Remote sensing of canopy condition across the northeast: Trends and patterns 1984-2009

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- **Forest condition across the northeast is predominantly stable, likely because of the rapid ingrowth and regrowth following small scale disturbance.**
- **However, spatial patterns are evident, with significant long-term decline concentrated in upper elevational spruce/fir/birch forests.**

Funding support for this project was provided by the Northeastern States Research Cooperative (NSRC), a partnership of Northern Forest states (New Hampshire, Vermont, Maine, and New York), in coordination with the USDA Forest Service.
http://www.nsrcforest.org

Project Summary

Forest health in the northeast is of increasing concern due to climate change and anthropogenic pressures. In order to monitor canopy condition across the region, this study uses remote sensing images, which can be used to assess the crown condition of forests over long time periods and large areas. A forest health rating based on canopy "greenness", photosynthetic capacity, canopy density and water content was applied to Landsat TM5 satellite imagery to quantify yearly forest health from 1984 to 2009, as well as changes and trends in health over that time period.

Initial results indicate that forest condition varies from year to year, primarily due to drought and insect outbreaks, but that the condition of forested ecosystems across the region as a whole has remained relatively stable over the past 25 years. This is likely due to the natural resilience of northeastern forests and their rapid recovery, regrowth and ingrowth following small scale disturbances.

A regional geospatial analysis indicated that declining trends over the 25 year study were only significant in high-elevation spruce-fir-paper birch forests. A field investigation of declining, stable and improving sites indicated that stands with less species diversity, structural complexity, as well as lower nutrient and water availability were associated with more severe decline trends.

While these results emphasize the natural resiliency of northeastern forests in terms of overall canopy productivity, it is not able to identify changes in species composition or stand structural characteristics. It is therefore possible that species declines have occurred, but ingrowth of competing species maintains canopy condition as characterized by the health index.

In spite of this overall resiliency, there are spatial patterns where decline trends are evident. This highlights the sensitivity of upper elevational forests in the region where low soil nutrient availability, climate extremes and sensitive species converge. Possible causes of long-term decline at these locations include the interacting effects of acid deposition, injury from extreme climate events (winter injury, late frost, ice storms, etc.) and a lack of secondary species to rapidly fill gaps created by mortality and decline.

Background and Justification

- Northeastern forests are experiencing many natural and anthropogenic stressors.
- Most efforts to assess and monitor forest health cover only a fraction of northeastern forest area and identify only severe decline events (i.e., widespread defoliation and mortality) at one point in time.
- Recently released historical archives of satellite imagery provide a unique opportunity to assess entire regions in wall-to-wall coverages with increasing accuracy and detail.
- The resulting data products not only provide a more complete picture of northern forest condition, but also allow us to examine spatial patterns in long-term forest health trends.
- The ability to quantify trends in forest health not only provides a missing regional scale assessment of the status of forests, but also allows for the investigation of what factors might be the strongest drivers in decline.

Methods

Predicting forest condition using satellite derived vegetation indices

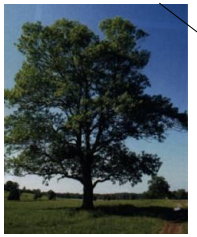
To capture a full range of decline symptoms in the image, including pre-visual stress conditions, we collect a suite of canopy characteristics for **ground truthing and image calibration**.

Defoliation

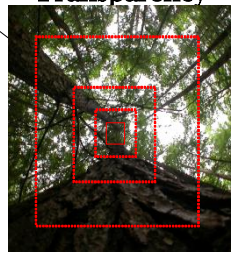
Fine Twig Dieback

Live Crown Ratio

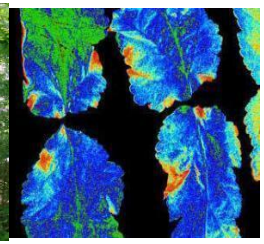
Overall Crown Vigor

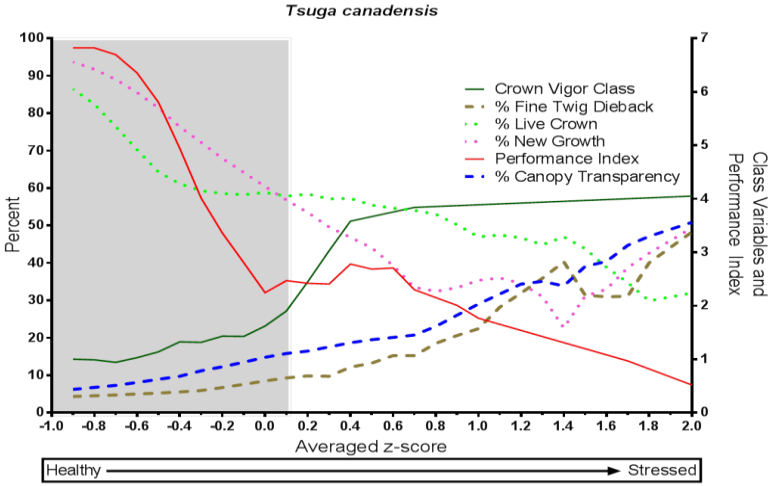


Digital Canopy Transparency



Chlorophyll Fluorescence





Z-score normalization and averaging of all variables creates a **continuous summary decline value**

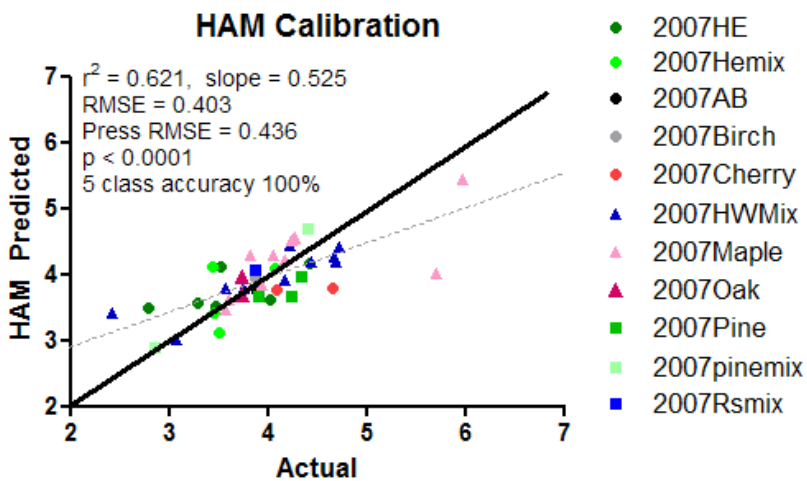
Methods

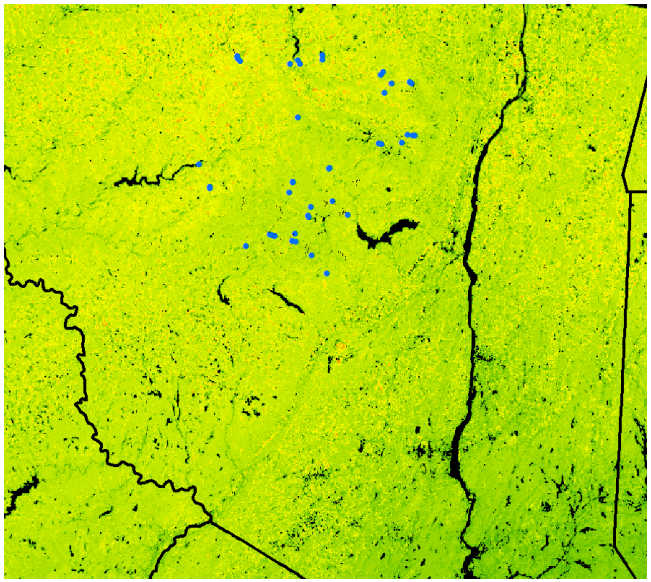
Predicting forest condition using satellite derived vegetation indices

Create a predictive model based on a suite of known vegetation indices in a mixed stepwise multiple linear regression……
And apply the equation to the imagery.

Term	Landsat TM5 Equation	Paremeter Estimate	Absorbance Feature
Intercept		-51.763	
B5	*B5*	0.946	canopy moisture content, leaf area index and total biomass
Aoki	*B2/B4*	0.706	chlorophyll content
MCARI2 *(Modified Chlorophyll Absorption Ratio)*	*1.5 * ((2.5*([B4]-[B3])) - (1.3*([B4]-[B2]))) / (Sqr((((2*[B4]+1) * (2*[B4]+1))) - (6*[B4] - (5*(Sqr([B3])))) -0.5)))*	-0.236	green leaf area index
SIPI *(Structural Independent Pigment Index)*	*([B4]-[B1])/([B4]-[B3])*	54.536	carotenoids:chlorophyll
Flo *(Chlorophyll Fluoresence Index)*	*([B4]-[B2])/([B5]-[B3])*	0.451	Chlorophyll fluoresence

Model development based on 3 years of measurements on 45 mixed species plots in the Catskills region of New York.





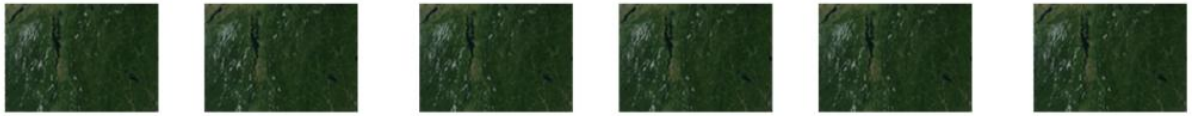
Methods

75 Landsat scenes were downloaded, pre-processed and calibrated to predict the summary decline rating

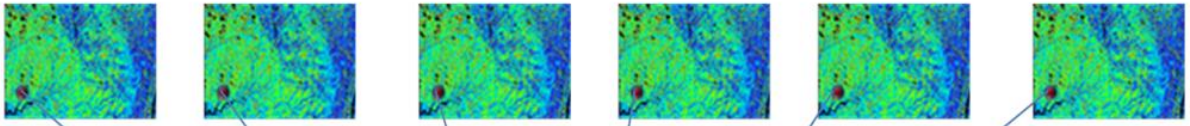
1984, 1985, ... 2008, 2009

Archived **Landsat 5 TM** Imagery from mid-growing season with <10% cloud cover

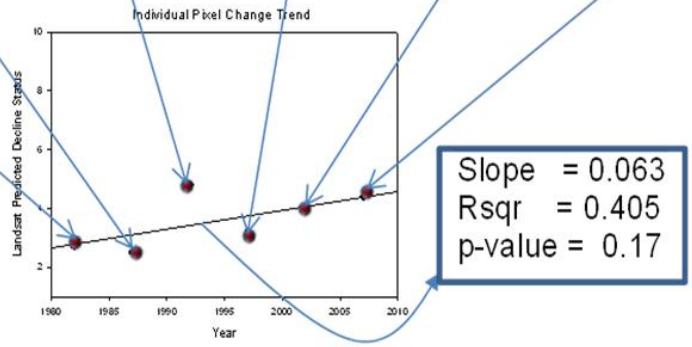
Mosaicked, geo-registered, atmospheric corrected northern forest coverage



Predicted northern forest **health status**



For **every pixel**, predicted health status is plotted for all years. A line is fit to this data and the **slope** of that line (long term trend in health status) becomes the new forest health "**trend**" value for that pixel.

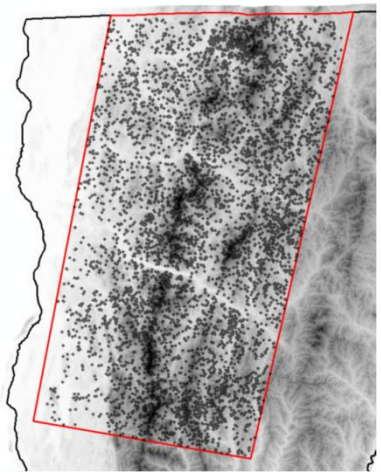


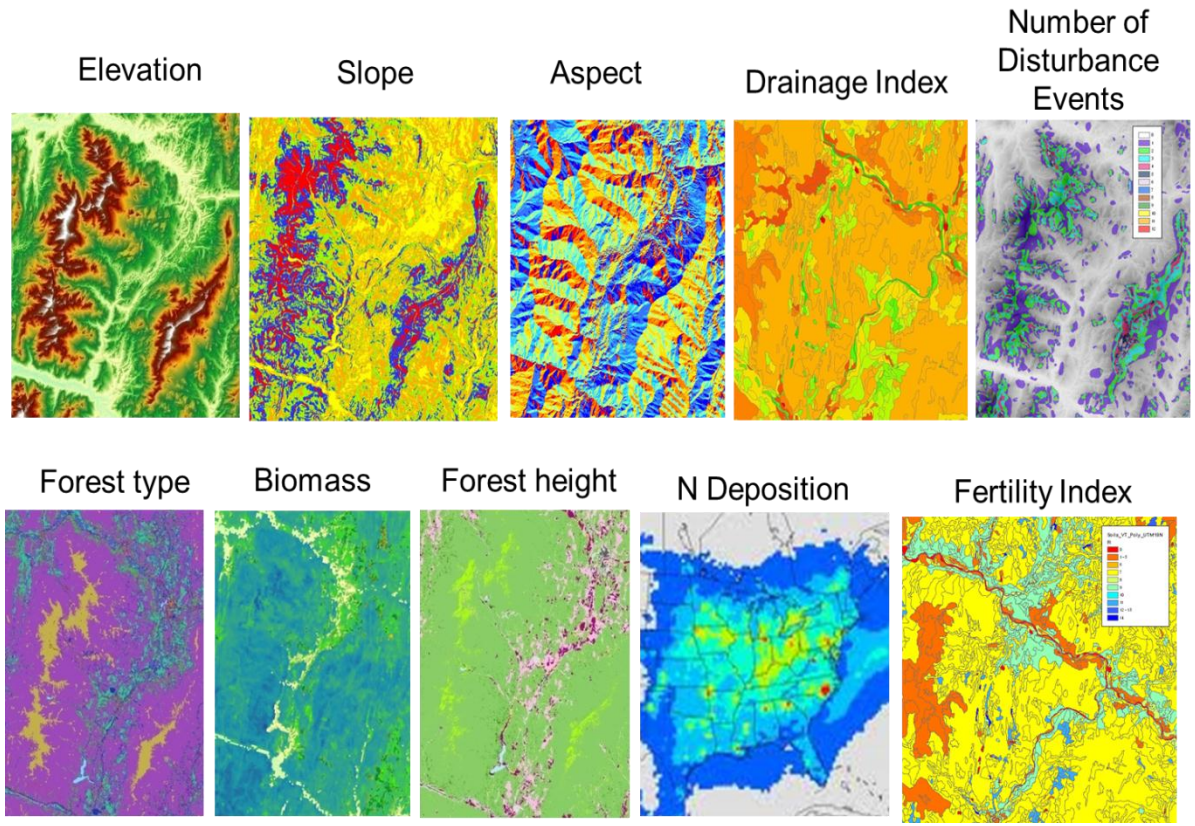
Calculate Trend Slope for each pixel

Methods

Examining spatial patterns and relationships between site characteristics and long-term decline trends

A geospatial database based on over 5000 randomly selected forested pixels was created and linked to a suite of environmental GIS layers and the forest condition trend product

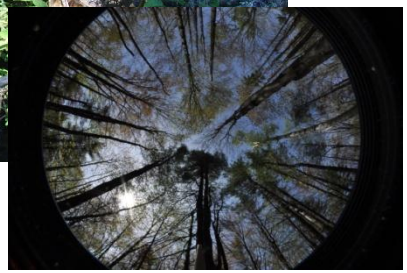




Methods

Field investigation of declining and improving sites

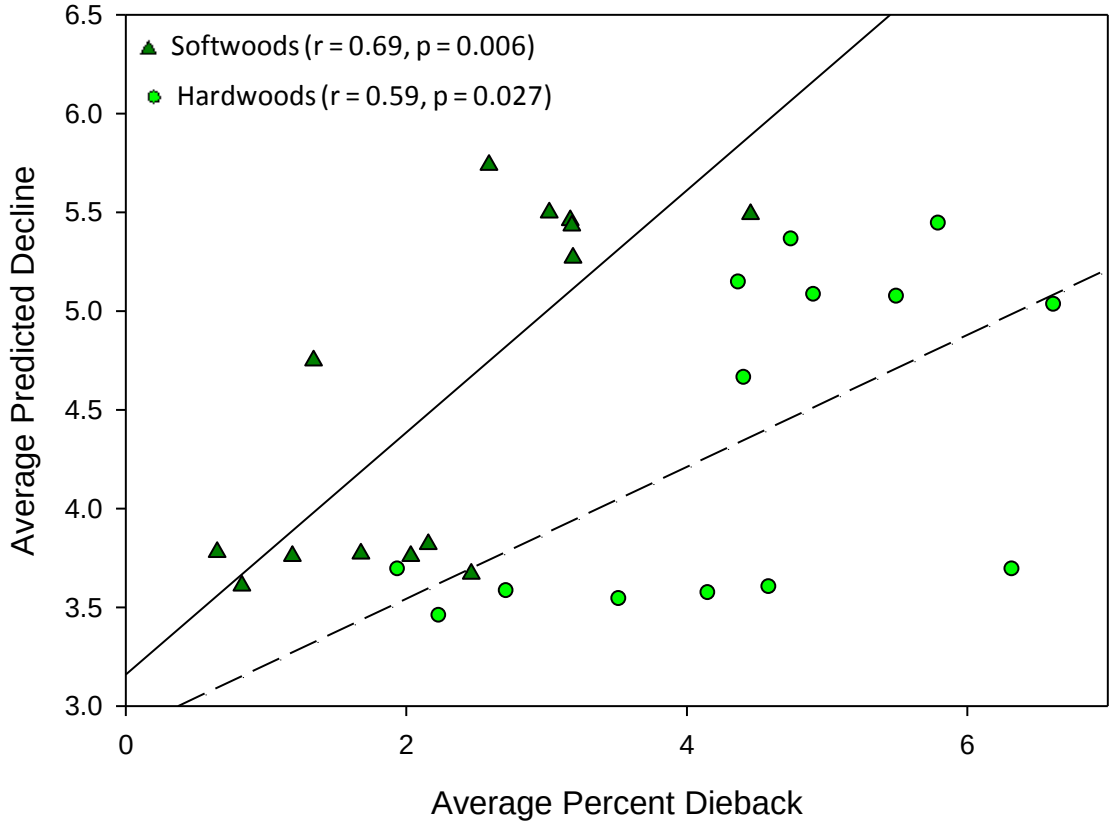
Soil chemistry and tree cores were collected from 30 paired plots of declining and improving pixels to identify potential differences not captured in GIS data layers.

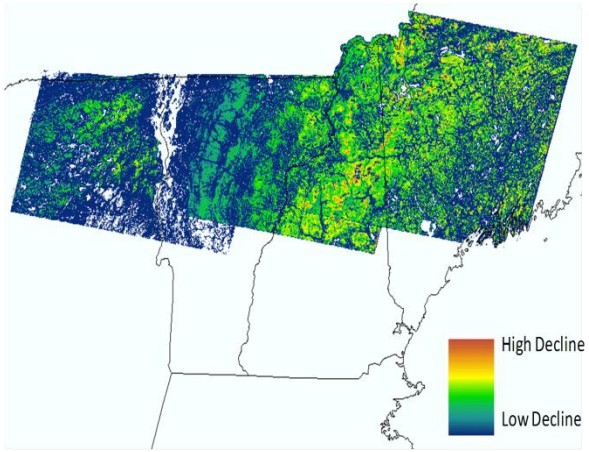


Decline Trend Results

Validation of yearly forest decline

FIA measured percent dieback averaged by state (x- axis) compared to predicted summary decline value (y-axis). The relationship is better for conifer (triangle) than hardwood stands (circles).

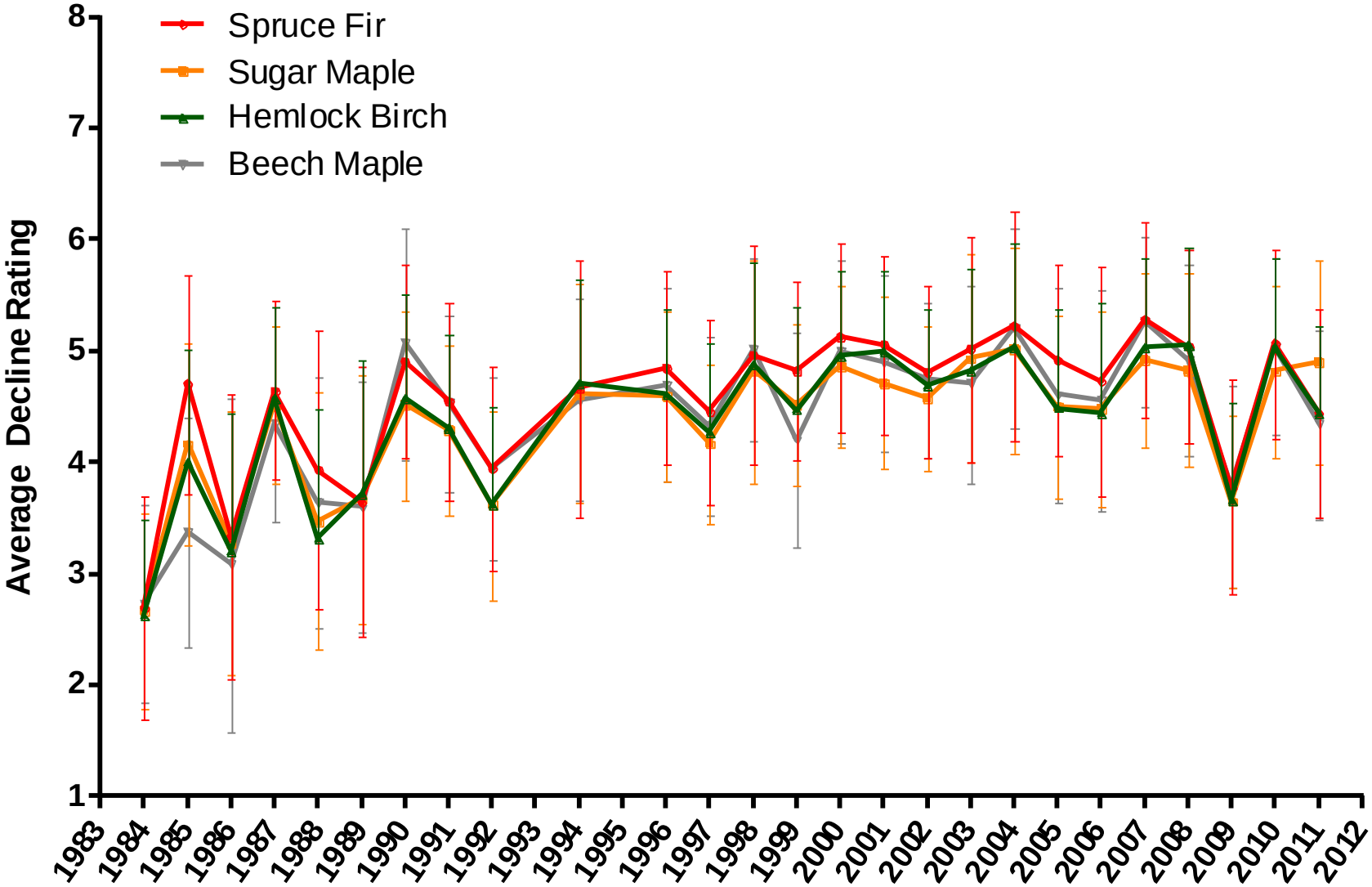




While field validation for all 25 years of imagery is not available, comparison to statewide FIA dieback measurements shows a strong correlation between our predicted condition and field metrics.

Decline Trend Results

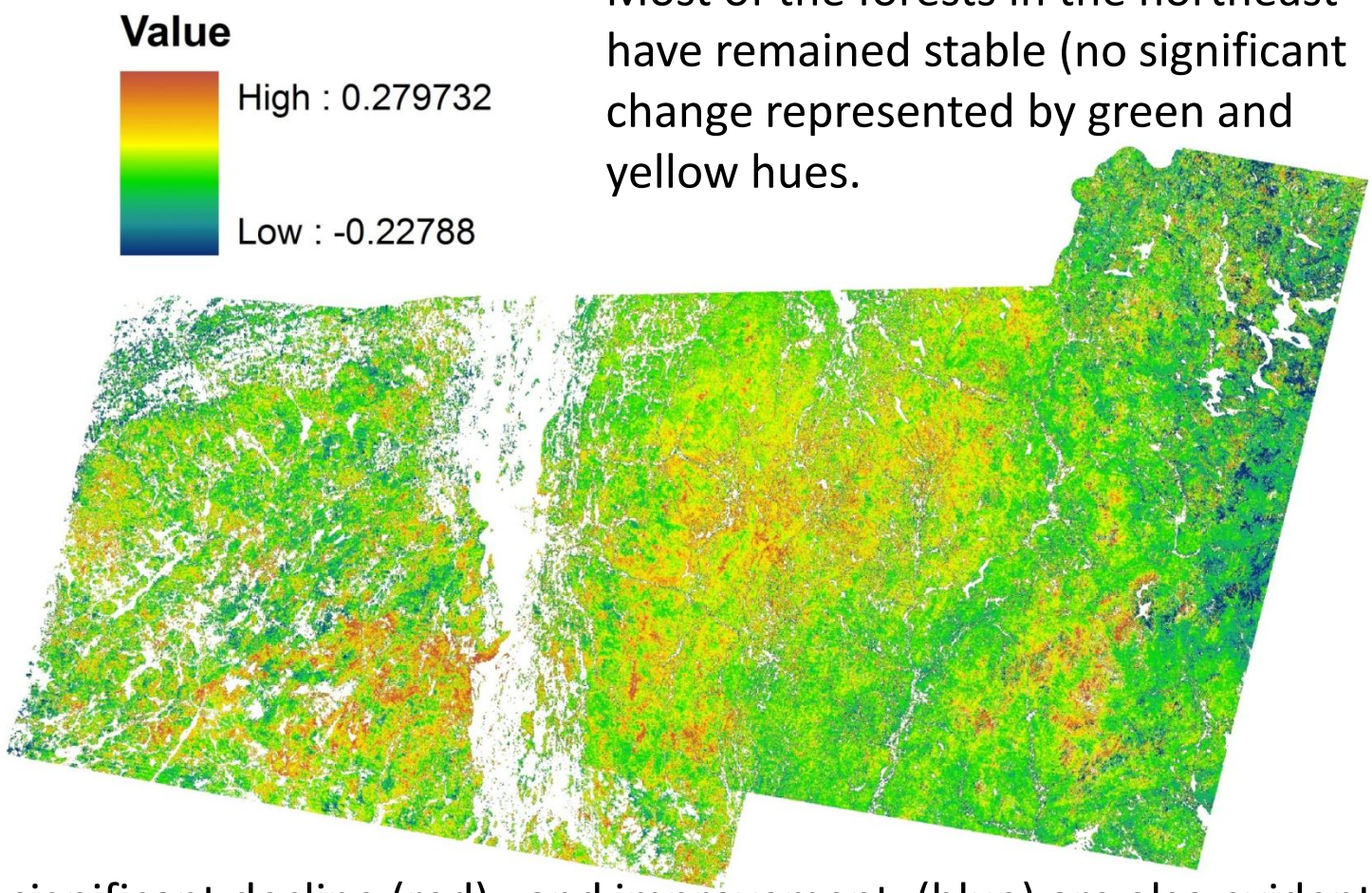
Forest condition varies from year to year, primarily driven by precipitation patterns.



Decline Trend Results

The final decline trend product reports the average yearly change in forest condition over the 25 year study.

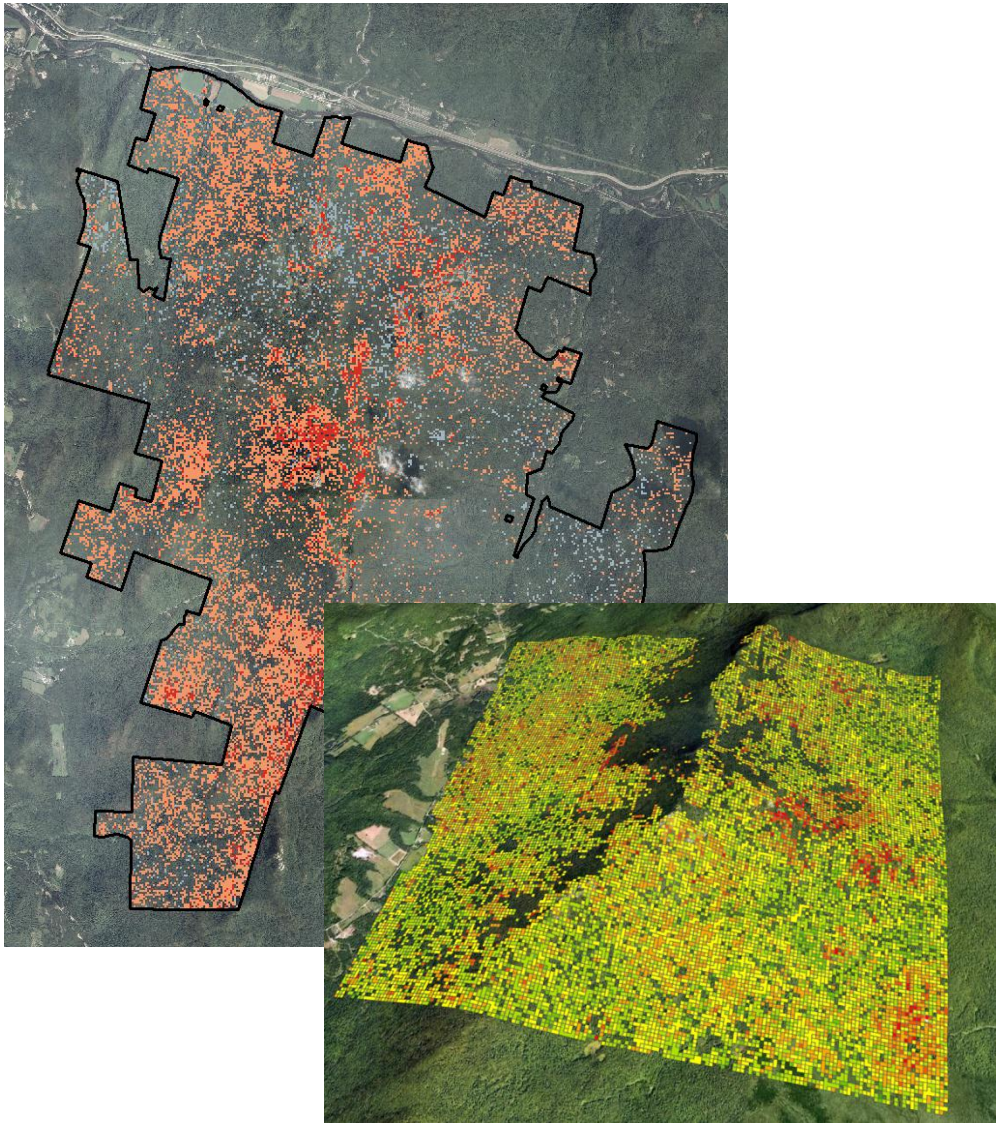
Most of the forests in the northeast have remained stable (no significant change represented by green and yellow hues.

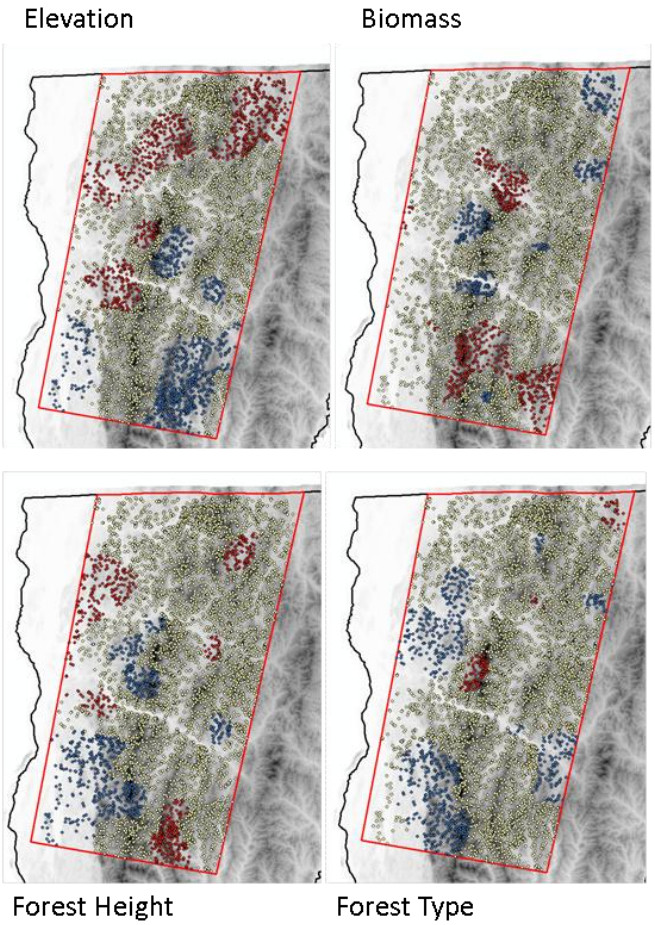


Patches of significant decline (red), and improvement (blue) are also evident.

Decline Trend Results

Smaller scale spatial patterns of decline exist





Geographically weighted regression and cluster analyses indicate variable significance varies by geographic location.

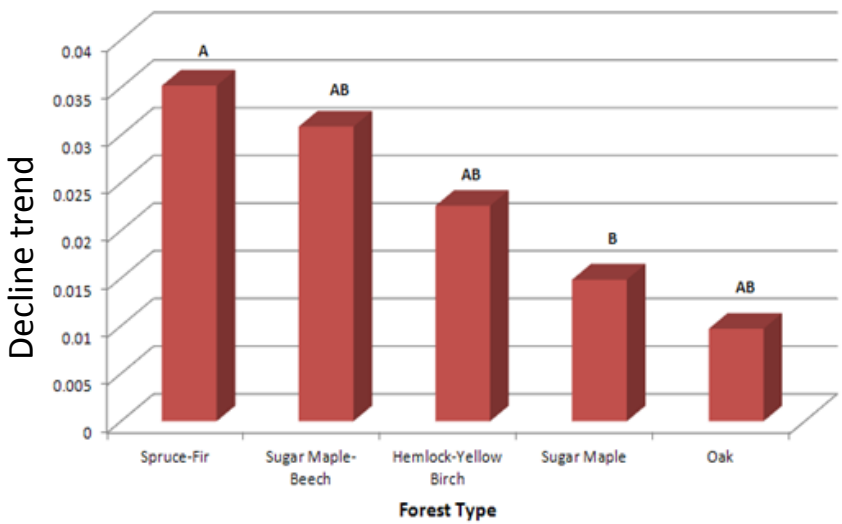
Geodatabase Results

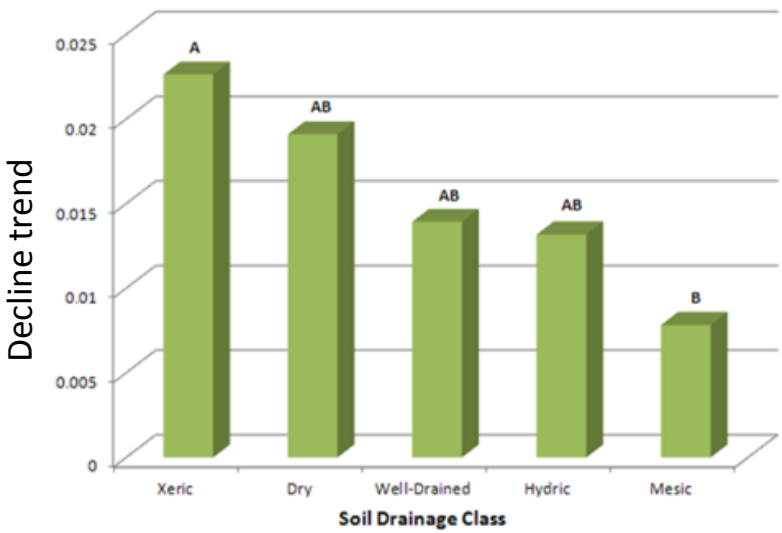
Across the entire region, decline was significantly correlated with:

- higher elevations, steeper slopes and higher total biomass

Decline was also significantly higher in:

Spruce / Fir / Birch and Sugar Maple / Beech Stands and on **Xeric Soils**





Geodatabase Multivariate Results

A multivariate, geographically weighted regression , examining all variables and their potential interactions found that:

Decline increases as:

- Elevation, biomass and forest height increase

Decline is higher in:

- spruce-fir and beech-maple forest types and
- stands that have experienced multiple disturbance events

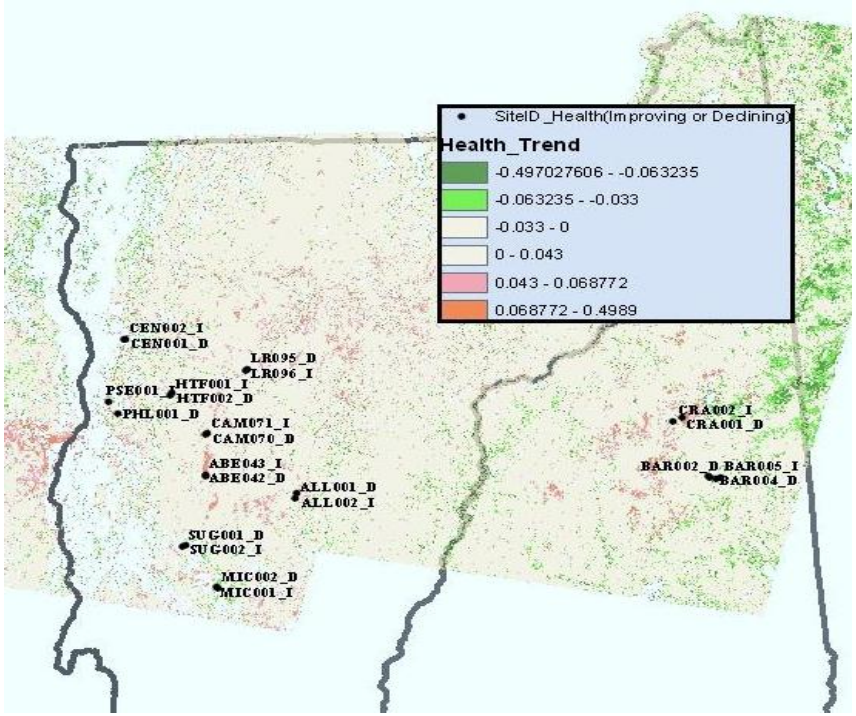
The fit of this model varied geographically, with the strongest relationships in areas of extreme terrain. It is likely accuracy at lower elevations is impacted by land use and land change variables not captured in the geospatial data layers.

Overall, the model could explain only 21% of total variability in forest decline trends, indicating that there are likely other variables influencing forest health not captured in the model.

Field Investigation Results

Pairs of declining and improving plots with similar species composition found that declining stands had:

Had more rapidly drained soil textures,
Lower calcium and higher aluminum concentrations in the organic soil horizon.



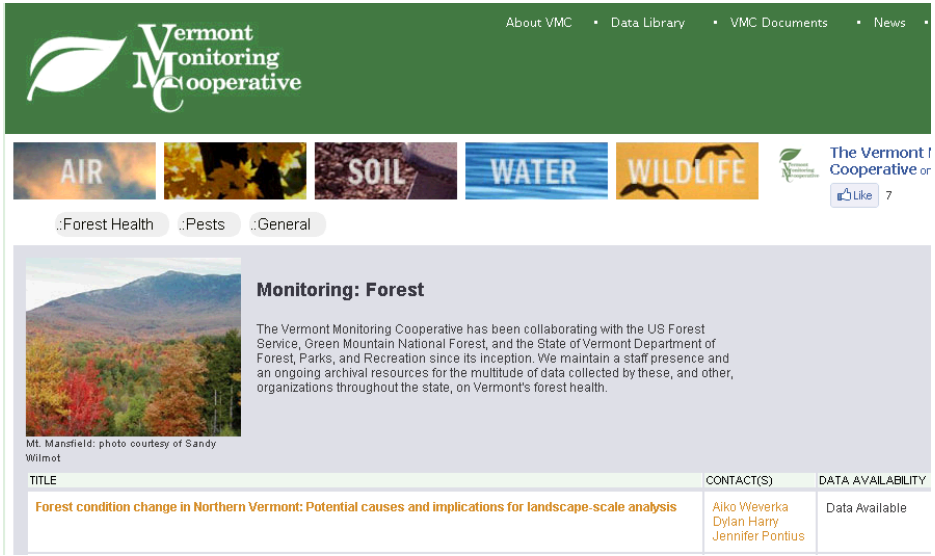
Outreach Efforts

- Both undergraduate and graduate students have been actively involved in research effort throughout (from image processing to manuscript preparation)

- A module for the Satellites, Weather and Climate teacher training program was created, using this work as an example of assessing climate impacts on forest ecosystem function.

SWAC: Overview of Climate, Phenology and Satellites Module

Learning Objective:
Investigate climate impacts on vegetation phenology through the collection and analysis of field measurements, digital photographs and satellite data.



•Both the data and GIS data layers compiled as a part of this project are currently being archived with the Vermont Monitoring Cooperative and will ultimately be available for public download via their web portal: http://www.uvm.edu/vmc/research/forest.php

Implications and applications in the Northern Forest Region

- Remote sensing is a viable option for long-term, landscape scale monitoring of forest condition. This is particularly relevant now that the USGS has made the entire Landsat archive freely available to the public.

- Examination of the 25 years included in this study indicate that the primary driver of yearly variability in forest condition is precipitation.

- Considering climate models predict more frequent extreme weather events and longer duration between rain events, this could result in increasing variability in forest condition across the region.

Implications and applications in the Northern Forest Region

•Region wide, forest condition is predominantly stable over the past 25 years. This highlights the natural resilience of forests in the northeast, where small scale disturbance can be quickly replaced by regrowth and ingrowth. This is especially true in stands with higher species diversity, indicating the need to manage for more complex stand composition and structure.

•Smaller scale spatial patterns exist, highlighting more sensitive forest stands at upper elevation sites where low site nutrient status, steep slopes, rapid drainage and extreme climate conditions converge.

•Many declines at upper elevations have been attributed to acid deposition. While deposition rates have decreased over the past decade, this data suggests that impacts on forest condition are still present.

Future Directions

- Because of the free archive of Landsat TM imagery across the globe, an expansion of this approach to new regions would provide a larger geographic examination of forest condition trends.
- A more detailed examination of forest response to specific stress events identified with this work could further inform the mechanisms of resilience in northeastern forests.
- Ongoing efforts are attempting to link the yearly imagery created as a part of this project to yearly increment core data (basal area increment growth). This will help inform long-term trends in forest productivity and carbon sequestration rates.

List of Products

Peer-reviewed Publications

Submitted but under review or revision:

- Pontius, J.; Martin M.E. A hyperspectral approach to multi-spectral forest decline assessments. International Journal of Remote Sensing. Anticipated publication 2013.
- Pontius, J.; Martin M.E.; Olson M.G.; White K.M.; Young W.L.; E. Regan. Forest Health Trends in the Northeastern United States: a 25 year Landsat TM assessment. International Journal of Applied Earth Observation and Geoinformation. Anticipated publication 2013.

Student Theses

- Olson, M. 2012. Remote sensing of forest health trends in the northern green mountains of Vermont. University of Vermont Masters Thesis. Burlington, Vermont.
- Weverka, A. 2012. Remote sensing of forest productivity in northeastern forests. University of Vermont Masters Thesis. Burlington, Vermont.
- Harry, D. 2012. An investigation of Northeastern forest health over the past 26 years. University of Vermont Honors College Thesis.

List of Products

Conference presentations

- Pontius, J. and Martin, M. 2012. Remote Sensing of Canopy Condition Across the Northeast: Trends and Patterns 1984-2009. 2012 Eastern CANUSA Forest Science Conference, November 2, 2012, Durham, NH.
- Pontius, J. and Martin, M. 2012. Quantifying forest health trends across time and space: a hyperspectral approach using multi-spectral imagery. Ecological Society of America Conference, August 7, 2012, Portland, OR.
- Weverka, A. and J. Pontius. 2012. Remote sensing of productivity in northeastern forests. Ecological Society of America Conference, August 10, 2012, Portland, OR.
- Harry, D, Pontius, J and A. Weverka. An investigation of northeastern forest health over the past 26 years. UVM Student Research Symposium, April 17, 2012, Burlington, VT.
- Weverka, A. and J. Pontius. Exploring the relationship between remotely sensed metrics of forest canopy condition and radial tree growth. UVM Student Research Symposium, April 17, 2012, Burlington, VT.
- Pontius, J., Olson, M., White, K., W. Young and E. Reagan. 2011. Remote Sensing of Canopy Condition Trends in Northern VT: 1984-2009. Vermont Monitoring Cooperative 2011 Annual Meeting, October 31, 2011, Burlington, VT.
- Pontius, J. and Martin, M. Remote Sensing of Forest Health Trends in the northeastern United States. Northeastern Ecosystem Research Cooperative Conference, November 8-10, 2010, Saratoga Springs, NY .
- Pontius, J., Olson, M., Reagan, E., White, K. and W. Young. 2009. Remote Sensing of Forest Health Trends in the Northeastern United States. UVM Student Research Symposium, April 22, 2009, Burlington, VT.

List of Products

Leverage for additional funding:

Funding	Title	End date	Award
URECA	The role of soils in long term forest decline and recovery	2011	$ 3,260
NSRC - Graduate Research Grants	Forest condition change in Northern Vermont and New Hampshire: Potential causes and implications for landscape-scale analysis	2012	$ 3,500
NSRC - Graduate Research Grants	Quantifying forest vegetation phenology in Vermont: Remote Sensing of 28 year trends in northeastern vegetation phenology	2012	$ 5,000
MacIntire-Stennis	A top down approach to quantifying historical trends in Vermont's vegetation phenology in response to decadal climate change.	2012	$ 61,912

List of Products

Publically available Web products:

We are currently working with the UVM Spatial Analysis lab and the Vermont Monitoring Cooperative to bring data layers for forest condition in each year, and the final decline trend into a public portal for data download.

KML format will allow anyone with access to Google earth to explore the coverages and incorporate this information into their forest management efforts.

Anticipated release: January, 2013