DETERMINATION OF FOREST COMMUNITIES IN A TEMPERATE MOUNTAINOUS FOREST USING REMOTELY SENSED AND ANCILLARY DATA OF VARYING SPATIAL RESOLUTION

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ABSTRACT: Techniques for identifying forest communities were explored for an area near Spruce Knob, West Virginia, containing representative Appalachian forest communities and one of the more southerly outliers of the red spruce community. The utility of spatial and spectral resolution in the determination of forest communities was examined by comparing classifications of digitized aircraft photography at 3 meter spatial resolution and of TM imagery, using the six non-thermal bands and those equivalent to color infrared photography, at 30 meter resolution. The aircraft-based classification provided much greater detail, demonstrating a greater refinement in response to the small characteristic distance of change in these temperate mountainous forests. The larger TM pixel averaged much of this detail to produce a classification of more uniform classes and graduated change, which may be less representative of the surface vegetation but nevertheless useful for studies of larger areas. The addition of the blue and mid infrared TM bands does improve the classification when compared with the color infrared-equivalent bands of TM. The inclusion of elevation and aspect adds additional information and capability which may result in a more accurate delineation of forest associations and composition. More work will be required to fully develop and utilize its potential for describing and understanding forest communities.

INTRODUCTION

Importance of the temperate mountainous forest

The tropical rain forest and high latitude boreal forest are receiving extensive study as part of the Global Change Research Program due to their importance to global carbon cycle balances and global climate modeling. The temperate forest is also very important because of its effect on local and regional climate as well as its contribution to global ecological processes.

The temperate mountainous forest presents a number of difficulties from a remote sensing perspective because such forests have a smaller characteristic spatial scale, both in terms of plant communities and in terms of overall extent; have frequently been harvested or otherwise disturbed by human activity; and generally occur in mountainous terrains, adding the factors of slope, aspect and elevation and their impact on reflectance and climate. The proposed development of high spatial and spectral resolution sensors together with the growing availability of Digital Elevation Model (DEM) data will make it possible to better analyze and characterize these forest communities so that their contribution to global and local processes can be studied.

The work reported here is part of a larger project funded under a NASA EPSCOR Grant to study patterns and periodicities in mountainous terrain.

Description of Study Site at Spruce Knob, West Virginia

The Spruce Knob USGS 7.5 minute quadrangle in West Virginia was chosen as the initial study site because it lies at the intersection of the Northern Hardwood and Southern Appalachian Forest Associations along the northeast-southwest trending Appalachian Mountain Chain. Its forest communities are representative of those throughout much of the Appalachians, so techniques developed here should be widely applicable throughout the Eastern mountainous regions. Spruce Knob also provides one of the more southerly outliers of red spruce, a survivor of the last glacial period. Ongoing research (e.g., Adams and Stephenson, 1989; Johnson et al., 1992; and DeHayes, 1992) suggests that red spruce in West Virginia are already under stress from climatic variations and other factors and may provide an early indicator of climate change.

The mountain ridges trend northeast-southwest separated by deep valleys and dissected by narrow, deep ravines and trellis drainage patterns. This site includes portions of the Spruce Knob - Seneca Rocks National Recreation Area and the surrounding Monongehela National Forest. The forest communities change with elevation and with aspect. Cove (1929) describes the progression from beech-maple in the foothills through oak-hickory to spruce-birch above 4000 feet (1219 meters). Recent work by Brannon et al. (1994), patterned after research by Whittaker (1975) in the Great Smoky Mountains, has related the prevalence of various species to elevation and through available moisture to aspect. On moister slopes cove hardwoods and hemlocks give way to northern hardwoods (beech and maple) between 2500 and 3000 feet (762 and 914 meters), followed by red spruce-yellow birch above 3500 feet (1067 meters) and pure stands of red spruce above 4500 feet (1372 meters). Oaks predominate at the lower elevations on sheltered and drier slopes, with red spruce-yellow birch and pure red spruce at the higher elevations. If conditions are extremely dry or exposed, pines may be found on the slopes and heath barrens or grass balds on the summits. Plantations of red pine have been planted in some locations, also.

Within this study site an area surrounding The Mountain Institute, part of an international educational and research organization dedicated to preserving mountain environments and cultures, has been chosen for more intensive study (Figure 1). Except for limited harvest and grazing, this area has been largely undisturbed for decades. A large pasture in the center is flanked by red spruce on the east, which appear darker, and northern hardwoods on the north, west and east. The Mountain Institute is located just north of the largest red spruce stand east of the pasture. Red pine plantations (also darker than the surroundings) can be found in the northwest corner. A riparian community consisting of open brushland with sapling trees follows Big Run on the west. What appears to be a similar landcover can be seen in forest clearings on the aerial photograph. The elevation ranges from 1051 meters

(3448 feet) to 1287 meters (4223 feet) and various aspects are provided by the slopes on either side of Big Run, along the sides of the ridges on the west and by hollows north and south of The Mountain Institute on the east side.

DATA

To explore the effect of spatial and spectral characteristics on the ability to differentiate forest communities, a number of data types will be examined in the overall project. For these preliminary results we have concentrated on two of the most widely used data products. A Landsat Thematic Mapper (TM) scene acquired on July 17, 1993, with six visible, near infrared and mid infrared bands at 30 meter spatial resolution covered the study site and was of excellent quality. In the same month color infrared aerial photography was flown over the area at a scale of 1:12,000 by the US Forest Service. A frame covering the intensive study site was digitized using color filters on a Nikon AX1200 Flatbed Scanner at the Marshall University Remote Sensing Applications Center to provide a three-band (green, red and near infrared) digital image with 3 meter spatial resolution.

Digital elevation model data for the Spruce Knob 7.5 minute topographic quadrangle was obtained from the US Geological Survey (USGS).

Ground truth data consisting of tree species, trunk diameter and precise location were gathered for eight sites of 60 meter diameter located using Global Positioning System (GPS) in July and September of 1995. In addition a windshield survey was performed for all driveable roads within the study area, stopping at 0.1 mile intervals to identify the canopy tree species and understory at over 200 locations in September. Two of the detailed field measurement sites and 16 of the windshield sites lie within the intensive study site. Ten observations of more distant tree stands have been added to expand the coverage within this subset to more community types.

ANALYSIS TECHNIQUES

Analysis was performed using the PCI EASI/PACE Image Analysis Software in the Laboratory for Terrestrial Physics (LTP) Computer Facility at the NASA Goddard Space Flight Center. TM data for the Spruce Knob quadrangle were geographically referenced to the aircraft image using 12 ground control points with a residual error of less than 0.5 pixels. The DEM elevation data were registered to the same base using the same transform equation. Data layers for aspect and slope were derived from the elevation data and also registered to the aircraft base.

Unsupervised classifications were then performed on the digitized color infrared aircraft image, the TM image (six bands) for the corresponding area and a three-band version of the TM image, containing those bands which most closely resemble color infrared photography (Bands 2, 3 and 4). Layers for the elevation and aspect data were added separately to the aircraft and TM (six bands) images and unsupervised classifications were again performed. The parameters (allowed numbers of clusters, merging and splitting criteria and number of iterations) remained the same for all classifications, resulting in from 56 to 71 clusters. These clusters were then assigned to 5 or more forest types, pasture or road, based on spectral signature, geographic location, proximity to other similar classes and appearance on the aerial photograph.

The PCI software allowed another interesting approach to exploring multilayered data sets termed "Modeling". A new image could be created by assigning a value to the combination (logical and) of a range of values in two or more bands (e.g., red spruce clusters 1-5 and elevation 1000-1050 meters = 25 in the new image). The classified aircraft and TM images were mapped to a series of 12 and 14 classes, respectively, so that forest types which were a little different spectrally could be treated separately. The elevation and aspect data were divided into ten intervals over their range in the image (increments of about 20 meters and 36 degrees, respectively). Images were then created combining classes from the aircraft image classification with elevation and with aspect, respectively.

The locations of the ground measurements were digitized from the locations recorded on the Spruce Knob quadrangle using Global Positioning System (GPS) data for the detailed measurement sites and the windshield observations. The positions were transferred to the aircraft image base and samples of 100 pixels and 1 pixel, respectively, were extracted from the aerial photograph and TM based classifications, and compared with the ground truth. The results are discussed below.

RESULTS

Classification based on spectral, spatial and terrain information

Classification images based on aircraft and TM (six bands) are presented in Figures 2 and 3. The forest types include riparian/brushland in light medium grey, two types of hardwood in white and medium grey, red pine plantations in dark grey, and red spruce or red spruce and yellow birch in very dark grey. The pasture adjoining The Mountain Institute is shown in light grey and portions of the roads are in black.

A number of variations were observed within the hardwood and riparian/brushland classes which will be investigated in future field work. In particular, there were two distinctly different groupings of hardwood signatures. Hardwood 1 (in white) appears to be the dominant type east of the creek and on the lower slopes west of the creek. Hardwood 2 (in medium grey) borders the west of the pasture and occurs as small stands within the pasture and just north of it and as two large stands on the ridges west of the creek. These latter areas were harvested but have to some degree grown back. Since hardwood 1 occurs at lower elevations, it is possible that it represents primarily maples while hardwood 2 contains greater proportions of beech along with maples. It is also possible that hardwood 1 represents more mature or denser stands than hardwood 2.

The aircraft based classification is, of course, far more detailed and textured due to its finer spatial resolution. The two hardwood types are interspersed among each other to a far greater extent than in the TM classification. The bushes and saplings associated with the creekbed (riparian/brushland) are mingled with hardwood. Lines of red spruce can be seen in the red pine plantations.

In the TM classification these effects are averaged, allowing apparent trends to be seen more clearly. Two levels of riparian forest may indicate a gradual transition from creekbed to the dominant hardwood association. On the north and west facing slopes east of the creek, the contribution of hardwood 2 is generally overwhelmed by that of hardwood 1; while on the other side of the creek the east-facing stand of hardwood 2 appears more uniform than in the aircraft version. The presence of red spruce in the red pine plantings is still evident, but as isolated blocks where the spruce signature apparently exceeds that of the pine. While detail has clearly been lost, the classifications are quite similar. Evaluating the nature and impact of this loss of detail will have to await our next field visit once the snow melts.

The TM classification using the color infrared bands was very similar to the one based on all six non-thermal bands. There were a few anomalies, such as road pixels and excess hardwood 2 in the field and some missing hardwood 2 on the west side of the creek. It would seem that the additional blue and mid infrared bands make a contribution in identifying forest types.

The addition of the elevation to the color infrared aircraft bands had a dramatic effect on the classification. The slopes on the west (and to a lesser extent east) sides of the creek are delineated quite clearly. This is shown in an intermediate shade of grey on the west side of the creek; the east side was merged with riparian/brushland. Highland areas which appeared as riparian in the previous classification (and might be wet meadows) were generally classified as hardwood. The degree of mixture of hardwoods 1 and 2 decreased, with hardwood 1 generally predominant. The same was true for red pine and red spruce, but areas of red pine appear to have been lost. In general, the amount of vegetative detail appears to be less. Although this might reflect a more orderly classification, it may also represent missing information. As additional bands are added to the classification, their effect can overshadow the variability associated with the previous bands. This may in fact clarify and improve the identification of forest types or it may hide interesting and potentially meaningful variations.

The effects described above were even more pronounced when the aspect was combined with the aircraft bands to produce a classification. The creekbed riparian community was essentially lost, but the east facing slopes west of the creek are clothed in almost uniform hardwood 2. Hardwood 1 generally predominates over hardwood 2 elsewhere but the more subtle ridge structure on the east side of the creek is revealed (shown in a slightly darker grey). An area of hardwood 2 south of the pasture, which appeared mixed on the basic classification and almost disappeared on the elevation classification, is now a major feature. Two of the red pine plantations are clearly visible but one shows more as red spruce than red pine.

Preliminary Accuracy Assessment

A preliminary accuracy assessment was performed using the 28 observation sites mentioned above (Table 1). The selection of sites needs more refinement but several observations can be made. The line of demarcation between hardwood 1 and riparian/brushland needs to receive more study. Shadows cast on the road as it approaches the bridge over the creek near the top of the image produce a darker area which is misinterpreted as spruce or pine. Otherwise, the classifications based on the digitized aerial photograph alone and combined with elevation provide a better correspondence to the ground truth. A more complete accuracy assessment with a larger number of field observations will be developed to provide a more definitive evaluation.

Table 1

Cover Type	Classification based on				
(Number of Sites)	Air	TM (6)	TM (3)	Air & Elev	Air & Asp
Red Spruce (3)	3	2	2	3	2
Red Pine (2)	2	2	2	0	2
Hardwood1 (10)	8	5	5	7	9
Hardwood2 (2)	2	2	2	2	2
Riparian (8)	6	3	3	8	1
Pasture (3)	3	3	3	3	3
Total Correctly Identified	24	17	17	23	19

"Modeling"

"Modeling" preserves the full spectral detail in the classification while adding an additional dimension, either of elevation or aspect (or both). While one can examine the coincidence of certain classes with an elevation or aspect range, the assignment of combinations is based primarily on a priori knowledge. For instance, red spruce are generally found above 4000 feet (1219 meters). This could be quite useful in separating red spruce and red pine, which are spectrally quite similar, at least on the July data. It could also reveal associations which might be worth investigating. Using this approach it was possible to separate red pine from red spruce, hardwood 2 on the slopes west of the creek from that by the pasture and to clearly display the lower elevations associated with the creekbed. Using aspect and the basic classification in a model also separated hardwood 2 east and west of the creek but did not appear to have much beneficial effect on separating red spruce and red pine or on delineating the creekbed. This approach will require more knowledge to fully appreciate its capabilities but it looks like a very powerful tool for extending acquired information to a larger area.

CONCLUSIONS

The effect of spatial and spectral resolution on the determination of forest communities was examined by comparing classifications of digitized aircraft photography at 3 meter spatial resolution and TM imagery, using the six non-thermal bands and those equivalent to color infrared photography, at 30 meter resolution. The aircraft-based classification provided much greater detail, demonstrating a small characteristic distance of change in these temperate mountainous forests. The larger TM pixel averaged much of this detail to produce a classification of more uniform classes and graduated change, which may be less representative of the surface vegetation but nevertheless useful for studies of larger areas. The addition of the blue and mid infrared TM bands does improve the classification when compared with the color infrared-equivalent bands of TM. The inclusion of elevation and aspect adds additional information and capability and may be useful in creating a more accurate forest delineation. Future work will examine other areas within the study site and other data sources as well as exploring some of the interesting implications noted above.

In the next decade a number of spaceborne sensors are planned which will dramatically increase the spatial and spectral information available to scientists and planners. Aircraft and satellite remotely sensed data being gathered today can be analyzed to determine the utility of these data for applications in the temperate forest. The results of this series of studies, when completed, can be used for selecting sensors and data types for continuing forest studies. These results can also be combined with indications from historic MSS and TM data which span decades to demonstrate changes in forest composition and health and to integrate the contributions of temperate forests into the global research on climate and carbon and water cycles.

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Figure 1. Color infrared aerial photograph of the intensive study site centered on The Mountain Institute taken in July 1993.

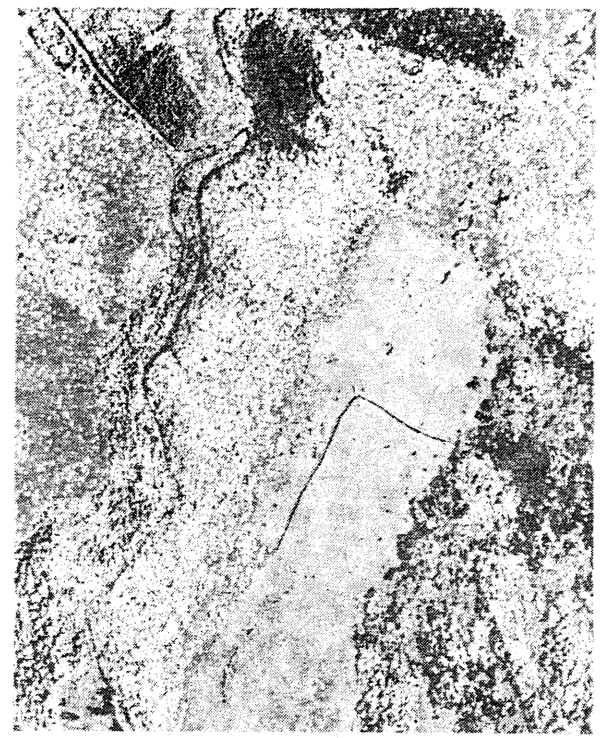

Figure 2. Classification based on digitized color infrared aerial photograph.

Figurre 3. Classification based on July 17, 1993, TM data (six bands).

Figure 4. Classification based on July 17, 1993, TM data (three bands comparable to color infrared photography).

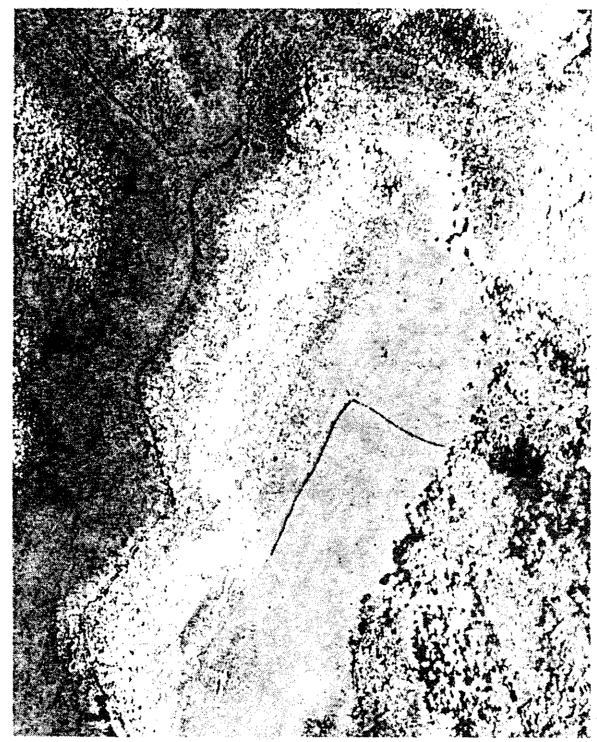

Figure 5. Classification based on digitized color infrared aerial photgraph and elevation data.

Figure 6. Classification based on digitized color infrared aerial photograph and aspect data.