Special Technology Development Program
Final Report and Project Profile

PROJECT NUMBER (from original application)**:** USDA-FS-02-DG-1244225-020

PROJECT TITLE Quantifying Hemlock Forest Health in the Mid-Atlantic States Using Remotely Sensed Change Detection Techniques

YEAR OF REPORT SUBMITTAL: 2004

PROJECT STATUS : Completed

EXPECTED COMPLETION DATE OF THE PROJECT (fiscal year)**: 2003**

ACTUAL COMPLETION (FISCAL) YEAR (if completed project)**:** 2004

SUBJECT (from original application form)**:** Monitoring, remote sensing

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

PROJECT OBJECTIVE(S) (from original application)**:**

To use remotely-sensed change detection techniques to quantify the spatial extent and severity of hemlock decline and dieback in the Mid-Atlantic states associated with the infestation of the insect hemlock wooly adelgid (HWA)(*Adelges tsugae*).

BRIEF DESCRIPTION OF PROJECT (from original application form):

Our previous research efforts in northern New Jersey have resulted in the development of a promising methodology using readily available Landsat Thematic Mapper (TM) imagery and change detection techniques. We propose that a relatively simple, effective, and cost-efficient methodology using remotely sensed data, change detection techniques, and related geo-spatial technologies will provide the means to quantify the spatial extent and severity of hemlock decline associated with HWA across the larger Mid-Atlantic region. In this project we expand on our initial efforts to further refine our Vegetation Index Differencing (VID) change detection methodology to quantify the spatial extent and severity of hemlock decline and to apply this methodology across a larger study area that includes northern New Jersey, eastern Pennsylvania and southern New York.

CHANGES TO PROJECT SCOPE OR OBJECTIVES (Changes from the original proposal and reasons for the changes.)**:**

The spatial extent of the project area was reduced from that originally proposed to cover a more restricted area of the Mid-Atlantic states of southern New York, northern New Jersey and eastern Pennsylvania. The final study area included Landsat TM Path/Row 14/31-32 and 15/31-32 and excluded Path 13 (i.e. Connecticut). Several issues and problems related to the imagery and processing arose throughout the project period. Addressing these issues and making the necessary adjustments and corrections usurped much of the project time originally intended for mapping a larger region.

The original objective was to examine the efficacy of taking the results of our pilot project and apply them in an operational monitoring context. Accordingly we proposed to use standard Landsat 7 imagery processed by and available through the U.S. Forest Service to map the current conditions (as of 2001). This standard USFS imagery is in an Albers projection and resampled using cubic convolution. Other public domain Landsat imagery were acquired from various sources to document the earlier time periods as part of the change detection mapping. Thus the time series of Landsat imagery varied in projection systems (UTM, Albers), resampling method (NN, CC), pixel size (25, 28.5 and 30 meters), and season (fall versus spring). This inconsistency in image processing and format presented a great challenge to the development of robust hemlock decline mapping techniques. Further processing was therefore required to correct these inconsistencies.

ADDITIONS TO PROJECT SCOPE OR OBJECTIVES (Describe additional accomplishments expected from the project.):

The time-series maps of hemlock health resulting from part of this project (path 14) provided us with an opportunity to analyze spatial and temporal trends in hemlock decline, and the relationship between the rate of decline and topography. This work led to additional publications now in preparation.

BRIEF DESCRIPTION OF PROGRESS THIS YEAR:

By early summer 2004, the Landsat scenes for path 15 (eastern PA) were processed. Upon completing the health maps for path 15, we discovered that the maps were highly inaccurate with regard to hemlock condition. Closer investigation revealed slight registration errors among the multiple images in Path 15. Though less than 1 pixel in many cases, these errors impacted the accuracy of the resulting maps of hemlock condition. The Path 15 imagery was normalized to the solar conditions of the original Path 14 data used to develop the health model. In addition, the sequence of processes was refined to reduce resampling of the data. All Path 15 imagery thus had to be meticulously reprocessed over the summer and fall of this year.
The final maps were prepared and the results look promising. Following review of the Path 15 maps by the PA State Cooperator, we will distribute the final maps to the USDA Forest Service and other agencies.

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

Name	**Affiliation (Office or Dept.)**	**Phone, E-mail, Fax**
Brad Onken	Forest Health Protection, Morgantown WV	Phone: 304.285.1503 Fax: 304.285.1505 Email: bonken@fs.fed.us

Role	**Time Commitment**

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

Name	**Affiliation (Office or Dept.)**	**Phone, E-mail, Fax**
Richard Lathrop	Center for Remote Sensing Rutgers University	Phone: 732.932.1580 Fax: 732.932.2587 Email: lathrop@crssa.rutgers.edu

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

Name	**Role**	**Time Commitment**
Richard Lathrop		

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

Name	**Affiliation (Office or Dept.)**	**Phone, E-mail, Fax**
Charlie Burnham	**Maryland**	
Sherri Hutchinson	**West Virginia**	
Mike Burminham	**New York**	
Bob Rabaglia	**Maryland**	
Mike Blumenthal	**Pennsylvania**	
Mark Mayer	**New Jersey**	
Brad Onken	**USFS, Northeast Area**	
Michael Montgomery	**USFS, Northeast Area**	

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

Name	**Role**	**Time Commitment**
Mike Blumenthal	Provided feedback on health maps. Met with us at Rutgers to discuss types of data needed about location and condition of hemlock stands in PA. He supervised PA foresters in collecting additional field data throughout 2004 to refine the PA hemlock base map and to evaluate the accuracy of PA health maps.	30+ days
Brad Onken	Met with us in the field to evaluate map accuracy and to refine methods for evaluating the degree of defoliation per tree and plot. Provided field crew to collect 2001 field data needed to update health model. Provided historical data from other hemlock plots in PA.	15+ days
Mark Mayer	Guided Rutgers field crew to the locations of the permanent hemlock plots monitored by NJ Forestry. Assisted in collection of GPS coordinates for NJ plots. Provided historical plot data collected over the past 10 years. Provided additional information as needed.	10+ days
Michael Montgomery	Met with us in the field to evaluate map accuracy and to refine methods for evaluating the degree of defoliation per tree and plot. Provided additional field data to assess accuracy of the health maps. Assisted in the comparison of crown-rating metrics used by NJ Forestry versus those used by the US Forest Service in the NPS (DEWA) hemlock plots	15+ days

A. FUNDING

1) First fiscal year funded: 2003

2) Funds obligated from beginning of project through final fiscal year (extend table as needed):

Fiscal Year	STDP Funding	Other-Source funding	Source
2003	28,627	40,896	Rutgers University
2004	18,995		
Total	47,622	40,896	

3) Funds not used from previous fiscal year: $0
If there are unused funds, what is the reason for not using them?

B. PROPOSED OUTPUT(S):

1) List proposed outputs

Digital GIS raster maps of hemlock health per year of imagery, for Path 15 (eastern PA) and Path 14 (NJ, southern NY).

Digital GIS raster maps of coniferous forests classified from Landsat imagery of the coverage area, to serve as a mask for the health maps.

Technical report of methods used to process imagery and develop statistical model.

CD's of data and supporting documents.

2) Were the proposed outputs delivered?

a) Y N Partial, Explain **Partial.**

Five, full-scene GIS raster maps of hemlock condition for Path 14, Row 31, (1992, 1994, 1996, 1998, 2001) were provided to NJ Forestry and the NPS Delaware Water Gap NRA (DEWA). Maps and data for Monroe County in PA and two townships in northern New Jersey were provided to Thomas Holmes, US Forest Service, Southern Research Station, and Elizabeth Murphy, a graduate student at NCSU.

We are now correcting problems discovered with the remaining Path 15 (eastern PA) data this past summer. We expect to have the output products ready by the end of 2004.

The Technical report outlining the VID change detection methodology was delivered (11/2004).

3) Were the outputs delivered on time?

a) Y N Partial, Explain **Partial.**

The final data for Path 14, Row 31, were delivered to all interested parties, whenever they requested the data. After the path 15 maps have been reviewed by Pennsylvania Department of Conservation and Natural Resources (PA DCNR) personnel, we will reproduce and distribute all final products to the US Forest Service, the NPS, state agencies, and any other interested parties. Delivery is expected by the end of 2004.

C. TECHNOLOGY / METHOD USE

1) Were the proposed or actual outputs used? Y N Yes

a) Describe briefly how outputs were used

i) List user groups

NJ Forestry used the final outputs for path 14, row 31, to guide decisions and field work in their forest health monitoring program.

The National Park Service used the same outputs for analyses and reports related to management and planning decisions for hemlock forest stands in the Delaware Water Gap NRA.

Thomas Holmes, US Forest Service, Southern Research Station, is using the data for analyses of economic impacts of hemlock decline.

Elizabeth Murphy used data for Monroe County, PA, for her PhD dissertation on the economic impacts of hemlock decline on residential property values.

Denise Royle, graduate student at Rutgers University, processed the imagery and used the maps for her dissertation on landscape analyses of hemlock decline in New Jersey.

ii) Time period output used 2001 to present

iii) Geographic extent of use: the Mid-Atlantic states of New York, New Jersey and Pennsylvania.

iv) Pest organisms: *Adelges tsugae* (hemlock woolly adelgid)

v) Resources affected/protected (e.g. wildlife habitat protected, risk reduction for insect disease, etc.) *Tsuga canadensis* (eastern hemlock)

vi) If outputs were not used provide the reasons the project may not have provided a usable product.

vii) Negative results

Yes, some difficulties were encountered in adapting our methods for application across a wider region. These difficulties were surmounted but resulted in an extension of the time table and a reduction in the study area.

viii) Guidance for future development projects

Yes, see below in next section.

ix) Did we learn anything from this project?

Yes, see sections below.

<u>Imagery and Processing:</u>

- Landsat imagery is cost-effective source of data for monitoring hemlock health across states and regions.
- Archived Landsat imagery is invaluable in providing baseline data and a historical perspective of past hemlock condition. It also provides the necessary data for spatial and temporal analyses of hemlock decline.
- Important to establish baseline reflectance with archived data for infested areas. Current data can be used as baseline data for future monitoring.
- Landsat is useful for detecting moderate to severe defoliation in hemlock stands, but it is not effective for detecting canopies in earliest stages of infestation, even if low levels defoliation have occurred.
- Spring (leaf-off) data can be used with fall (leaf-off) imagery, with additional processing (normalizing), but it is advisable to use anniversary dates whenever possible.
- Either Landsat5 and/or Landsat7 imagery can be used together, but as with spring/fall data, corrections are necessary.
- All image processing must be performed meticulously with great attention to registration.

Failing to do so affects the effectiveness of the statistical model. Ironically, although these processes are performed to increase the signal and reduce the noise in the data, they change and potentially degrade the data, especially when resampling is involved.

- To save time and expense, and to reduce any degradation of the data with additional processing, we recommend that all Landsat imagery be processed by the same vendor, and preferable delivered as orthorectified data. At the very least, images with the same projection, resampling and pixel size should be selected, whenever possible, keeping additional resampling to a minimum.
- All imagery should be orthorectified in areas of hilly or mountainous terrain.
- Outputs in 8-bit format are preferable to 16-bit or float data to reduce processing time, computer memory, and storage space.
- Software tools that save processing time are now available free online, and should be employed whenever possible. For example, one tool uses the image header file and the offsets in the histogram to produce the code (spatial model) to convert raw DN to atmospherically corrected reflectance in one step. It produces the downloadable code within seconds, thus saving several hours of calculations and model preparation by the user.

<u>Field data</u>:

- Need consistent and timely field data to update the model as required, especially when useful imagery becomes available;
- Hemlock canopy is more easily evaluated in the field during leaf-off seasons. Foliage on neighboring deciduous trees prevents a clear view of the hemlock canopy against the sky.
- Need objective, more accurate metrics for quantifying canopy condition on the ground, and at the spatial scale of satellite imagery (e.g, circular plots larger than 1 pixel in diameter, instead of long, narrow transects).
- Cooperator involvement is invaluable, especially with regard to the collection of local data and to independent review and validation of map outputs..
- Accurate GPS coordinates are critical for correctly locating ground plots in the imagery,

but signals are weak and have been distorted by the forest canopy. We need better methods for obtaining accurate coordinates under dense canopy, e.g., extending the GPS antenna to the tree-top to get better signals.

Analysis and modeling:

- The health model can be successfully used in adjacent Landsat paths, but we don't yet know how far a model can stretch over time and space. Our model seemed to be effective for about 12 to 14 years in path 14, but then needed updating.
- Good base maps of hemlock stands are needed to reduce errors of commission such as including pine and other conifers. Healthy, non-hemlock evergreens look like healthy hemlocks spectrally, and therefore cause estimates of damage to be underestimated.
- The health model can apparently be extended to adjacent paths, but only if all imagery is normalized to the path used to develop the model;
- Maximum rate of decline is a better variable than annual condition for vulnerability analyses, because it reduces effects of HWA spread patterns and the length of time a stand has been infested.
- Spectral indices or other independent variables that incorporate healthy tree growth over time, as well as defoliation, may reduce or prevent the need to periodically update the health model.
- Different change-detection methods should be tested with regard to the degree of processing performed on the imagery. Methods that can successfully employ raw, orthorectified imagery would be more cost-effective, and current health maps could be produced more quickly as imagery becomes available.

Spatio-temporal patterns of decline:

- Hemlocks decline at differential rates across the region, and these rates are clustered spatially.
- More than 100 transition patterns were observed to occur across the region, but they can be grouped into four ecologically meaningful patterns: 1) no decline observed, 2) decline

without improvement, 3) decline followed by improvement, 4) decline, improvement, then decline once more to severely or completely defoliated condition.

- HWA-related damage spread northward and westward over time, with northward spread faster than westward spread.
- Of four topographic variables examined with respect to rate of decline (elevation, slope, aspect, curvature), all were weakly correlated with rate, the relative importance of the variables shifted over time, elevation and slope were more highly correlated with rate of decline than aspect and curvature.
- Hemlocks growing on sites of marginal quality (very steep slopes, dark ravines, bedrock ridgetops) declined more rapidly than hemlocks growing on sites with better quality (flat to shallow slopes, slightly concave (valley) or convex (ridge). The better quality sites often showed improvement some years.

D. DISTRIBUTION OF OUTPUTS

1) University and/or Research Involvement

a) List the Universities and/or Research Units involved

Rutgers University

North Carolina State University

b) Number of graduate theses written

Royle, D.D. 2002. A landscape analysis of hemlock decline in New Jersey. PhD Dissertation, Rutgers University. 195 pp.

Elizabeth Murphy. PhD work at NCSU (in progress)

Dissemination of Results

c) Number of peer-reviewed journal articles accepted for publication

i) List journal(s) and targeted audience

Journal of Nematology, forest pathologists, GIS analysis

Royle, D. D. and R. G. Lathrop. 2002. Discriminating *Tsuga canadensis* hemlock forest defoliation using remotely sensed change detection. *Journal of Nematology* 34(3):213-221.

Forest Science, forestry researchers and managers

Royle, D.D. and R.G. Lathrop. 2004. Remote sensing of spatio-temporal patterns in Eastern Hermlock Decline. To be submitted.

d) Number of reports written

i) List report(s) and targeted audience

(technical report of methods and analyses; federal and state agencies?)

e) Number of presentations made

i) List meeting/conference(s) & professional society-sponsor(s)

Royle, D. 2004. Use of satellite imagery to monitor HWA impacts. 15th USDA Interagency Research Forum on Gypsy Moth and Other Invasive Species, January 13-16, Annapolis, MD.

Montgomery, M. E., D. W. Williams, K. S. Shields, J. R. Steinman and D. D. Royle. 2003. Detection of insect damage to oak and hemlock forests: Integration of remotely-sensed and FIA data. 5th Annual Forest Inventory and Analysis Symposium, November 18-20, New Orleans, LA.

Holmes, T., E. Murphy, D. Royle, K. Bell, and B. Byrne. 2003. The economic imp[acts of hemlock woolly adelgid. 14th Annual Conference of Southern Appalachian Man and the Biosphere (SAMAB) Program, November 4-6, Asheville, NC.

Lathrop, R.G. and D.D. Royle. 2001. *Monitoring hemlock forest health using satellite change detection techniques*. Special Symposium: Application of GIS and GPS precision agriculture technologies in nematology and plant pathology. Abstract of Joint Meeting APS/MSA/SON, Salt Lake City, UT, Aug. 25-29, 2001. Phytopathology 91, No. 6(Supplement), p. 167.

Royle, D. D. and R. G. Lathrop. 2003. Monitoring eastern hemlock decline: Applications for detecting invasive species. Invasive Exotic Plant Detection & Assessment: Developing and Applying Uniform Approaches Across the Florida Landscape, February 12-14, Florida International University, Miami, FL.

Royle, D. D. and R. G. Lathrop. 2002. A landscape analysis of hemlock decline in New Jersey. 13th Annual Conference of Southern Appalachian Man and the Biosphere (SAMAB) Program, November 5-7, Gatlinburg, TN.

Royle, D. D. and R. G. Lathrop. 2002. Spatial and temporal patterns in hemlock decline in northern New Jersey. Pp. 67-72. *In*: Lashomb, J., Onken, B. Shields, K., Linnane, J., Souto, D.,

Rhea, R. and R. Reardon, eds. Proceedings of the Hemlock Woolly Adelgid Symposium. East Brunswick, NJ, February 5-7, 2002. USDA Forest Service Technical Report.
In: *Proceedings of the Hemlock Woolly Adelgid Symposium*, Feb 5-7, 2002, East Brunswick, NJ.

Royle, D. D., R. G. Lathrop and J. M. Hartman. 2002. Temporal and spatial patterns in eastern hemlock decline. 17th Annual Symposium, International Association for Landscape Ecology, April 23-27, Lincoln, NE.

2) Technology Transfer Activities

Several informal workshops were held at the Rutgers University Center for Remote Sensing & Spatial Analysis with the USDA Forest Service and Pennsylvania Department of Conservation and Natural Resources (PA DCNR) personnel demonstrating the VID change detection methodology.

a) Number of sessions: 2

b) Number of participants: 10

c) List participating agencies and organizations:

USDA Forest Service

Pennsylvania Department of Conservation and Natural Resources (PA DCNR)

E. REFINEMENT OF T&M

1) Does the project investigate use with or use of other forest health management tools?

The project relies on the use of forest health monitoring plots for both calibration and validation of the remotely sensed change mapping techniques.

2) Do the results of the project improve on existing technologies?

Yes. Early efforts in monitoring hemlock health throughout the Northeast included the establishment of forest health monitoring plots by the USDA Forest Service in cooperation with State foresters. Although these plots provided important information about the rate and pattern of defoliation on individual trees, and a general map of HWA infestation, detailed information as to the spatial pattern of declining health and dieback of eastern hemlock forests is not available in mapped form at anything less than a county-level of resolution. The results of this project provide a regional picture of present state of hemlock decline as well as detailed mapped information (down to the stand level) with quantifiable confidence limits.

The project mapped hemlock stands into 4 levels of damage (Dead, Severe, Moderate and Light/Healthy) and calculated area estimates by damage class. Compared with the alternative of mapping HWA-associated hemlock decline using visual interpretation of aerial photography, satellite remotely sensed change detection provides a much more cost and time effective approach for a regional-scale analysis as proposed. In addition, the Hemlock Damage maps resulting from this project should be useful in planning biological control activities (e.g., targeting the location of the release of biological controls agents to have the biggest impact with least expense). The Hemlock Damage maps are in a digital format ready for input to most GIS packages increasing their utility in ongoing federal and state level forest health activities.

3) Did the project identify new research or technology needs?

Yes. The project identified some of the difficulties in applying this remotely sensed change detection technique in an operational context. Additional research needs to be undertaken in correcting and registering imagery to provide the highest quality change detection outputs.

4) Did the project result in new technologies?

Yes. The project resulted in the further development and refinement of remotely sensed change detection techniques to map hemlock decline into 4 levels of damage (Dead, Severe, Moderate and Light/Healthy) within +- one damage class.

5) Product leveraging

a) Was the project part of a development sequence?

i) No.

ii) Does the project build-on or is it the result of past Research and/or STDP project results?

Yes. This project builds on earlier work funded through the Cooperative Forest Health Management program (Project: Mapping Hemlock Decline in New Jersey, Grant No. NA-96-0007).