Final Report
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Fuel Classification for the Southern Appalachian Mountains using Hyperspectral Image Analysis and Landscape Ecosystem Classification – Task 4

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Study Locations:
Great Smoky Mountains National Park, Near Townsend, TN. Tennessee 2nd Congressional District.

Nantahala National Forest, near Highlands, NC. North Carolina 11th Congressional District.

Chattahoochee National Forest, near Clayton, GA. Georgia 9th Congressional District.

Sumter National Forest, near Westminster, SC. South Carolina 3rd Congressional District.

Executive Summary

Excessive fuel loading and rapid urbanization are of concern throughout the southern Appalachian Mountains. Prescribed burning has been attempted only recently in these mountains and fuel models are not available. This project used a two-phase approach to model fuel loading in the region. The first phase tested and existing Landscape Ecosystem Classification Model as a basis for classification of fuels in mountainous terrain. We expected fuel classes to be correlated with the same variables used to define landscape units (geography and topography).

Phase one used over 1,000 study plots throughout 4 states to measure fuels over a variety of topographic and disturbance conditions. Pilot studies showed that the Landscape Ecosystem Approach was difficult to use and provided little extra information than by stratifying sample plots by topographic position (southwest-facing upper and lower slopes, northwest-facing upper and lower slopes, and ridges). Therefore, each plot was described by topographic position. Disturbances were described by existing conditions and confirmation from management records. Common disturbances included fire, windthrow, southern pine beetle attack, and harvesting. Sampling required approximately 3 years to complete because of the remote locations of most sample plots.

Lessons learned in Phase One:

- Few fuel differences occurred among topographic positions for undisturbed plots, indicating that fuel accumulation is no greater on highly productive sites than on less productive sites.
- Ericaceous shrubs were less common than expected and may be problem fuels in only limited areas.

- Disturbance history and type played a greater role in determining fuel loads than did topographic position.
- Disturbances were common, particularly on exposed slopes.
- Fire tended to decrease some fuels while beetle attack, harvesting, and windthrow increased most fuels.
- Fuel loads described by this study are directly applicable to fire planning and fire behavior modeling and can help to determine where fuel measurements for planned fire should be concentrated.

Once Phase One was completed, the second phase was to determine if fuels in each class can be detected from aerial images using hyperspectral image analysis. Signatures of reflectance values were developed for important fuel categories with ground measurements. Analysis of hyperspectral images identified areas on the ground containing each category of fuel loading. Ground crews verified the accuracy of these signatures and improvements were made. Validation of the signatures was done by image analysis and ground truthing.

An unexpected result of phase one was that woody fuels varied little among topographic positions, with the exception of disturbed sites and the presence of ericaceous shrubs. Because of these results, we changed our emphasis for hyperspectral imaging to the techniques for mapping ericaceous shrubs. We suggest that disturbed sites and topographic position are simple to identify with hyperspectral imaging but these features can be identified by other methods (Landsat or aerial photography) that are much less expensive, making hyperspectral imaging impractical. Also, this part of the project was limited to the study area on the Nantahala National Forest due to data limitations in the other areas.

Lessons learned in Phase Two

- The advantages of using hyperspectral imagery for mapping include improved spatial resolution (2 m) and improved spectral resolution (37 channels for a broader range of energy bands.
- The disadvantages include; the technology is untested for these specific uses and it may be too expensive for practical forest management purposes.
- The use of hyperspectral data and the new method of using the hyperspectral library (STIHL) with the Enhanced Spectral Angle Mapper (ESAM) to identify members of the understory plant community matches the needs of forest research and fire management.
- The ability to detect changes in species distribution is within the capabilities of hyperspectral technology.
- By utilizing techniques outlined in this study as well as combining others such as NDVI and other spectral indexes, it may be possible to obtain rough assessments of fuel loads without the labor and time consuming ground surveys.
- Hyperspectral field profiles (spectra) of the plant species, created under natural conditions, have the highest likelihood of comparing favorably with the spectra extracted from remotely sensed imagery.

PHASE ONE

Fuel Loads on Disturbed and Undisturbed Sites in the Southern Appalachian Mountains

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Abstract- Fire planning can be difficult is the southern Appalachian Mountain region due to limited knowledge of fuel distribution. This study provides extensive measurements of Appalachian fuels with sampling fuels in four states, using over 1,000 study plots that were stratified by topographic position and disturbance history. Few fuel differences occurred among topographic positions for undisturbed plots, indicating that fuel accumulation is no greater on highly productive sites than on less productive sites. Ericaceous shrubs were less common than expected and may be problem fuels in only limited areas. Disturbance history and type played a greater role in determining fuel loads than did topographic position. Disturbances were common, particularly on exposed slopes. Fire tended to decrease some fuels while beetle attack, harvesting, and windthrow increased most fuels. Fuel loads described by this study are directly applicable to fire planning and fire behavior modeling and can help to determine where fuel measurements for planned fire should be concentrated.

Introduction

The southern Appalachian Mountains have long been appreciated for their diversity of plants and plant communities. Many factors combine to establish this diversity including a mosaic of soils, aspects, elevations, weather patterns, and disturbances. However, a key factor for several communities has been missing for several decades: fire. Lightning- and man-caused fires played a significant role in the evolution of southern Appalachian plants and plant communities (Van Lear and Waldrop 1989). Fire exclusion policies on public lands likely reduced the diversity of the southern Appalachian Mountains and have increased fuel loads. Changes in forest structure that have resulted from the succession of fire-dependent pine-hardwood communities to hardwood-dominated stands, as well as an abundant ingrowth of flammable understory species such as mountain laurel (*Kalmia latifolia* L.) have made it necessary to update fuel load estimates for the region (Harrod and others 2000, Vose and others 1999). Increased fuel loads are a particular concern in these mountains because the numbers of retirement communities and single homes multiply each year. The major causes of wildfires in the region are debris burning and incendiary fires, which become more common with population growth.

Even prescribed burning had limited use in the southern Appalachian Mountains until the mid- to late 1980's. Land managers perceived fire as too dangerous because of the difficulty of controlling fires on steep slopes and the potential for soil erosion and damage to valuable hardwoods. Today burning is limited and most prescribed fires are for fuel reduction, wildlife habitat, and restoration of endangered species or threatened communities. Fire managers of the region are gaining skills for prescribed burning but they lack basic information that is readily available for other regions. Models of fuel loading and photo series have not been developed. Thus, fire managers use limited measures of fuels or best guesses of fuel loading to predict fire behavior and develop fire plans. Most tend to overestimate fuel loads to allow a margin for error.

Prediction of fuel loading in the southern Appalachian Mountains can be as complex as the mountains themselves, because fuels are closely associated with site and forest cover type. Studies by Iverson and others (2003), Kolaks and others (2004), and Waldrop and others (2004) suggest that loadings of dead and down fuels are controlled by the varying inputs associated with different species and productivity levels across the landscape and varying decomposition rates at different sites (Abbott and Crossley 1982). At any given time since disturbance, fuel loads are a function of the amount input from dying vegetation minus the amount lost from decay. Waldrop and others (2004) also showed that fuels can be distributed across the landscape by gravity or by cultural treatments.

A few researchers have studied fuel loading across the landscape by measuring inputs and losses from decomposition. Waldrop (1996) used a gap model (Shugart 1984) to predict fuel loads on undisturbed sites on the Cumberland Plateau of East Tennessee. Fuel inputs were approximately 65% greater on mesic sites than on xeric sites based on predicted tree growth and mortality. However, fuel accumulation was nearly identical on both sites because of higher decomposition rates in the mesic sites (8% vs. 6%). Kolaks and others (2003) collected fuels data in the Southeast Missouri Ozarks to determine if aspect had an effect on fuel loading in previously undisturbed stands. Aspect ranges included exposed slopes (135-315 degrees), ridges with no aspect, and protected slopes (315-135 degrees). They found no difference in loading of 1-, 10-, and 100-hour fuels or vertical structure of fuels across aspects, suggesting that the different input and decomposition rates across the landscape balance the loading of these fuels. However, the authors found significantly higher loading of 1,000-hour fuels on protected slopes, possibly due to logging and/or redistribution by gravity. Stottlemyer and others (2006) found that some fuels were closely associated with Landscape Ecosystem (LEC) unit in the mountains of northeastern South Carolina. The LEC system was developed by Jones (1991), Hutto and others (1999), and Carter and others (2000) to describe similar ecological units on the basis of topography and plant community assemblages. Cover of *Vaccinium* sp. was greater on dry LEC units while large diameter fuels and *Rhododendron* sp. were more common on moist units. Large diameter fuels were suggested to be from recent windthrow that had not decomposed.

Brudnak and others (2006) posed the question of how best to divide the landscape to measure fuel loads. Potential alternatives were to stratify plots by topographic position, time since disturbance, or by an LEC system. This study found that classification by discriminant function analysis was somewhat more successful using the LEC system or time since disturbance. However, they concluded that the LEC approach was only marginally more accurate than the use of topographic position. The LEC system requires training to use and has been developed for only small portions of the southern Appalachian Mountains. Therefore, the authors suggested that a combination of topographic position and time since disturbance would provide the simplest means to interpret fuel loads.

This study is a portion of a two-phase study to describe fuels in the southern Appalachian Mountains. The general approach was to develop a fuel model from extensive ground measurements (phase 1) and then to determine if those fuel types could be detected using a high-resolution remote sensing procedure known as hyperspectral imaging (phase 2). In this paper, we report the results of phase 1. Following the recommendation of Brudnak and others (2006), our specific objectives were to determine if loading of any fuel type varied by topographic position or time since disturbance.

Methods

We desired to obtain an exhaustive data set of fuel loading in the southern Appalachian Mountains because of the limited documentation of these fuels and the extremely diverse topography of the region. Therefore, we selected study sites in four states representing much of the range in elevation and topography of the region. To facilitate hyperspectral imaging in phase 2, we selected one 10-square mile area in each state: SC, NC, GA, and TN. Field measurements and hyperspectral images were collected from all four areas.

Study sites included: the Sumter National Forest in northwestern South Carolina, the Chattahoochee National Forest in northeastern Georgia, the Nantahala National Forest in western North Carolina, and the Great Smoky Mountains National Park in southeastern Tennessee (figure 1). The study area in SC is bisected by the Chauga River and has short, steep slopes trending southwest to northeast with the Brevard Fault Zone, a narrow band of low-grade metamorphic rock. Elevations range from 1,000 to 1,900 feet. The Chattahoochee National Forest study area is characterized by short, steep slopes, with elevations ranging from 800 to 2,000 feet. The Nantahala National Forest lies in an area described as the High Rainfall Belt of the southern Appalachians, receiving an average of about 80 inches of rainfall annually (Carter and others 2000). Slopes in this study area are steep, and elevations range from 2,000 to 4,500 feet. The Great Smoky Mountains National Park also lies in the High Rainfall Belt of the southern Appalachians; elevations here range from 1,100 to 3,000 feet, with topography characterized by long ridges, steep slopes, and deep ravines. Specific study areas for each forest or park were selected that would provide the full range of topographic positions and where there was an active burning program so that managers would benefit from the fuels data being collected.

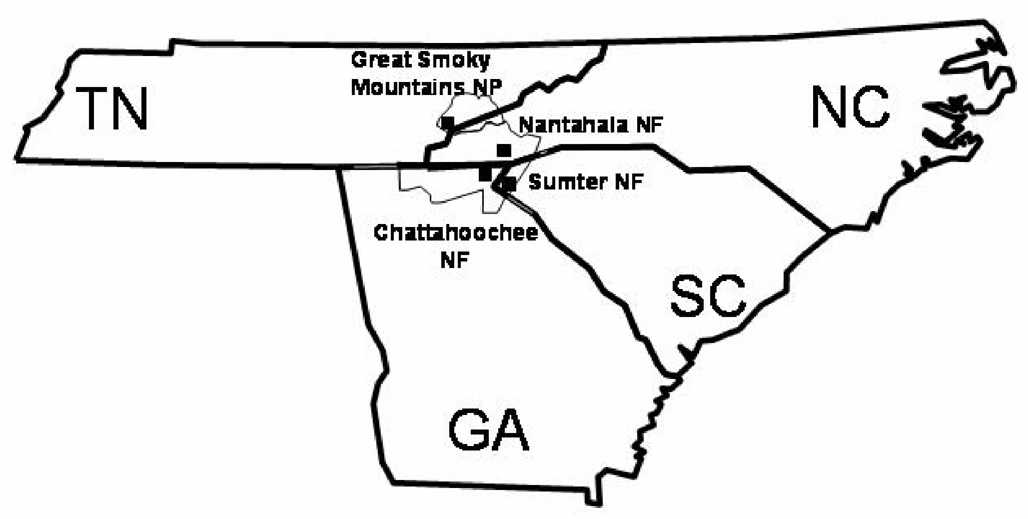

Figure 1. Location of 10-square mile study areas in the southern Appalachian Mountains.

Plot locations were generated randomly within each 10-square-mile study area using ArcView® GIS (Geographic Information System) software and were stratified by slope position and aspect. Fifty plots each were located on middle and lower slopes on either northeast (325 to 125 degrees) or southwest (145 to 305 degrees) aspects (figure 2). An additional 50 plots were on ridgetops for a total of 250 plots in each of the four study areas (1,000 total). A global positioning system receiver was used to locate the plots in the field. Additional plots were included when necessary to give adequate representation of all slope position/aspect combinations. The resulting dataset had measurements from

1,008 plots. Field measurements over this large area and for this large sample required approximately 3 years (June 2002 through April 2005).

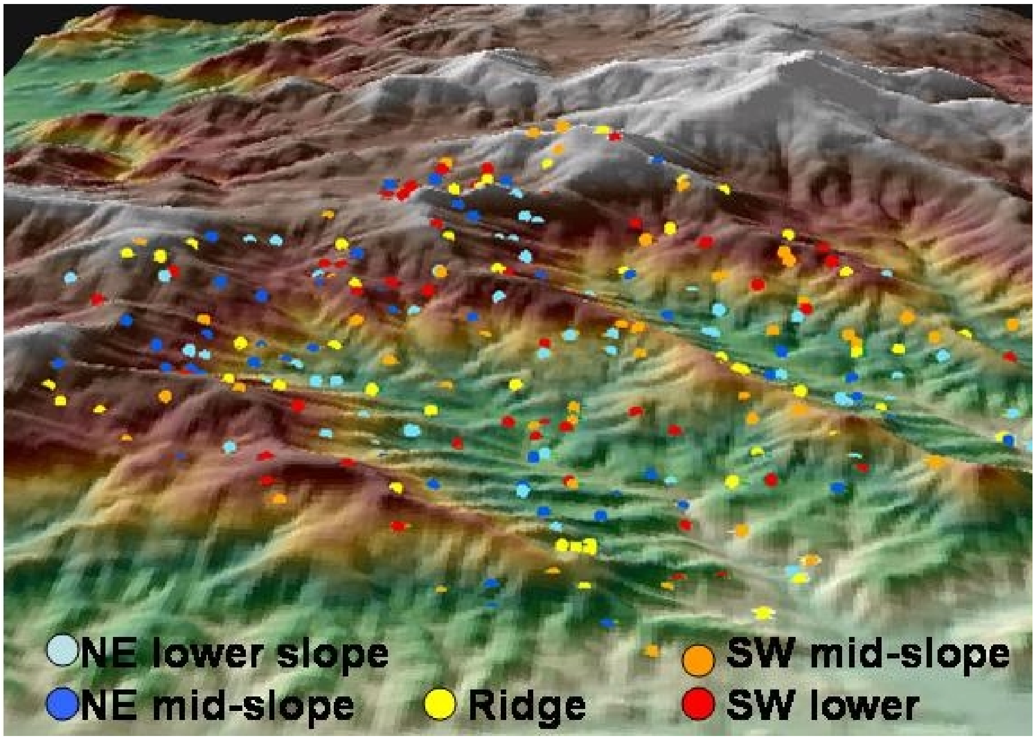

Figure 2. Example plot locations within a 10-square mile study area selected by random sampling using ArcView® GIS software and stratified by topographic position.

Fuels were measured in a 50- by 44-foot plot, using Brown's (1974) planar intersect method. Orientation of each plot was determined randomly by looking at the sweep hand of a wristwatch and multiplying those seconds by six; the resultant number was the azimuth assigned to the center fuels transect. Adding 23 to the center transect azimuth established the right transect and subtracting 22 from the center transect azimuth established the left transect.

Along the first 6 feet of each transect, we counted the numbers of 1- and 10-hour fuels (0 to 0.25 inch diameter and 0.25 to 1 inch diameter, respectively); along the first 12 feet of each transect, we counted the number of 100-hour fuels (1 to 3 inch diameter). All fuels greater than 3 inches in diameter were classified as 1,000-hour fuels and were counted along the entire length of each transect. We grouped the 1,000-hour fuels by diameter, species (hardwood or softwood), and decay class (solid or rotten). At the 12-, 25-, and 40-foot marks along each of the 3 transects we measured litter depth, duff depth, and down and dead woody fuel height. Fuel weights were calculated from these intercept counts using Brown's (1974) equations and specific gravity estimates for southern species developed by Anderson (1982).

All trees taller than 4.5 feet were measured within the entire plot area. Trees were identified by species, assigned to a 2-inch diameter class, and given a crown class of 1 (dominant or codominant; receiving sunlight), 2 (midstory; crown is mingling with the dominants), or 3 (understory; crown is completely below midstory). We also noted a tree's status as live or dead. On one half of each plot, we estimated the percent coverage of shrubs, primarily rhododendron (*Rhododendron maximum* L.), mountain laurel (*Kalmia latifolia* L.), lowbush blueberry (*Vaccinium pallidum* Ait.), and highbush blueberry (*Vaccinium constablaei* Gray, *V. corymbosum* L., *V. fuscatum* Ait., and *V. stamineum* L.).

We visually estimated evidence of disturbance and assigned one of five disturbance categories to each plot: none, fire, logging, beetle kill, or windthrow. To corroborate field observations, we obtained disturbance records for each site from offices of the appropriate jurisdiction, e.g., National Park Headquarters.

We distinguished 5 strata for the 250 plots at each study area based on a combination of slope position and aspect. In the field we visually estimated slope position and categorized it as either an upper or lower slope. If the landscape appeared to decrease in elevation on at least two sides we categorized a plot location as ridgetop. Aspects were considered northeast-facing if they fell within the range of azimuths from 325° to 125° and southwest-facing if within 145° and 305°.

Disturbed and undisturbed plots were analyzed separately by analysis of variance using topographic position as the independent variable. Dependent variables included weights of 1-, 10-, 100-, and 1,000-hour fuels plus cover of mountain laurel and rhododendron. Mean separation was by linear contrast. All differences were considered significant at α=0.05.

Results and Discussion

Of the 1,008 plots measured in this study, 70 percent (705) showed no signs of recent disturbance while 30 percent (303) had been disturbed. Among the undisturbed plots, composition of major species groups was similar across topographic positions (Table 1). Total basal area averaged 127 ft^2 per acre across all plots; it was greatest on lower slopes and decreased toward the ridges. Oaks were the most dominant species group followed by pines. The most common oak species, in order of basal area dominance, included chestnut oak (*Quercus prinus* L.), scarlet oak (Q. *coccinea* Muenchh.), and northern red oak (*Q. rubra* L.). Chestnut and scarlet oaks were most common on dry sites and northern red oak was most common on moist sites. White pine (*Pinus strobus* L.) was the most common pine throughout all study sites and was somewhat more common on northeastern slopes than on southwestern slopes. Maples and yellow-poplar were somewhat more common on ridges and southwestern upper slopes.

Table 1. Basal area (ft^2/ac) and percent) per acre by major species or species groups and topographic position on 705 undisturbed study plots in the southern Appalachian Mountains of TN, NC, GA, and SC (n=705).

Species Or Group	Northeastern Lower	Northeastern Upper	Ridge	Southwestern Upper	Southwestern Lower	All Plots
Maples	14.7 (11)	11.8 (9)	16.5 (14)	10.6 (9)	10.7 (8)	13.0 (10)
Hickories	3.9 (3)	3.4 (3)	4.6 (4)	7.2 (6)	4.3 (3)	4.7 (4)
Yellow-poplar	6.4 (5)	10.9 (9)	16.7 (14)	13.5 (11)	10.3 (8)	11.7 (9)
Pines	29.7 (22)	32.4 (26)	15.3 (13)	19.8 (16)	35.6 (27)	26.0 (21)
Oaks	44.8 (34)	43.4 (34)	32.7 (27)	34.8 (28)	42.4 (32)	39.2 (31)
Hemlock	7.4 (6)	3.4 (3)	10.2 (9)	7.4 (6)	3.4 (3)	6.5 (5)
Understory	14.8 (11)	9.0 (7)	12.6 (11)	18.7 (15)	11.2 (8)	13.3 (10)
Other Overstory	11.9 (9)	12.4 (10)	11.0 (9)	11.3 (9)	14.8 (11)	12.3 (10)
Total BA	133.7	126.7	119.6	123.2	132.7	126.7

Downed woody fuels showed few differences in loading in undisturbed plots across aspect and slope positions (Table 2). There was a general trend among woody fuels to have lower loads on ridges and increased loads at lower slope positions, suggesting redistribution by gravity. However, differences were not significant for 10-, 100-, and 1,000-hr fuels and for fuel height. Ten-hour fuels averaged approximately 0.90 tons per acre at all slope positions and 100-hour fuels weighed approximately 3.4 tons per acre. Fuels in the 1,000-hour class ranged from 15 to 19 tons per acre. One-hour fuels were significantly lower on ridge plots than at all other slope positions but no other differences were found. The litter on 705 sample plots followed an opposite pattern, tending to be heaviest along the ridges and decreasing downhill on both southwest and northeast slopes, suggesting that decomposition exceeded leaf litter inputs on the wetter sites. Even though this difference among site types was significant, the relative differences were small. There was approximately 12 percent less litter on northeast lower slopes (1.69 t/ac) than on ridges (1.92 t/ac). Lack of significant differences among woody fuels was surprising because of the large sample size. However, these findings closely agree with those of Kolaks and others (2003) and Waldrop (1996) indicating that down woody fuels tend to be uniformly distributed across slopes and aspects, suggesting a balance between inputs and decomposition.

Table 2. Fuel Characteristics of undisturbed plots by slope position and aspect in the southern Appalachian Mountains of TN, NC, GA, and SC (n=705).

Slope/ Aspect	Litter (t/ac)	1-hr (t/ac)	10-hr (t/ac)	100-hr (t/ac)	1000-hr (t/ac)	Fuel Ht (in)	Kalmia (%)	Rhododendron (%)
Northeast Lower	1.69 a[1]	0.30 b	0.89	3.5	18.7	4.1	11.3 a	37.7 c
Northeast Upper	1.94 b	0.32 b	0.91	3.5	14.6	4.5	13.5 a	17.9 b
Ridge	1.92 b	0.27 a	0.93	3.6	15.1	4.3	12.7 a	3.7 a
Southwest Upper	1.80 ab	0.30 b	0.88	3.3	17.3	4.2	25.8 b	8.1 a
Southwest Lower	1.67 a	0.30 b	0.87	3.2	15.6	4.0	14.8 a	16.1 b

[1] Means followed by the same letter within a column are not significantly different at the 0.05 level.

Another component of fuels in the southern Appalachian Mountains that must be considered is live fuel cover, particularly from ericaceous shrubs. Vose and others (1999), Waldrop and Brose (1999), and Phillips and others (2006) indicate a strong relationship of fire intensity to cover of mountain laurel (*Kalmia latifolia* L.). Van Lear and others (2002) discussed the importance of rhododendron species on the ecology of the southern Appalachian Mountains. Even though these are generally moist-site species, they occasionally ignite and can act as vertical fuels. In this study, both mountain laurel and rhododendron (*Rhododendron* sp.) were missing from most measured plots (absent on 58% of plots for mountain laurel and 75% for rhododendron) but occurred in thick clumps where they were found. Mountain laurel was found at all aspect/slope position combinations but was significantly more abundant on southwest upper slopes (Table 2). Wildfires that might occur could reach dangerous intensities if they burned uphill on dry southwest slopes and ran into thickets of mountain laurel. Rhododendron was also present at all slope/aspect combinations, but it was more common on moist lower slope and northeast-facing plots.

Disturbance was fairly frequent in the 4 study areas, occurring on 30 percent of sampled plots. The most common form of disturbance was fire, impacting 35 percent of disturbed plots (11 percent of all plots). Wind was the second most frequent disturbance; it impacted 25 percent of disturbed plots and 8 percent of all plots. Study plots showing signs of disturbance were much more common on ridges and southwest-facing slopes than on northeast-facing slopes (Table 3). Plots disturbed by southern pine beetle, harvesting or fire were 3 to 5 times more numerous on these exposed sites than on the more protected northeastern slopes. Windthrow was observed on approximately equal numbers of plots across all slope positions.

Table 3. Number of study plots by disturbance type and slope position in the southern Appalachian Mountains of TN, NC, GA, and SC.

Disturbance Type	Northeast Upper	Northeast Lower	Ridge	Southwest Upper	Southwest Lower
None	135	128	159	130	152
SPB[1]	2	2	16	12	8
Harvest	4	6	16	18	5
Fire	12	18	50	35	22
Wind	18	11	19	14	14

[1] Southern pine beetle

Patterns of fuel loading on disturbed plots were similar to those on undisturbed plots with few differences in loading across slope and aspect positions (Table 4). Weights of litter, 1-hour, 10-hour, and 100-hour fuels did not vary significantly and averaged 1.73, 0.33, 1.10, and 4.4 tons per acre, respectively. Cover of mountain laurel and rhododendron varied by slope position but followed predictable patterns similar to those of undisturbed plots. Loading of 1,000-hour fuels followed a different pattern on disturbed sites, however, with higher loading at down slope positions. Northeastern lower slopes had the highest loading of these large woody fuels. Weights of 10-hour, 100-hour, and 1,000-hour fuels on disturbed plots (Table 4) were considerably larger than those on undisturbed plots (Table 2). For example, 1,000-hour fuels weighed an average of 29.7 tons per acre on disturbed plots but only 16.3 tons per acre on undisturbed plots. This difference is likely caused by a large influx of woody fuels that have not completely decomposed after the disturbance. Our results suggest that lower slope positions receive greater loading of large woody fuels than do higher slope positions due to gravitational repositioning and higher productivity. However, if these sites remain undisturbed long enough for fuels to decompose, loads there will be similar to those found at other slope positions.

Table 4. Fuel Characteristics of all disturbed plots by slope position and aspect in the southern Appalachian Mountains of TN, NC, GA, and SC (n=303).

Slope/ Aspect	Litter (t/ac)	1-hr (t/ac)	10-hr (t/ac)	100-hr (t/ac)	1000-hr (t/ac)	Fuel Ht (in)	Kalmia (%)	Rhododendron (%)
Northeast Lower	1.75	0.29	1.03	5.0	42.4 b[1]	5.1	4.2 a	27.3 c
Northeast Upper	1.55	0.30	0.98	3.6	29.2 ab	4.6	8.2 ab	17.0 b
Ridge	1.76	0.36	1.26	5.2	21.7 a	5.8	6.6 ab	1.9 a
Southwest Upper	1.72	0.35	1.13	4.2	24.1 a	5.2	10.9 ab	3.8 a
Southwest Lower	1.87	0.34	1.12	4.1	31.1 ab	5.2	16.0 b	13.5 b

[1] Means followed by the same letter within a column are not significantly different at the 0.05 level.

The type of disturbance had significant impacts on fuel loads in the four 10-square mile study areas. Litter accumulation was significantly lower on burned plots than on plots that had not been disturbed but there were no differences due to southern pine beetle, harvesting or wind (Table 5). One-hour and 10-hour fuels tended to be greater on disturbed plots than on undisturbed plots with those increases being significant with beetle attacks in 1-hour fuels and beetle attacks, harvesting, and fire for 10-hour fuels. The increase in 10-hour fuels after fire may be unexpected. However, most fires kill small trees and shrubs and eventually increase loading of small woody fuels (Scholl and others 1999, Waldrop and others 2004). Harvesting did not increase 100-hour and 1,000-hour fuels, probably because these fuels were removed from the site. Other disturbances leave dead trees in place and, therefore, significantly increased the loading of larger woody fuels. Fuel heights were significantly increased by all disturbances with the exception of harvesting. Cover of mountain laurel was significantly reduced by harvesting and wind. Rhododendron cover was significantly reduced by harvesting and fire.

Table 5. Fuel Characteristics of plots on all slope and aspect positions by disturbance type in the southern Appalachian Mountains of TN, NC, GA, and SC (n=1,008).

Disturbance	Litter (t/ac)	1-hr (t/ac)	10-hr (t/ac)	100-hr (t/ac)	1000-hr (t/ac)	Fuel Ht (in)	Kalmia (%)	Rhododendron (%)
None	1.79 b[2]	0.30 a	0.89 a	3.4 a	16.2 a	4.2 a	15.8 c	21.4 b
SPB[1]	1.84 b	0.44 b	1.33 c	5.2 b	28.6 b	6.1 c	14.8 bc	9.5 ab
Harvest	1.90 b	0.32 a	1.27 c	3.4 a	13.2 a	4.5 ab	3.1 a	0.5 a
Fire	1.56 a	0.30 a	1.05 b	4.7 b	20.4 ab	5.4 bc	11.6 bc	7.7 a
Wind	1.72 ab	0.32 a	0.97 ab	4.8 b	43.2 c	5.1 bc	6.2 ab	16.7 b

[1] Southern pine beetle attack

[2] Means followed by the same letter within a column are not significantly different at the 0.05 level.

Additional analyses were conducted to determine if differences in fuel loading occurred at each of the slope positions. Few differences were seen among disturbance types on northeastern slopes because of the relatively small number of disturbed plots at this aspect. On lower northeastern slopes, 1,000-hour fuels were increased by windthrow but decreased by all other forms of disturbance (Table 6). Litter on upper northeastern plots was significantly reduced by fire but increased by beetle attacks. Ten-hour fuels on upper northeastern plots were significantly reduced by windthrow, a pattern which cannot be explained. Fuel patterns on ridges and upper southwestern plots closely followed those described for all plots (Table 5) with the exception that litter weights did not vary by disturbance type on ridges and 10-hour fuels did not vary on upper southwestern slopes. Few differences occurred on southwestern lower slope positions, which is

Table 6. Fuel Characteristics of plots by slope position and disturbance type in the southern Appalachian Mountains of TN, NC, GA, and SC (n=1008).

Disturbance	Litter (t/ac)	1-hr (t/ac)	10-hr (t/ac)	100-hr (t/ac)	1000-hr (t/ac)	Fuel Ht (in)	Kalmia (%)	Rhododendron (%)
Lower Northeastern Slopes								
None	1.71	0.30	0.90	3.5	19.8 b[1]	4.2	12.0	36.0
SPB	1.38	0.31	0.49	1.1	2.7 a	4.8	3.3	27.0
Harvest	1.90	0.32	1.27	4.0	9.3 a	5.3	4.6	39.1
Fire	1.45	0.31	0.74	4.8	8.6 a	3.7	10.6	23.8
Wind	1.82	0.24	1.03	5.2	69.4 c	5.6	1.1	32.4
Upper Northeastern Slopes								
None	1.93 bc[1]	0.32	0.88 b	3.6	14.4	4.4	10.5	16.6
SPB	2.86 d	0.56	1.15 b	6.0	22.6	7.7	11.1	13.8
Harvest	2.24 cd	0.22	1.34 b	2.8	25.3	4.3	3.9	6.7
Fire	1.09 a	0.28	1.08 b	4.2	30.3	4.4	9.6	19.6
Wind	1.57 b	0.29	0.45 a	1.7	22.6	4.5	13.9	36.7
Ridges								
None	1.87	0.28 a[1]	0.95 a	3.7 a	14.6 a	4.3 a	15.8	12.1
SPB	1.64	0.47 c	1.43 b	5.3 ab	31.9 b	5.8 b	11.3	3.6
Harvest	1.80	0.38 bc	1.39 b	4.3 ab	5.2 a	4.8 ab	0.1	2.1
Fire	1.73	0.32 ab	1.19 b	5.4 b	16.9 a	6.2 b	7.3	0.2
Wind	1.71	0.31 ab	1.04 ab	6.0 b	37.3 b	5.4 ab	8.2	8.1
Upper Southwestern Slopes								
None	1.78 b	0.30 a	0.88	3.4 a	17.2 a	4.2 a	25.1	8.4
SPB	1.98 b[1]	0.45 b	1.34	6.1 b	27.0 ab	7.1 b	23.0	10.7
Harvest	1.87 b	0.30 a	1.07	3.2 a	15.2 a	4.4 a	3.0	2.9
Fire	1.41 a	0.31 a	1.00	4.1 ab	20.6 a	5.0 a	21.0	4.7
Wind	1.77 ab	0.37 ab	1.15	5.4 ab	37.2 b	5.3 ab	10.9	8.5
Lower Southwestern Slopes								
None	1.66	0.30 a	0.87	3.2	15.6 a	4.0	14.8	16.0
SPB	1.93	0.30 b[1]	1.31	3.2	33.6 b	5.3	15.1	13.3
Harvest	1.92	0.29 a	1.39	1.9	17.3 ab	3.3	6.1	10.2
Fire	1.65	0.27 a	1.04	4.4	28.1 b	5.4	21.3	20.7
Wind	1.72	0.38 ab	0.90	3.8	34.6 b	4.9	10.3	11.1

[1] Means followed by the same letter within a slope position and column are not significantly different at the 0.05 level.

probably a result of small sample size because disturbances are less common on protected sites. In addition, mountain laurel and rhododendron cover did not vary among disturbance types at any slope position. These species vary more among than within slope positions and disturbances reduced the number of sample size of plots with these species present.

Conclusions

Information on fuel loading is in great demand for the southern Appalachian Mountains because prescribed burning is relatively new to the region, topography is complex, and few past studies have measured fuels. This project represents the most extensive measurement of forest fuels in the southern Appalachian Mountains to date. We measured fuels in 1,008 study plots in one large study area in each of four states. Study plots were stratified by topographic position and disturbance history. The project identifies the type, amount, and range of fuels that can be expected on most southern Appalachian sites where prescribed fires would be planned.

One hypothesis was that fuel loading would vary by topographic position because of the different species composition and productivity levels associated with slope position and aspect. This hypothesis proved to be false for the majority of fuel variables measured, as long as the plots showed no visible signs of disturbance. Weights of litter and 1-hour fuels varied somewhat among slope/aspect positions but weights of 10-, 100-, and 1,000-hour fuels and fuel height did not vary. This result was surprising because of the large sample size that we used for analysis (705 undisturbed plots). The result gives support to the conclusions of Kolaks and others (2003) and Waldrop (1996) who described the dynamics of fuel inputs and outputs into southern Appalachian ecosystems.

Both studies suggested that the differences in fuel inputs, associated with site quality at different topographic positions, were balanced by differing decomposition rates. Productive sites tend to have higher decomposition rates (Abbot and Crossley 1982), thus removing the higher fuel inputs sooner. The balance between inputs and decomposition deserves additional study in the southern Appalachian region.

Fuels that did vary by topographic position in undisturbed plots included the ericaceous shrubs. Mountain laurel was most common on dry southwestern slopes while rhododendron was most common on moist northeastern lower slopes. Although these patterns are well documented in other literature, the extent of cover had not been measured. We were surprised by the absence of these species on most study plots. Only 25 percent of plots had any rhododendron present and only 42 percent had mountain laurel. These shrubs grow in dense thickets and act as vertical fuels causing crown fires, when present (Vose and others 1999, Waldrop and Brose 1999, Phillips and others 2006). However, this problem was not widespread through our study sites and may only become a concern where it exists along the wildland-urban interface.

Another hypothesis was that fuel loads would be altered by disturbance. That hypothesis proved to be true because disturbance was common throughout study plots and it either increased or decreased fuel loads. Some form of disturbance occurred on 30 percent of randomly sampled plots and at all topographic positions. Disturbance was most common on ridges and upper southwest-facing slopes. Fire and windfall were the most common forms of disturbance. Fuel loads were altered, depending on the type of disturbance. When present, outbreaks of southern pine beetle increased 1-, 10-, 100, and

1,000-hour fuels and fuel height. Harvesting increased 10-hour fuels and decreased mountain laurel and rhododendron cover. Fire also decreased mountain laurel and rhododendron cover but it increased 10- and 100-hour fuels, a pattern attributed to the death of small trees and shrubs. Windfall was present at all topographic positions, decreased cover of mountain laurel, and increased loading of 100-hour and 1,000-hour fuels.

This study provided an exhaustive collection of data and the first widespread description of fuels in the southern Appalachian Mountain. Results are useful to fire managers in a number of ways. Numbers provided for fuel loading on undisturbed plots can be used directly for fire planning or fire behavior modeling with a fair degree of accuracy because of our large sample size, the low degree of variability among sample plots, and the widespread (4 states) sample design. If additional fuel measurements are desired, this study provides guidance for where those plots should be placed. Fuels were most highly variable where sites had been disturbed or dense cover of ericaceous shrubs was present. These sites should be easily identifiable through remote sensing or stand management records. The study also provides insight to the degree, type, and topographic position of disturbances that occur in the region.

Acknowledgements

This study could only be conducted through a generous grant from the Interagency Joint Fire Science Program, Boise Idaho. We are grateful to the dedicated professionals who spent countless hours hiking to plots and measuring fuels in some of the most remote regions of the southern Appalachian Mountains. Among these

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Phase Two

Forest Fires and the Environment -- Using a Hyperspectral Library as a Tool for Determining the Need for Prescribed Burning

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Abstract

Forest fires across the United States have produced situations that threaten human life, harm rare species, destroy valuable property, and emit large amounts of smoke, which potentially cause health and other environmental problems. Forest fires are often either caused by the carelessness of humans or ignited by lightning under natural conditions. In the eastern U.S. one of the most critical conditions is the heavy accumulation of fuel loading of the forest floor, which includes dead wood and under-story canopy thickets. In the Southern Appalachian Mountains, the USDA Forest Service and the National Park Service are intentionally igniting closely controlled fires to reduce heavy accumulations of dead wood and thickets and to accomplish resource management and safety needs. This method is called prescribed burning. Though prescribed fires can temporarily reduce air quality and periodically get out of control, the benefits to overall fire management far out-weigh these risks. Prescribed fires are preceded by manual removal of some trees and thickets, construction of fire lines, and close coordination with local firefighting organizations. In the Southern Appalachians, the under-story thickets consist primarily of the ericaceous species rhododendron (*Rhododendron maximum*) and mountain laurel (*Kalmia latifolia*), which have excessively accumulated because of years of forest fire suppression policies. Mapping of rhododendron and mountain laurel distribution in the Southern Appalachian Mountains would be extremely helpful to forest managers but is filled with challenges because of the vast areas and remote terrain. This study uses the STI Hyperspectral Library as a powerful tool for detecting and mapping of this under canopy thickets. A map of rhododendron distribution covering 30 square miles of study area was produced through a detailed process of image analysis and ground-truthing.

Introduction

The ericaceous species rhododendron and mountain laurel compete with and substantially limit reproduction and growth of both woody and herbaceous vegetation (Van Lear and Johnson 1983, Swift and others 1993) and therefore are thought to have a major negative impact on hardwood and other valuable species. When present, rhododendron and mountain laurel can burn with extreme fire behavior resulting in a mixed severity or stand replacement fire (Waldrop and Brose 1999). Identification, classifying and mapping understory thicket species is important for forest management, environmental conservation and scientific research. The traditional method of field surveys is labor-intensive, costly and cannot cover broad regions very easily. Remote sensing has already been employed widely towards tree classification with varying degrees of success. These successes have been limited to minimal, or isolated study areas and not yet generally applicable (Martin et al., 1998). The difficulty lies not only in the extreme similarity of vegetation spectra between species but also in the natural variability of spectra within a species (Cochrane, 2000; Gong et al., 1997). Small differences can be attributable to chemical make-up--chlorophyll, lignin, cellulose, and silica--as well as to physical parameters within the leaves of tree species--internal structure and arrangement of air pockets, not to mention the varying illuminating and atmospheric conditions that remote sensing systems must handle (Cochrane, 2000; Gong et al., 1997; Yu et al., 1999). For these reasons, the study of species identification in vegetation remote sensing is still in its infancy.

Remotely sensed mapping of understory bushes is even more difficult than the classification and identification of the tree species. Therefore it is necessary to develop new technology to meet the needs. The key problems are: 1) the typical hyperspectral profiles of most thicket species cannot be found in the current spectral libraries such as the Jet Propulsion Laboratory Spectral Library (JPLSL), Johns Hopkins University Spectral Library (JHUSL), USGS Vegetation Spectral Library (USGSVSL) or IGCP264 Spectral Library, 2) the threshold angle has to be increased when using the Spectral Angle Mapper (SAM) of ENVI classification software because of the lack of spectral profiles of particular plant spectra in the spectral libraries. To solve these problems, the investigators at Clemson University have created The Strom Thurmond Institute Hyperspectral Library (STIHL). The STIHL contains 512 bands covering ultra violet, visual and near infrared channels from 350 nm to 1050nm. The spectral library consists of two groups of plant species spectrum: 1) wetland plant spectrum and, 2) mountain thicket species spectrum. The former has been used to classify and map the invasive species purple loosestrife *(Lythrum salicaria)* in the Hudson River valley of New York

(Guoxiang Liu et al. 2005). The latter is employed in this Joint Fire Science Program project for the first time.

Mapping Methodology

The study area for this project is the Nantahala National Forest , located in Macon County, North Carolina containing the headwaters of the Chattooga River. It is in the same geographic region which was used to develop the LEC (Landscape Ecosystem Classification) System for high-elevation (3600 ~4500 feet) mountains (Carter et al. 2000). This area is from latitude 35^{o} 2’ 4.72” N, longitude 83^{o} 29’ 59.87” to latitude 35^{o} 5’ 25.56”, longitude 83^{o} 33’ 42.49” covering about 40 mils^{2} (Figure 1).

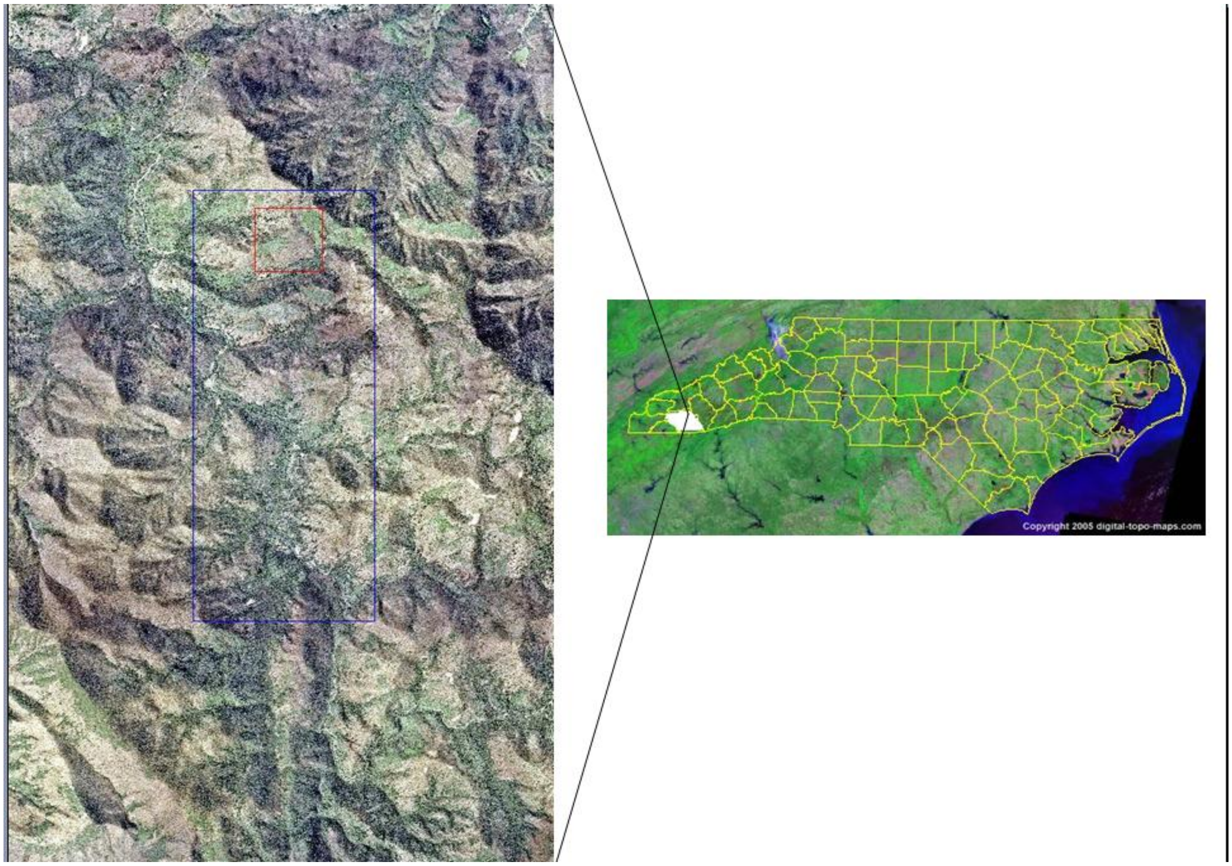


Figure 1. The study area located in Macon County, North Carolina.

The advantages to using hyperspectral imagery for mapping include; improved spatial resolution (2 m), improved spectral resolution (37 channels for a broader range of energy bands. The disadvantages include; the technology is untested for these specific uses and it may be too expensive for practical forest management purposes. Specifically the hyperspectral image analysis method includes: 1) developing a hyperspectral library compiler; 2) building our in-house, Strom Thurmond Institute Hyperspectral Library (STIHL) based on the field signal measurements of the plant species; 3) finding the highest match score between signals located as "spectrally pure" pixels in the imagery of Pixel Purity Index and the signals of the STIHL; 4) extracting spectral signals from the pixels with the highest match score from the DAIS 3715 Hyperspectral Imagery; and 5) utilizing the extracted spectral signals as the training signals for the supervised classification using the Spectral Angle Mapper. The creation of the STIHL is essential as most hyperspectral profiles of plant species are not found in the most common hyperspectral libraries such as the USGS Vegetation Spectral Library, the Jet Propulsion Laboratory Spectral Library, or the Johns Hopkins University Spectral Library. The STIHL uses a sensor which has 512 bands covering ultra violet, visible, and near infrared wavelengths from 350nm to 1050nm. The authors derived the "spectrally pure" rhododendron and mountain laurel pixels and obtained the typical spectral signals to be used as the supervised classification training signals.

Acquisition of Airborne Hyperspectral Imagery:

The **GER DAIS 3715** (**G**eophysical & **E**nvironmental **R**esearch Corporation **D**igital **A**irborne **I**maging **S**pectrometer) hyperspectral imager which utilizes 37 spectral bands, covering the visible to thermal infrared wavelengths of the energy spectrum, was mounted in a twin engine Cessna Cherokee and used to acquired imagery between 10:00 and 14:00 hours respectively. This time period was used in order to ensure that sun angles would be nearly vertical for all flight-lines. The flight altitude was 500 ft. agl, the flight speed was 83 knots, and the spatial resolution of the hyperspectral imagery was about 2X2 meters.

Acquisition of Plant Species Spectra:

During each fly-over and within several flight-lines, the ground crew conducted fieldwork collecting ground control points (GTP) utilizing global positioning system (GPS) receivers to mark the GTPs as well as the field sample plots. Ground crews also acquired the spectra of desired plant species with a 512 band GER 1500 handheld scanning spectrometer. These spectra were used to create STIHL hyperspectral library for identification, classification and mapping of the plant species via the hyperspectral imagery coincidentally acquired (Figure 2). Several different plant species of interest reflect solar spectra at different intensities and are greatly differentiated between 0.8*um* and 1.0*um*. This spectral differentiation provides the spectral signature for each species that can then be applied to the pixels of the imagery to extract maximum likelihood spectra of specific species and make the spectral identification of the specific species possible.

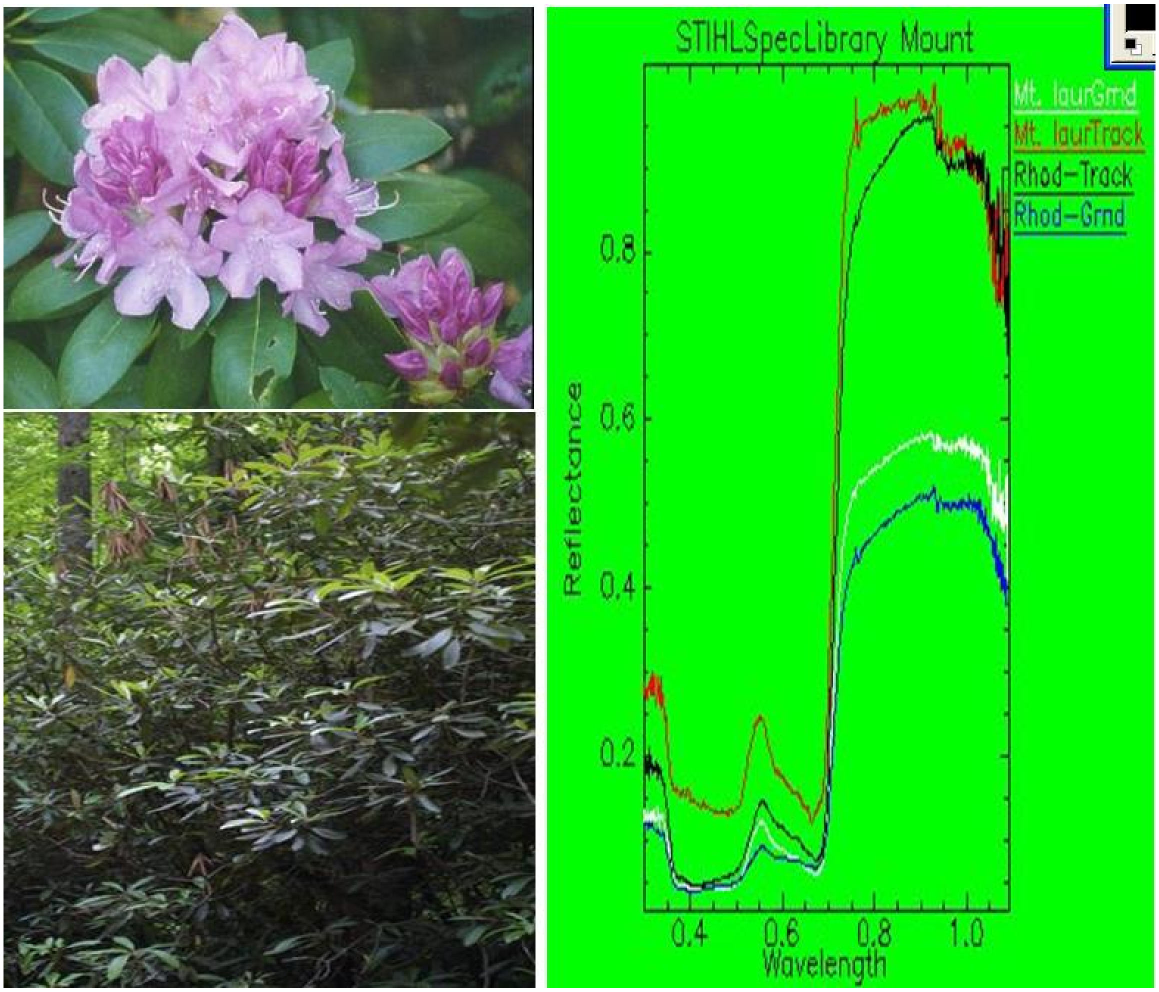


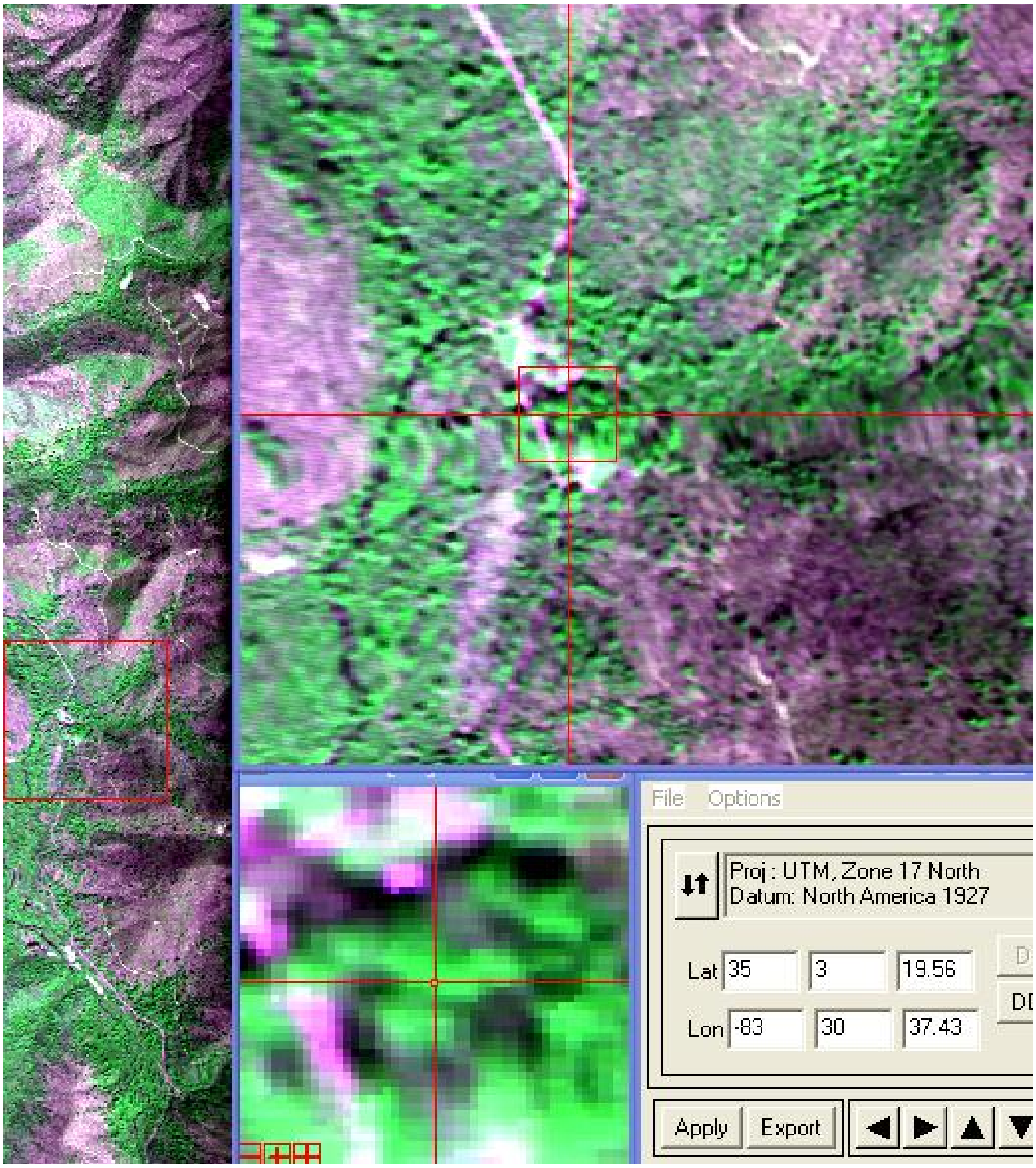
Figure 2. Rhododendron and Mountain Laurel Hyperspectral Profiles in the STIHL

Pre Processing of GER DAIS 3715 Imagery Raw Data:

A) Geometric Rectification: Imagery received from the flight crew and delivered to the Spatial Analysis Laboratory at the Strom Thurmond Institute was in its raw format with no processing performed. The geometrical rectification of the hyperspectral DAIS 3715 raw data included geo-correction, geo-referencing, assembling image mosaics and re-projecting images using ENVI software programs. Because the topography of the two study areas is mountainous, numerous algorithms and new software code were generated to work with the ENVI software in order to compensate for image distortion and pixel displacement at different elevations.

B) Atmospheric Calibration: It was necessary to perform an atmospheric correction before DAIS 3715 hyperspectral imagery could be analyzed for land cover classification or spectral signature derivation for any of the species of interest. Because of the lack of absorption bands of water vapor (940 and 1150nm) in D3715 hyperspectral imagery, special gain files, offset files and control files had to be created. This was necessary in order to use the atmospheric correction software ACORN for the final spectral corrections. Figure 3 shows a DAIS 3715 hyperspectral image that was geometrically rectified and atmospherically calibrated.

C) Minimum Noise Fraction (MNF): After performing the geometrical and atmospheric calibration, the **GER DAIS 3715** hyperspectral imagery was processed using the **MNF** procedure**.** When undertaking classification of hyperspectral imagery, it is desirable (because of the voluminous channels/bands of data available) to find a process of selecting the optimal subset of channels/bands to be used in subsequent analyses (such as land cover classification or spectral signature derivation). Principal components analysis is commonly used to determine which channels/bands are highly correlated with appropriate eigenvalues attached to the principal components. The MNF analysis is then used with the hyperspectral data to separate noise from eigenvalues and to reduce further computations. The MNF analysis provides an image that displays

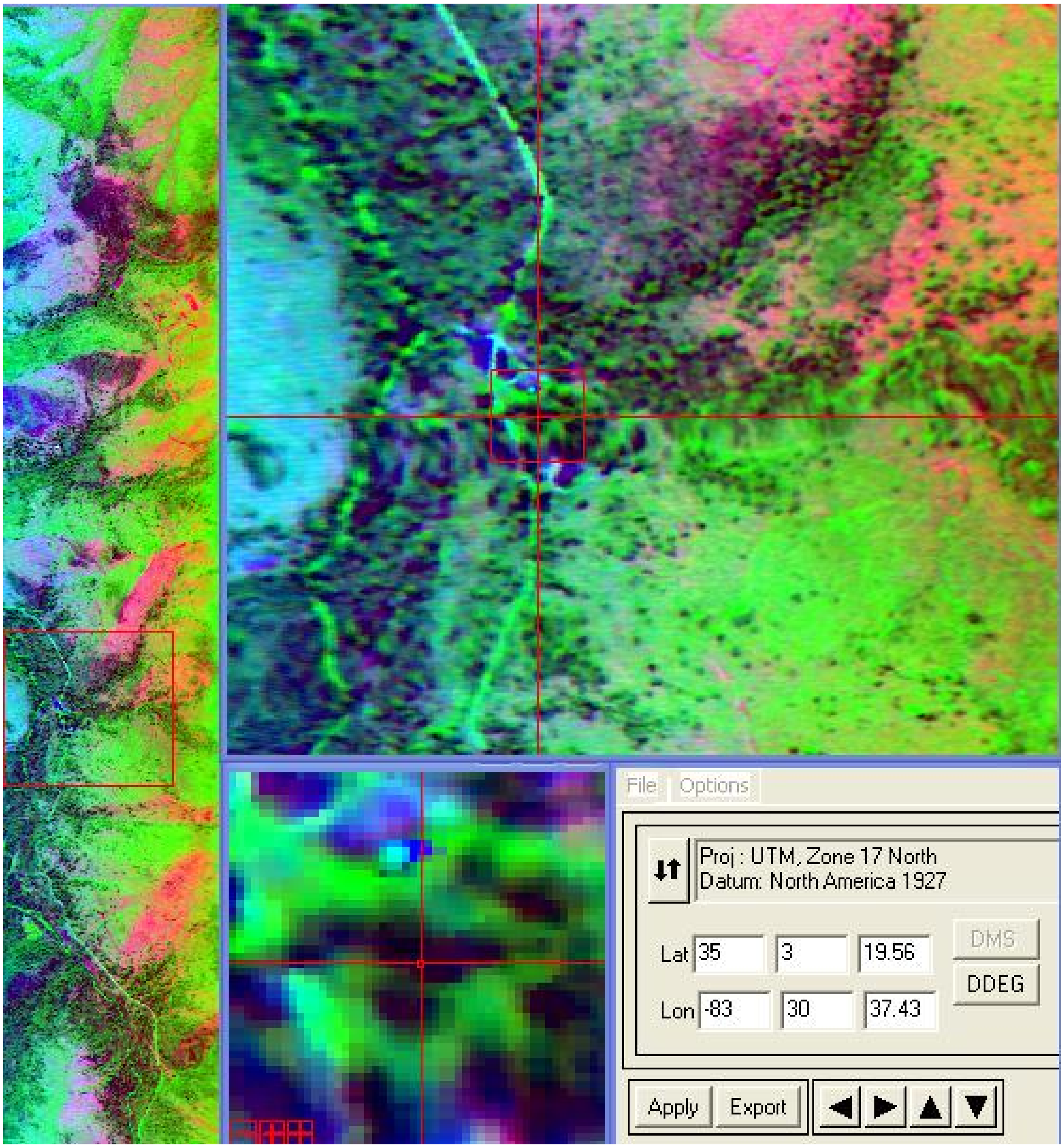


Proj : UTM, Zone 17 North
Datum: North America 1927

Lat 35 3 19.56
Lon -83 30 37.43

Figure 3. Geometrically rectified and atmospherically calibrated hyperspectral flight line 6.

minimum noise data with lighter colored areas (generally) containing the least amount of noise or variation within a pixel (Van Wagtendonk, 2000). The MNF provides a useful filtering step in determining where the pure pixels of the material of interest (in this case, rhododendron or mountain laurel) are most likely to exist. The MNF image derived from a subset of hyperspectral imagery is shown in Figure 4.



Proj : UTM, Zone 17 North
Datum: North America 1927

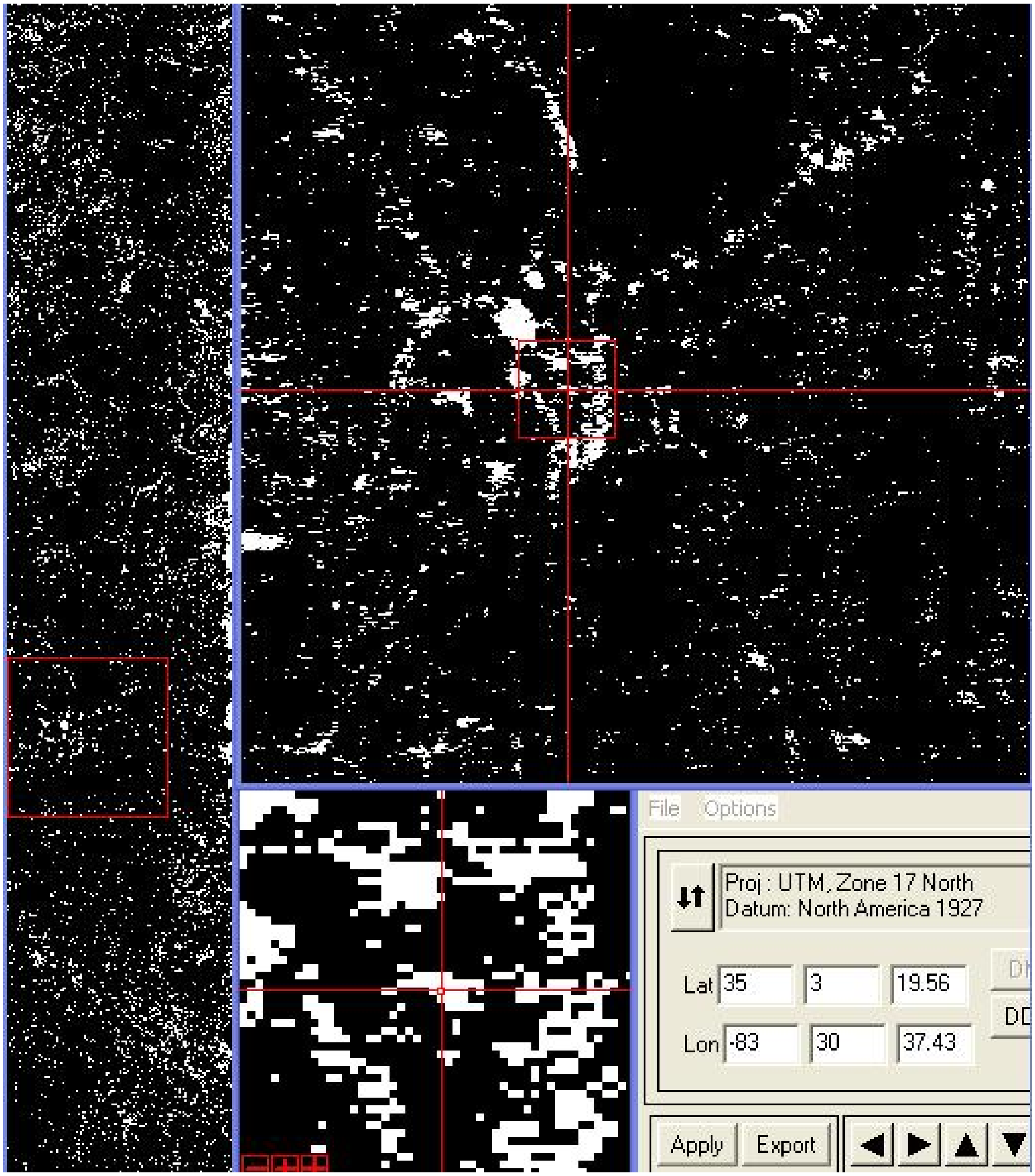
Lat 35 3 19.56
Lon -83 30 37.43

Figure 4. The Minimum Noise Fraction (MNF) image of hyperspectral flight line 6.

Analysis of Hyperspectral Data

A) Pixel Purity Index (PPI): An additional process found in the ENVI software suite, the **Pixel Purity Index,** was performed to find the most "spectrally pure" pixels in the minimum noise fraction (MNF) image. The object is to find pixels that are dominated by the material of interest (for example, rhododendron) as opposed to pixels that are mixed with many other species or land covers. The PPI process examines where pixels fall within an n-dimensional data cloud. The more pure a pixel, the more it is likely to fall within a distinct dimension within the data cloud. A user-specified threshold helps determine how much of the data will be considered a hit. Those pixels with the most hits are considered the most pure. The derived PPI image is used to locate the pixel group of the “highest match score” for creating the Region of Interest (ROI) in the next step. The PPI derived image was shown in Figure 5.

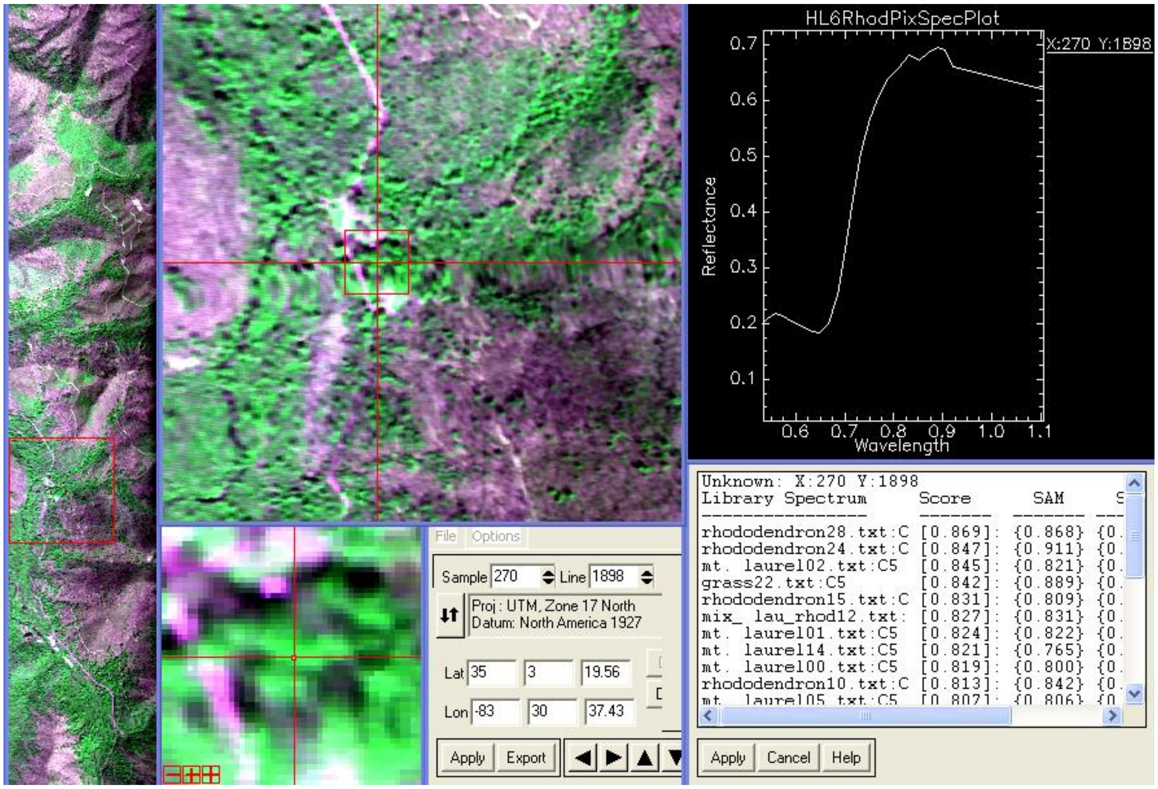
B) Using STIHL to Create the ROIs: The self-built hyperspectral library (STIHL) was used as the “Input Spectral Library” for operating the Spectral Analyst Routine. This process was implemented in order to locate the pixels of the target species (rhododendron) which would then help create the region of interest (ROI). The highest match scores (0 = no match, 1 = 100% match) indicated that the spectra of the pixels could be considered as that of the target species (Figure 6). Pixels in the hyperspectral imagery having the highest match scores of spectra closely matching the spectrum of rhododendron as defined in the STIHL were marked together as a Region of Interest (ROI) (Figure 7).



Proj : UTM, Zone 17 North
Datum: North America 1927

Lat 35 3 19.56
Lon -83 30 37.43

Figure 5. The Pixel Purity Index (PPI) image derived from MNF image.



Sample 270 Line 1898

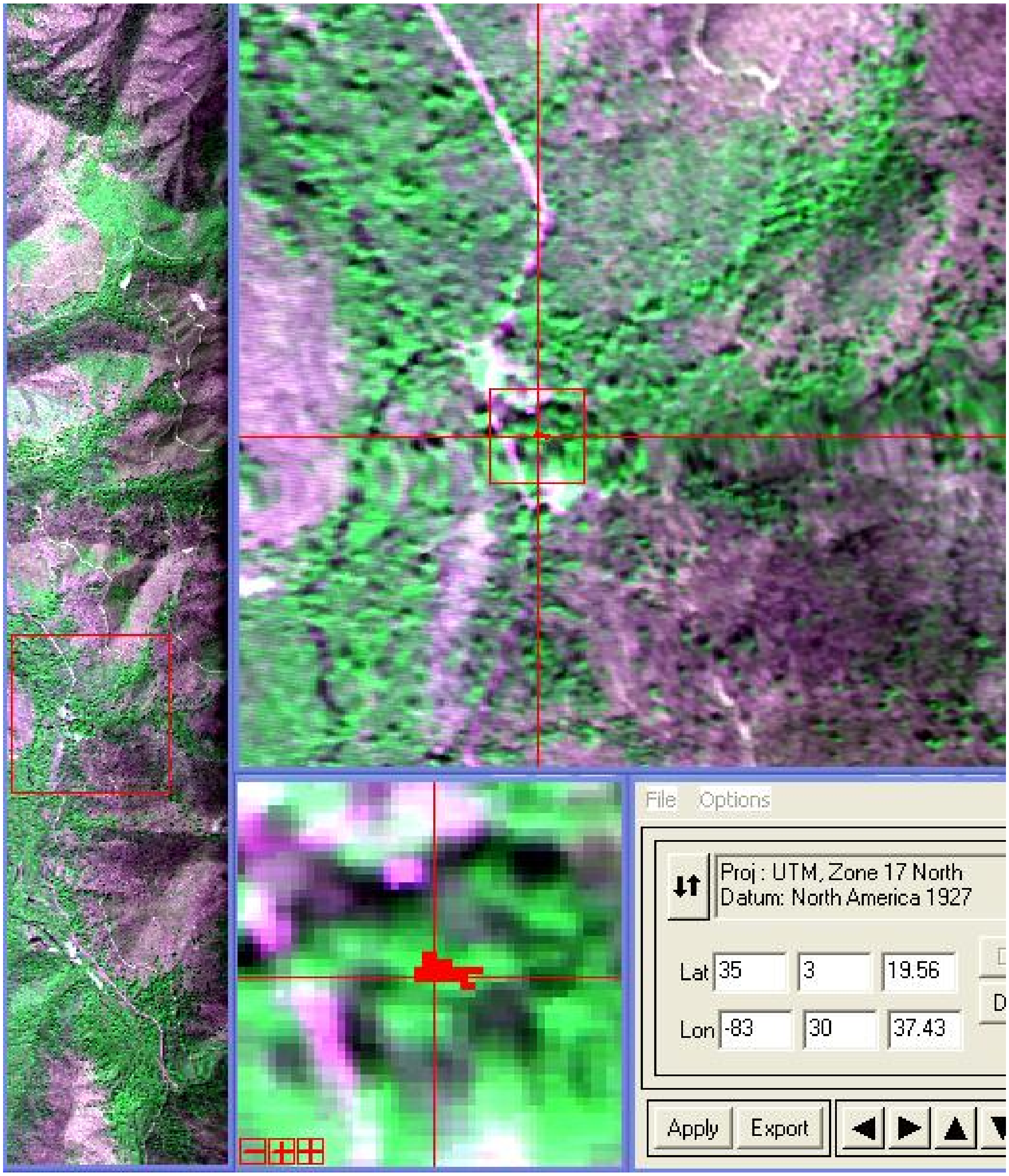
Proj : UTM, Zone 17 North
Datum: North America 1927

Lat 35 3 19.56

Lon -83 30 37.43

```
Unknown: X:270 Y:1898
Library Spectrum      Score      SAM     S
-----------------    --------  --------  ---
rhododendron28.txt:C [0.869]:  {0.868}  {0.
rhododendron24.txt:C [0.847]:  {0.911}  {0.
mt. laurel02.txt:C5  [0.845]:  {0.821}  {0.
grass22.txt:C5       [0.842]:  {0.889}  {0.
rhododendron15.txt:C [0.831]:  {0.809}  {0.
mix_ lau_rhod12.txt: [0.827]:  {0.831}  {0.
mt. laurel01.txt:C5  [0.824]:  {0.822}  {0.
mt. laurel14.txt:C5  [0.821]:  {0.765}  {0.
mt. laurel00.txt:C5  [0.819]:  {0.800}  {0.
rhododendron10.txt:C [0.813]:  {0.842}  {0.
mt. laurel05.txt:C5  [0.807]:  {0.806}  {0.
```

Figure 6. A pixel with high match score for rhododendron found using the PPI image



Proj : UTM, Zone 17 North
Datum: North America 1927

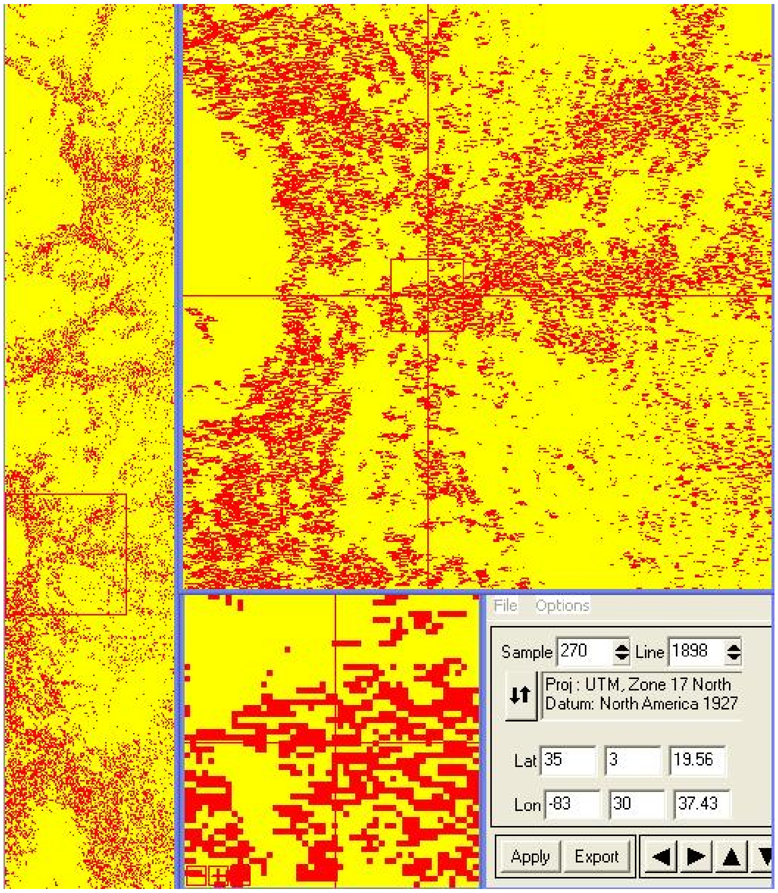
Lat 35 3 19.56
Lon -83 30 37.43

Figure 7. A region of interest (ROI) of rhododendron pixels.

C) Supervised Classification: The supervised classification of Spectral Angle Mapper (SAM) was performed using the multiple mean spectral signals extracted from the ROIs as the training signals for identification and mapping of the fuel load indicator species, rhododendron and mountain laurel. Remote sensing scientists have used the supervised classification Spectral Angle Mapper (SAM) for identifying and mapping plant species with success recently (Kruse, F. A. et al. 1993, Lass, L. W et al. 2002). The SAM classification is a method for directly comparing image spectra to known spectra (usually determined in a lab or in the field with a spectrometer) or an endmember. Endmember spectra used by SAM are derived from ASCII files, spectral libraries, or can be extracted directly from the image (as region of interest (ROI) average spectra). SAM compares the angle between the endmember spectrum vector and each pixel vector in n-dimensional space. Smaller angles represent closer matches to the reference spectrum. Pixels further away than the specified maximum angle threshold in radians are not classified. ENVI recommends the default threshold as 0.1 radians, this is the maximum acceptable angle between the endmember spectrum vector and the pixel vector (in n# bands dimensional space).

This method is typically used as a first cut in the classification process and works well in homogeneous regions. The USGS, JPL and JHU maintain their large spectral libraries, mostly composed of mineral, soil types and man-made materials such as concrete buildings, roof materials or asphalt reads. Most of the spectra which comprise these libraries are obtained from the laboratory where the illumination and other conditions can be controlled and the target samples can be prepared very carefully. These spectra can be closely matched with the spectra extracted from image pixels in a homogeneous areas. Therefore, the Spectral Angle Mapper (SAM) employing the USGS, JPL and JHU spectral libraries with a maximum threshold angle of 0.1° for the classification of minerals, soils and man-made materials in areas of homogeneous regions works very well. However, when using SAM with the USGS, JPL and JHU spectral libraries for plant species classification, the 0.1° threshold angle recommend by ENVI does not work well. In the worst case, some classifications provide no useful results. Users must increase the threshold angle for the SAM classification in order to use USGS, JPL and JHU spectral libraries as the standard reference spectra. Most researchers (Lass et al. 2004) utilize 1, 2, 3, 4, 5, and even 10 radians as the threshold angle. Park (2004) used a spectral angle of 0.3 radians, and DiPietro (1984) utilized SAM for a five target (Arundo, riparian woodland, scrub, annual grasses land and marsh land aquatic plants) classification at the 0.15 radian angle.

It was almost impossible for the project team to derive the identification and mapping of individual desired plant species using the traditional SAM and the USGS, JPL and JHU spectral libraries with the threshold angle of 0.1° -- the results revealed nothing. Increasing the threshold angle caused the plant class to be distributed everywhere. However, the threshold angle of 0.02° was used for the SAM classification with the STIHL and provided useful results with both rhododendron and mountain laurel. The classification map of rhododendron is shown in Figure 8.



Sample 270 Line 1898
Proj : UTM, Zone 17 North
Datum: North America 1927
Lat 35 3 19.56
Lon -83 30 37.43

Figure 8. Rhododendron classification map of flight line 6 using SAM with STIHL

Conclusions

This study employed a self-built hyperspectral library called the Strom Thurmond Institute Hyperspectral Library (STIHL) and an enhanced supervised classification (SAM) to detect, identify and classify the understory species rhododendron. The study provides some detailed information for the analysis of hyperspectral imagery for its use in image classification and spectral signature derivation. These processes include geometric rectification, atmospheric calibration, minimum noise fraction analysis, pixel purity analysis and creation of a region of interest through utilization of the STIHL. The supervised classification method, Spectral Angle Mapper (SAM), was utilized and target signals for rhododendron were derived directly from field measurements and were used as the training signals. Using these techniques, the accuracy of the identification and classification of a single species, rhododendron, is significantly increased. An accuracy of 90 % correct hits for the material of interest was obtained according to the ground verification.

The use of hyperspectral data and the new method of using the hyperspectral library (STIHL) with the Enhanced Spectral Angle Mapper (ESAM) to identify members of the understory plant community, to map distributions of species of interest and to track temporal changes in those distributions is appropriate and matches the needs in forest research and fire management. The ability to assess the implications of changes in species distributions is also within the capabilities of hyperspectral technology. By utilizing techniques outlined in this study as well as combining others such as NDVI and other spectral indexes, it may be possible to obtain rough assessments of fuel loads without the labor and time consuming ground surveys.

The innovative contributions of the Strom Thurmond Institute Hyperspectral Library are:

1. The creation of a unique hyperspectral library that includes many hyperspectral profiles of the mountain sub-canopy shrub species which cannot be found in the USGS, JPL and JHU spectral libraries.
2. All of the hyperspectral field profiles (spectra) of the plant species are created under natural conditions, which have the highest likelihood of comparing favorably with the spectra extracted from the remotely sensed imagery.
3. It can use threshold angles as small as 0.01 ~ 0.05 radians -- less than one tenth of the angle recommend by ENVI.

Acknowledgements

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Appendix 1. Crosswalk between proposed and delivered FFS outreach activities, as indicated in our Communication Plan, dated December 2001

Proposed	Delivered	Status
Discriminant functions to predict fuel loading by a Landscape Ecosystem Classification (LEC) System	A pilot study showed there was no advantage of the LEC system over easily usable measures of topography. Therefore, we concentrated our analysis on topographic position. Our results were a surprise showing little variability in fuel loads except where ericaceous shrubs existed in heavy clumps or where areas had been disturbed. Most were exceptionally localized and negated the value of a fuels map.	Preliminary results published by Brudnak and others (2006) and Waldrop and others (2006). Final results will be submitted to the CJFR, August 2006 (Phase One report).
Photo Series of fuels classes	An initial trial of a photo series was completed and published by Rideout-Hanzak and others (2006).	The final version should be submitted as a GTR by December 2006.
Biomass equations for shrubs	Equations completed for mountain laurel. Published equations for rhododendron proved adequate so new measurements were not necessary.	Mountain laurel equations will be published in the proceedings of the 14th Biennial Southern Silvicultural Research Conference, Feb. 2007.
Hyperspectral wave form signatures for each fuel type.	Available from the Strom Thurmond Institute Hyperspectral Library (STIHL). http://www.strom.clemson.edu.	Done
Hyperspectral fuels map.	A map of ericaceous shrub cover was produced for the Nantahala National Forest to be made available on the above web site.	Done
M.S. Thesis on fuels classification (done on one study area as a pilot for the larger study)	Stottlemyer, Aaron D. 2004. Fuel characterization of the Chauga Ridges region of the southern Appalachian Mountains. M.S. Thesis. Clemson University, Clemson, SC. 87pp.	Done
Preliminary photo series published in conference proceedings.	Rideout-Hanzak, Sandra; Brudnak, Lucy A.; Waldrop, Thomas A. 2006. Development of a photo guide for fuels in the southern Appalachian Mountains of northeast Georgia and western South Carolina. Pp. 518-520. In: Conner, Kristina F., ed. Proceedings 13th biennial southern silvicultural research conference. 2005 March 1-3; Memphis, TN: Gen. Tech. Rep. SRS-92; Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 640pp.	Done

Appendix 1. Continued.

Proposed	Delivered	Status
Pilot study of fuels classification published in conference proceedings.	Stottlemyer, Aaron D.; Shelburne, Victor B.; Waldrop, Thomas A.; Rideout-Hanzak, Sandra; Bridges, William C. 2006. Preliminary fuel characterization of the Chauga Ridges region of the southern Appalachian Mountains. Pp. 510-513. In: Conner, Kristina F., ed. Proceedings 13th biennial southern silvicultural research conference. 2005 March 1-3; Memphis, TN: Gen. Tech. Rep. SRS-92; Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 640pp.	Done
Investigation of statistical procedures for fuels classification published in conference proceedings.	Brudnak, Lucy A.; Waldrop, Thomas A.; Rideout-Hanzak, Sandra. 2006. A comparison of three methods for classifying fuel loading in the Southern Appalachian Mountains. Pp. 514-517. In: Conner, Kristina F., ed. Proceedings 13th biennial southern silvicultural research conference. 2005 March 1-3; Memphis, TN: Gen. Tech. Rep. SRS-92; Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 640pp.	Done
Preliminary fuels results published in a conference proceedings.	Waldrop, Thomas A.; Brudnak, Lucy; Phillips, Ross J.; Brose, Patrick H. 2006. Research efforts on fuels, fuel models, and fire behavior in eastern hardwood forests. In: Dickinson, M.; Brose, P.H., eds. Proceedings of fire in eastern oak forests. 2005 November 15-17; Columbus, OH. Gen. Tech. Rep. NE-?. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. [In press].	In press.
Final fuels results submitted to *Forest Ecology and Management*	Waldrop, Thomas A.; Brudnak, Lucy; Rideout-Hanzak, Sandra. Fuel Loads on Disturbed and Undisturbed Sites in the Southern Appalachian Mountains.	Paper drafted and under internal review to be submitted to the *Canadian Journal of Forest Research*
Hyperspectral results published as white papers on the Strom Thurmond Institute website	Enclosed draft report will be adapted for web distribution.	To be competed by September 2006.
Hyperspectral maps published as Forest Service GTR series.	Changes in the study due to fuels results made these maps inappropriate. A map of ericaceous shrub cover will be published.	December 2006

Appendix 1. Continued.

Proposed	Delivered	Status
Hyperspectral approach paper for a scientific journal such as *Photgrammetric Engineering & Remote Sensing*	Draft complete and under review.	Will be submitted by November 2006.
Hyperspectral approach paper for a trade journal such as *GIS World*	Manuscript in draft stage.	Will be submitted by October 2006.
Oral presentation	Waldrop, Thomas A.; Brudnak, Lucy; Phillips, Ross J.; Brose, Patrick H. Fuels, fuel models, and fire behavior in eastern hardwood forests. Fire in eastern oak forests. 2005 November 15-17; Columbus, OH	Done
Oral presentation	Waldrop, Thomas A. Fuels, fuel models, and fire behavior in eastern hardwood forests. Ecological impacts of fuel reduction workshop. 2005 January 24-25; Asheville, NC.	Done
Tour	Waldrop, Thomas A. Fuel loads in the southern Appalachian Mountains. Ecological impacts of fuel reduction workshop. 2005 January 24-25; Asheville, NC.	Done
Tour	Waldrop, Thomas A. Fuel loads in the southern Appalachian Mountains. 14th Biennial Southern Silvicultural Research Conference. 2007 February 24-25; Athens, GA.	Upcoming, February 2007.
Oral presentation	Stottlemyer, Aaron. Fuel characterization of the Chauga Ridges region of the southern Appalachian Mountains. Clemson University Graduate Seminar Series, January 2004.	Done
Oral presentation	Andrews, David Berry IV. Classification and accuracy assessment of understory fuel loading species in the southern Appalachians. Clemson University Graduate Seminar Series, September 2005.	Done
Oral presentation	Allen, Jeffrey. Hyperspectral Imaging of Forest Fuels. Presentation: to the 12th International Interdisciplinary Conference on the Environment, June 22nd - 24th 2006, Kailua-Kona, HI	Done
Web pages	Results posted on research unit web pages as temporary special features. http://www.srs.fs.usda.gov/disturbance/ http://www.strom.clemson.edu/	Done

Appendix 1. Continued.

Proposed	Delivered	Status
Poster	Stottlemyer, Aaron. Fuel characterization of the Chauga Ridges region of the southern Appalachian Mountains. Clemson University Natural Resources Graduate Research Conference March 2003.	Done
Poster	Andrews, David Berry IV. Classification and accuracy assessment of understory fuel loading species in the southern Appalachians. Clemson University Natural Resources Graduate Research Conference March 2005.	Done
Un-proposed M.S. Thesis on fuel classification accuracy	Andrews, David Berry IV. 2005. Classification and accuracy assessment of understory fuel loading species in the southern Appalachians. M.S. Thesis. Clemson University, Clemson, SC. 76pp.	Done
Tour	Waldrop, Thomas A. Fuel loads in the southern Appalachian Mountains. RX-310 Fire and fuels course, Nature Conservancy. 2004 November; Asheville, NC.	Done
Tour	Waldrop, Thomas A. Fuel loads in the southern Appalachian Mountains. Southern Applachian Man and the Biosphere Conference, November 2005. Asheville, NC	Done
Abstract	Liu, Guoxiang, Allen, Jeffery, Campbell, Craig E. Brudnak, Lucy. 2006. Forest Fires and the Environment -- Using a Hyperspectral Library as a Tool for Determining the Need for Prescribed Burning. Asia-Pacific Remote Sensing 2006 Conference	Done
Abstract	Liu, Guoxiang, Allen, Jeffery, Campbell, Craig E. Brudnak, Lucy. 2006. Detecting and Mapping Under-Story Shrubs Rhododendron Using the Self-Built Hyperspectral Library. 12th International Interdisciplinary Conference on the Environment, June 22nd - 24th 2006, Kailua-Kona, HI	Done