USE OF AERIAL HYPERSPECTRAL IMAGING FOR MONITORING FOREST HEALTH

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Abstract—This project evaluates the effectiveness of aerial hyperspectral digital imagery in the assessment of forest health of loblolly stands in central Alabama. The imagery covers 50 square miles, in Bibb and Hale Counties, south of Tuscaloosa, AL, which includes intensive managed forest industry sites and National Forest lands with multiple use objectives. Loblolly stands on upland sites within this area have a history of decline, root deterioration, and periodic severe southern pine beetle infestations. Forest Health Monitoring plots have been established throughout Alabama and other Southern States within the loblolly ecosystem. Additional Evaluation Monitoring (EM) plots are also established in the hyperspectral imagery assessment area. The database of the EM plots provides detailed information on soils, tree crown indicators of decline conditions, and root health/root pathogen interactions. The EM data provides reference points for the hyperspectral imagery.

INTRODUCTION

This hyperspectral imaging project is an extension of a Forest Health Monitoring assessment of loblolly pine (*Pinus taeda L.*) decline in central Alabama and a cooperative effort of the USDA Forest Service-Forest Health Protection Field Office in Pineville, LA, and Eastman Kodak Company, Rochester, NY. Loblolly decline has been prevalent on upland sites on the Oakmulgee Ranger District located predominately in Bibb, Hale, Perry and Chilton counties for the past 40 years. Periodic southern pine beetle epidemics and the district's reforestation efforts have gradually replaced a number of the declining stands with longleaf pine (*Pinus palustris Mill*), which is more suited for these sites.

The symptoms of loblolly decline are thinning of crown foliage and reduced radial growth, with mortality occurring within the 40- to 50- year age class. The Evaluation Monitoring (EM) data show that loblolly decline is a complex of biological events and site conditions that include: deterioration and necrosis of fine roots (Hess and others, in press), insect feeding, and vectoring of stain fungi of (*Leptographium spp.*) on primary roots (Eckhardt and others 2003), occurring on upland sites specific to loblolly host. Because the deterioration of fine roots precedes the expression of crown symptoms, hyperspectral imaging may be a useful tool for identifying the early stages of the decline complex. Hyperspectral imaging obtains a complete spectrum of electromagnetic radiation reflected from the earth's surface. The spectral range of 0.380 µm to 2.5 µm is optimal for forestry applications. The value of hyperspectral imaging over multispectral imaging is the ability to utilize the medium to fine scale spectral structure to monitor forest health.

Hyperspectral sensors provide the ability to detect discrete spectral changes while providing an airborne perspective needed for landscape level applications. Ground truth samples from tree crowns were measured with an Analytical Spectral Devices (ASD) field spectrometer during and 2 weeks after acquisition of the HYMAP imagery. Five categories of crown condition were initially identified representing the stages of decline. For this project, our objectives were to (1) evaluate the effectiveness and accuracy of hyperspectral products as a tool for monitoring forest health and detecting pest risk sites, and (2) determine the feasibility of hyperspectral products in forest management. Finding if hyperspectral measurements would aid in detecting a pre-visual stress of conifer stands was of specific interest.

METHODS AND PROCEDURES

Three flight lines 14 miles (22.5 km) long and 1.4 miles (2.3 km) wide, with 10-percent overlap, were established. Flight lines included 9 EM plots established to assess loblolly decline. Image data were collected September 2002 using Hyvista's hyperspectral mapping (HYMAP) instrument with a 5 m per pixel ground resolution. The spectral resolution was nominally 15 nm over the 0.380 µm to 2.500 µm spectral measurement range. Out of 126 bands collected, 115 were used in the analysis. Bands that were not detecting the surface were removed from analyses. The image data were calibrated to apparent reflectance.

Spectral measurements were collected on the ground, along with GPS coordinates, to register and calibrate airborne HYMAP images. Additionally, ground spectral measurements were acquired from 5 classifications of loblolly decline on EM plots to include: (1) Healthy – using FHM tree crown classification; (2) Pre-decline, defined as looking healthy from both the air and ground but under stress (e.g., fine root deterioration and reduced radial growth); (3) Decline, looks healthy from the air but is symptomatic when ground checked; (4) Fading, symptomatic from both the ground and the air; and (5) Dead with needles attached. Branch samples from each of the 5 classifications were taken and formed into a measurable crown shape. Ground spectral measurements sampled multiple examples of each classification found across all three flight lines. A primary objective of the ground measurements was to determine if foliar spectral differences could be detected

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in the 5 classes. Ground measurements also determined if the field results were spatially scalable to that of the HYMAP images.

Spectral measurements were also taken of other forest species, soils, and other surface materials to define the background spectral clutter not part of loblolly decline. Other forest types/species included longleaf pine, upland hardwoods, and bottomland hardwoods. Additional measurements included open fields, kudzu, cutover forest-brush, concrete, asphalt, and soils. The final classification requirement was to detect the decline condition independent of the spectral background clutter.

Two separate sets of ground truth data were collected. One set was used as training and the second for accuracy assessment. The first set included areas on Forest Service land, mostly homogeneous over several pixels and in flight line 2 of the HYMAP data set. The training areas included 16 areas of healthy forest and 7 areas of loblolly pine decline. Most of the damaged areas were of class types predecline and decline. By localizing the training data to a single flight line, the classification could be assessed over the broader range of spectral measurement variability encompassed by all three flight lines.

The second data set consisted of 60 regularly spaced field plots covering all 3 flight lines. For each plot, the forest type and condition classes were recorded using USDA Forest Service Region 8 Silvicultural Handbook codes. The 60 field plots were also classified as damaged or healthy based on a visual crown rating. It was not possible to determine the predecline class in these plots except for the EM plots.

A number of algorithms were evaluated by Kodak's hyperspectral group to maximize detection of loblolly decline including maximum likelihood classification, spectral angle matching, spectral mixture analysis, multi-layer feed forward neural network, and linear finite impulse response (FIR) filters. This report focuses on the results from FIR filters because these came closest to meeting the combined set of objectives. Other studies have demonstrated the use of filters (Gruninger and others 2001, Pinzon and others 1998). Unique to this study was relaxing the filter constraints over the rigid constraints of previous studies. Specifically, a hyperspectral forest health index (HFHI) is presented that is based on a single FIR filter. This filter is specific to loblolly pine stands.

RESULTS

It was possible to uniquely detect the five classes of loblolly decline with no error using only the ground spectral measurements. Five separate FIR filters (one filter for each class) could perfectly separate over 40 spectral measurements per class taken at multiple-look angles of the different stages of decline. However, we were unsuccessful in applying the same FIR filters determined from ground measurements to the spatial scale of the HYMAP image measurements. In addition, we were unsuccessful in finding a completely separate set of filters that could be used to classify the five classes of decline. Clearly, there were foliar differences, but these were not detectable at the spatial scale of the HYMAP images.

We succeeded in creating a FIR filter from the training data to separate healthy from predeclined and declined loblolly trees. The classified output product, figure 1, was derived from the HFHI image. Although the filter was trained with data from flight line 2 (the middle strip in the mosaic), the results demonstrate the ability of the filter to perform consistently under varying cross track path radiance indicated by 0.800μm bandpass in figure 2. Similar variability existed in all HYMAP bandpasses.

For the 60 field plots, the classification of forest health (damaged and healthy) resulted in an overall classification accuracy of 83.3 percent (table 1). Correct classification of 72.2 percent of the plots judged damaged and 88.1 percent of the plots judged healthy was achieved. The classification is sensitive to geo-referencing due to the small local pockets of loblolly decline and the accuracy of the handheld GPS units (± 10 m). The plot sizes used for accuracy assessment were not much larger than a single 5-m- imaged pixel on the ground. A few sparsely spaced loblolly pines in mixed hardwoods are a difficult problem to detect especially when the imaged spatial resolution is typically larger than a single loblolly crown. Classification

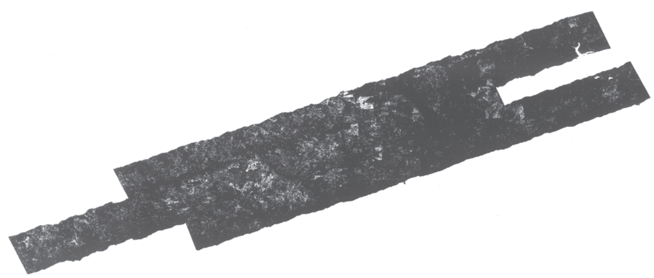

Figure 1—Classified image derived from the hyperspectral forest health index (HFHI). Bright areas signify areas of loblolly decline whereas darker areas signify healthy vegetation. Note that the lands managed for timber production in the upper right indicate much less decline than those of the Forest Service lands in the middle to lower left. The distribution of decline is speckled in the image and

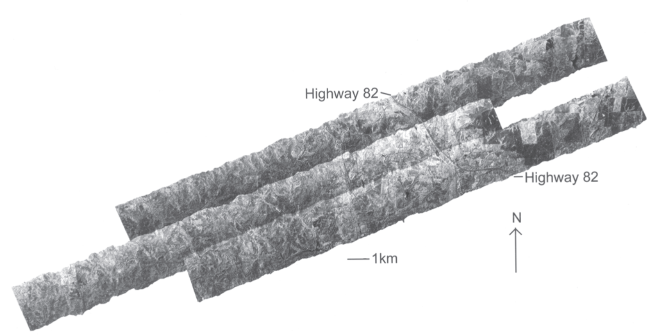

Figure 2—A mosaic of the three flight lines of the 0.800mm bandpass illustrates the spectral variability in cross track path radiance. Noticeable is a varying specular component from the forest also in the cross track scan direction. Training of the HFHI filter is performed specifically to be immune to small variations in calibration, specular reflectance, and path radiance.

Table 1—Hyperspectral classification of plot data

PID	St	FL	HFHI	Err	PID	St	FL	HFHI	Err	PID	St	FL	HFHI	Err
A3	H	1	108		A64-S2	H	1	135		A91	H	2	134	
A10	H	1	145		A66	H	1	202	E	A92	D	2	90	E
A21	H	1	156	E	A66-S1	H	1	104		A102-S1	H	2	110	
A22	H	1	77		A68	H	1	107		A108	D	2	148	E
A22-S1	H	1	129		A77	H	1	95		A109	D	2	168	
A22-S2	H	1	126		A79	H	1	105		A111	H	2	122	
A28	H	1	84		A80	H	1	113		C4	D	2	182	
A33	D	1	161		A81	H	1	152	E	C5	D	2	165	
A34	D	1	69	E	A83	H	1	131		C17	D	2	163	
A35-S1	D	1	145	E	A107	H	1	110		C18	D	2	191	
A36	H	1	131		C14	D	1	151		GS-2	H	2	144	
A41	H	1	74		C73	D	1	162		A28-S1	H	3	139	
A47	H	1	164	E	C73-S1	H	1	113		A82	H	3	121	
A50-S1	H	1	113		GS-1	D	1	153		A82-S1	D	3	161	
A51-S1	H	1	110		A52-S1	H	2	166	E	A94	D	3	158	
A51-S2	H	1	107		A55-S1	H	2	101		A93	H	3	106	
A52	H	1	98		A78	D	2	156		A97	H	3	68	
A61	H	1	76		A79-S1	D	2	198		A100	H	3	143	
A62	H	1	103		A88	H	2	127		A104	H	3	125	
A64-S1	H	1	28		A90	D	2	131	E	C39	H	3	140	

The plot ID (PID), health status (St with conditions of H healthy, D decline), flight line (FL), hyperspectral health index (HFHI) and error (Err) is recorded for each of the 60 plots. An HFHI value above 150 indicates a loblollystand class type to be pre-decline to decline. A value less than or equal to 150 indicates a healthy or other type of surface. Errors are delineated with an E in the Err field.

accuracy is significantly degraded given the potential for single-pixel, geo-referencing errors. For the most part, the errors in classification were made with HFHI values near the class boundary (e.g., values of 150), and these errors are within the uncertainty level of the filter. However, three plots (A34, A66, and A92) had HFHI values that were much larger than the filter uncertainty level. In rechecking these plots, both A34 and A92 were classified correctly by the filter but were near boundaries making them sensitive to GIS positioning errors. A66 was in a plot of 6 healthy long-leaf pines surrounded by a stand of declining loblolly pines. It is likely that the filter performance decreases for area sizes near the image spatial resolution.

The HFHI filter is not directly detecting damage as a specific foliar spectrum. Filters derived from foliage using the field spectrometer measurements did not correspond to the image measurements, taking into account calibration and atmospheric uncertainty. It is unlikely that hyperspectral measurements can be used to differentiate a series of forest damage classes specific to loblolly decline due to the low signal to clutter ratio between healthy and declined stands. As the filter is linear, the training works well outside the training area as long as the surface components are spectrally similar.

Attempts to reduce the spectral resolution or range resulted in lower accuracies, indicating the significance of medium- to fine-scale spectral measurements unique to hyperspectral systems such as HYMAP. The spectral complexity of healthy canopies and those in decline, along with atmospheric variability, required the full spectral range of the HYMAP instrument to optimize detection of forest health classes.

CONCLUSIONS

A single FIR filter achieved an accuracy of better than 83 percent to detect a class defined by loblolly pine with both previsual and visual decline. Hyperspectral measurements were required to detect and map areas of loblolly decline. Attempts to reduce the spectral resolution resulted in significantly lower classification accuracies. We postulate that discrimination of decline is due to the scattering affects of the forest stand components (healthy needles, chlorotic needles, cones, branches, and bark) controlled largely by the crown geometry.

ACKNOWLEDGMENTS

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