitor the spread of an invasive insect pest on a landscape scale. Such technologies are critical in the implementation of a successful integrated pest management program to ultimately control the spread of the hemlock woolly adelgid.

LITERATURE, CITATIONS, ATTACHMENTS, etc.:

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