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INTEGRATION OF DIGITAL ELEVATION MODEL DATA AND LANDSAT MSS DATA TO QUANTIFY THE EFFECTS OF SLOPE ORIENTATION ON THE CLASSIFICATION OF FOREST CANOPY CONDITION

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I. ABSTRACT

Over the past several years, research has been conducted at the Goddard Space Flight Center to develop techniques to facilitate the use of remotely sensed data for monitoring forest disturbances. A majority of this work has involved the digital analysis of Landsat multispectral scanner (MSS) data to detect insect defoliation of hardwood forests. The diverse terrain and topographic conditions typically associated with forest lands are known to cause variations in remotely sensed spectral data, leading to problems in accurately classifying forest cover conditions in mountainous terrain. This study assesses the utility of incorporating high spatial resolution digital terrain data with Landsat MSS data to reduce confusion between spectrally similar forest canopy conditions such as healthy vegetation and moderate defoliation.

The aspect category of each pixel in the central Pennsylvania study area was computed from the terrain data, and integrated with the Landsat MSS data and digitized ground reference data. Mean spectral response values were then extracted from the Landsat MSS data for each defoliation class within each aspect category. Results indicate that heavy defoliation is separable from either moderate defoliation or healthy forest, but these latter two forest canopy conditions cannot be consistently separated from one another even when accounting for any confounding effects on sensor response due to slope orientation (i.e., aspect).

II. INTRODUCTION

Discipline scientists within the Earth Resources Branch at the Goddard Space Flight Center (GSFC) have been conducting research over the past several years to develop and test processing and analysis techniques to facilitate the use of remotely sensed data for monitoring forest disturbances. Much of the research conducted thus far has involved the digital analysis of Landsat multispectral scanner (MSS) data to detect and assess defoliation of hardwood forests caused by gypsy moth caterpillars. This study addresses one area of related research; the integration of digital terrain data with Landsat MSS data to improve the accuracy of defoliation discrimination. As part of this study, an in-depth investigation of the spectral characteristics of various defoliation/aspect classes was conducted to determine the relationships among severity of defoliation, slope orientation (aspect), and spectral response. This paper will report on the results of this characterization study and the initial application of terrain data and Landsat MSS data for defoliation assessment.

III. BACKGROUND

Numerous researchers have addressed the use of Landsat data for monitoring gypsy moth defoliation.[1-8] These papers document: a) the gypsy moth life cycle and feeding habits, b) the remote sensing obstacles associated with monitoring a forest infested by the gypsy moth, and c) the many different image analysis and data manipulation techniques that have been evaluated relative to monitoring gypsy moth defoliation with Landsat MSS data. These studies generally agree that heavy defoliation can be discriminated from other levels of defoliation and healthy forest, but that heavy defoliation is often confused with non-forest land cover types, particularly agricultural classes. Techniques developed at GSFC have increased the accuracy of delineating areas of heavy defoliation by eliminating errors of commission with non-forest land cover types.[2-4]

The other major area of agreement among these studies is the difficulty in accurately distinguishing moderate defoliation from healthy forest. The inability to consistently and accurately separate areas of moderate defoliation from areas of healthy forest limits the applicability of Landsat data for defoliation assessment. Two possible causes of this confusion have been proposed.[3,4]

The first hypothesis concerns the relatively broad spectral bands and spatial resolution of the Landsat MSS. These sensor parameters may prohibit discrimination between moderate defoliation and healthy forest as they are currently defined by the user agencies (i.e., healthy = 0 - 30% leaf canopy removed; moderate = 30 - 60% leaf canopy removed). For example, crown density and canopy closure in a healthy forest stand may vary sufficiently to resemble moderate levels of defoliation.

The second possible cause of confusion between classes may be due to the effect of terrain variability upon sensor response. This phenomenon has been commonly referred to as the "topographic effect" on sensor response.[9-12] Holben and Justice[10] defined the topographic effect as the " . . . variation in radiances from inclined surfaces compared to radiances from a horizontal surface as a function of the orientation of the surfaces relative to the light source and sensor position."

Several studies have indicated problems in the interpretation of multispectral data in mountainous terrain due to topographic effects on sensor response.[13-15] Results from these studies agree with results previously obtained at GSFC during defoliation assessment research; namely, that the aspect of the training site strongly influences spectral response.[3,4] For example, areas of moderate defoliation on southeast aspects are spectrally similar to healthy forest on northwest aspects.

The purpose of this study was to investigate these possible sources of confusion and to test the utility of incorporating digital terrain data with Landsat MSS data to improve the classification of canopy condition. The initial approach was to characterize the multispectral data associated with the various canopy conditions and aspect categories. Subsequently, a comparison was made between two classification techniques; one in which the MSS data were stratified by aspect and the other in which they were not.

IV. THE STUDY AREA

The study area is located in central Pennsylvania, just west of Harrisburg, and encompasses the Wertzville 7.5 minute quadrangle (Figure 1). This area is located within the ridge and valley physiographic province. It contains three major ridges which are covered with mixed deciduous forests consisting of oak (*Quercus* sp.), hickory (*Carya* sp.) and maple (*Acer* sp.). Two of the ridges have an east-west strike and the other has a northeast-southwest strike. The elevation within the study area ranges between 46 meters and 420 meters, and the slopes on either side of the ridges are generally uniform. The area was chosen because it presented a variety of forest canopy conditions. In addition, a full complement of data were available, including: a) cloud-free Landsat MSS data acquired during both healthy and peak defoliation conditions; b) high spatial resolution digital terrain data; and c) digitized, defoliation ground reference data derived from aerial photography acquired within a few days of Landsat overpass.

V. DATA SOURCES

A. LANDSAT MSS DATA

Multispectral Landsat MSS data were used in this study. MSS data representative of healthy forest stand conditions were acquired on July 19, 1976. Data collected on June 27, 1977 represented peak defoliation conditions. These data were registered to the Universal Transverse Mercator (UTM) cartographic projection and resampled to 50 meter square cells as part of an earlier study.[2] For this study, the image portion corresponding to the Wertzville 7.5 minute quadrangle was extracted from the previously registered data set (Figure 2).

B. DIGITAL TERRAIN DATA

The digital terrain data used in this study were the Digital Elevation Model (DEM) data obtained from the USGS Digital Applications Team, Reston, Virginia (Figure 3). DEM data have a 30-meter horizontal resolution and should be distinguished from the 200-foot resolution Defense Mapping Agency (DMA) data. DEM data are derived from orthophotos and are available for selected 7.5 minute quadrangles in the USA.[16] They consist of an array of elevation values with a vertical resolution of 1-meter. Since the elevation data were supplied in the UTM projection, a separate registraion of these data with the Landsat MSS data was unnecessary. However, the data were resampled to a 50 meter grid, using cubic convolution interpolation, for integration with MSS data. After resampling, the DEM data were examined visually and areas of discontinuity were reassigned, with a zero value, as non-study area (Figure 4).*

C. FOREST CANOPY CONDITION REFERENCE DATA

The forest canopy condition reference data were generated from two separate sources: aerial photography and Landsat MSS data. The Division of Forest Pest Management, Pennsylvania Department of Environmental Resources, provided 1:48,000 scale color infrared aerial photographs collected on June 23, 1977. The photographs were interpreted with a stereo viewer to delineate areas of moderate and heavy defoliation. The boundaries of the delineated areas were transferred onto the topographic map using a Zoom Transfer Scope. The mapped boundaries were then digitized and a registered defoliation image with 50 meter square pixels was produced.

The 1976 Landsat MSS data, collected during healthy forest canopy conditions, had been classified to produce a forest/non-forest mask as part of an earlier study in this same area.[2] The airphoto-derived defoliation image described above was combined with this forest/non-forest mask to produce the forest canopy condition reference image (Figure 5). The resultant image contained four codes: 0 = non-forest, 1 = heavy defoliation, 2 = moderate defoliation, and 3 = healthy forest.

VI. ANALYSIS PROCEDURES

A. DATA SET PREPARATION

The initial step in the analysis was an assessment of the elevational accuracy of the DEM data. The location of 50 points of known elevation, such as bench-marks and road intersections, were identified on the Wertzville topographic map. The digitized coordinates of these points were converted to the corresponding line and sample coordinates in the original 30-meter DEM data. The elevations of these test points were extracted from the DEM data and compared to elevations obtained from the topographic map using a paired sample t-test. The test indicated that there was no significant (α=.01) difference between the elevations obtained from the topographic map and the DEM data.

The resampled, 50-meter DEM data were then processed to produce aspect categories. The aspect category of each pixel in the DEM image was calculated by computing the elevation difference between that pixel and the eight surrounding pixels. If the center pixel was higher than the surrounding pixels, it was designated a peak. If the center pixel was lower than all of the others, it was designated a pit. In the remaining situations, the steepest drop to a surrounding pixel was identified and this direction was designated as the center pixel's aspect category (Figure 6). This routine resulted in ten aspect categories: pits, N, NE, E, SE, S, SW, W, NW and peaks. The ten aspect categories were assigned codes 0 - 9, respectively, and non-study areas were identified with a unique code.

The categorized aspect data were then combined with the forest canopy condition reference data to produce an image of aspect/canopy condition combinations. The combined image represented the 30 possible aspect/canopy condition classes (i.e., 10 aspect categories X 3 condition classes) and non-study area. A histogram of the combined image revealed that certain aspect/canopy condition combinations did not occur with sufficient frequency to permit an adequate number of points to be sampled for subsequent statistical analyses. The lack of points for certain combinations was primarily a result of the predominant east-west strike of the ridges in the study area.

To obtain sufficient samples for testing, the peak and pit categories were dropped from the analysis and the remaining eight aspect categories were combined into four new ones: N and NW, E and NE, S and SE, and W and SW (Figures 7 and 8). These aspect categories were grouped on the basis of the predominant ridge pattern to increase the number of

*NOTE: The quality of DEM data have been found to be very good (i.e., elevation accuracy of ±7 meters for any given pixel). The discontinuities in data quality experienced in this study were caused by the use of substandard orthophotos. USGS preferred not to generate these data, but we made a special request to have the data generated for this study so as to take full advantage of the unique ground reference data already available.

pixels in each aspect/canopy condition class. This new aspect image was combined with the forest canopy condition reference image to produce an image containing thirteen category codes: 0 = non-study area, and 1 - 12 for the twelve aspect/canopy condition combinations. The non-study category now included all pixels in non-forest areas, areas of DEM data discontinuity, and areas designated as peaks or pits.

B. DATA CHARACTERIZATION

Characterization of the Landsat spectral data was based upon a random sample of 60 points taken from each of the twelve aspect/canopy condition categories. The spectral response values for each sample point were extracted from the MSS data and grouped by aspect class and canopy condition. These values were then used to compute population means and standard deviations for each of the twelve categories (Table 1). These data provided the basis for all subsequent evaluations and analyses performed in this characterization study, including: a) two factor univariate and multivariate analyses of variance, b) Student-Newman-Keuls multiple range tests, c) two-dimensional spectral plots, and d) maximum likelihood classification.

By applying the procedures in this order, a hierarachical series of tests was established in which each successive test returned more specific information than the preceding ones. The analyses of variance were applied, first, to determine whether canopy condition or aspect affect the reflectance values of the MSS data. If no effects were found, further testing would be fruitless. Next, the Student-Newman-Keuls multiple range test was applied to establish which canopy conditions and aspect categories produced distinguishable populations of MSS data. If separate populations could not be distinguished, then classification of individual pixels would certainly not succeed. Third, the two-dimensional spectral plots were produced to ascertain, qualitatively, the class separability on a pixel-by-pixel basis. Finally, the maximum likelihood classification was applied to demonstrate, quantitatively, the results obtained from the data characterization.

C. DATA CLASSIFICATION

Two classification techniques were applied to the multispectral data. The first approach involved the use of a standard maximum likelihood classification algorithm operating on the overall statistics created for each of the three canopy condition classes. These overall statistics were obtained by pooling data among the four aspect categories. Thus, this approach resulted in the classification of forest canopy conditions without regard for the topographic effect on sensor resoponse.

The second approach involved the use of a layered classification technique, where the multispectral data were stratified into one of the four aspect classes. Thus, the multispectral data in each stratum were classified, with a maximum likelihood decision rule, using the canopy condition statistics computed from the random points selected from that specific stratum. This layered approach, where forest canopy conditions in each aspect category were classified with statistics specifically derived from that aspect, was utilized to minimize the impact of topographic effects on sensor response.

VII. RESULTS AND DISCUSSION

Table 1 presents the mean and standard deviation of each MSS band for the twelve aspect/canopy condition combinations, as well as overall statistics for each canopy condition, computed by pooling the individual aspect statistics. These data were used in a two factor univariate analysis of variance (ANOVA) to determine whether canopy condition or aspect produced significant variation in the multispectral data. The results for the ANOVA, summarized in Table 2, indicate that aspect produced significant ($\alpha = .05$) variation only in the near infrared bands (MSS 6 and 7). This agrees with our intuitive expectations. Forest cover types characteristically have low reflectivity in the visible bands allowing atmospheric path radiance, which is only slightly affected by terrain variability, to dominate. On the other hand, forest cover types generally have high reflectivity in the near infrared bands, and, therefore, the topographic effect can play a much greater role in altering sensor response. The ANOVA results also indicated that canopy condition produced significant variation in all four MSS bands. Since heavy defoliation can involve the complete removal of canopy vegetation, revealing bare branches and the ground surface below, significant differences in reflectivity are not surprising.

A two factor multivariate analysis of variance (MANOVA) produced results consistent with those obtained from the

ANOVA. Both canopy condition and aspect produced significant (α=.05) variation in the MSS data.

The ANOVA and MANOVA statistical tests established that both canopy condition and aspect significantly affect the MSS data. Next, the Student-Newman-Keuls multiple range test was applied to the sample data to determine which factor levels were separable, i.e., which canopy conditions or aspect categories produced separable MSS data populations. This test uses the difference between sample means as a measure of separability. The results of this test are summarized in Table 3, first by canopy condition and then by aspect category. In both cases, the factor levels are listed so that the corresponding sample means are in ascending order from left to right. To aid in the interpretation of the results summarized in Table 3, note that if two or more adjoining factors are not separable (α=.05), they are underlined. The results for canopy condition indicate that heavy defoliation is separable from the other canopy conditions in each of the four bands. However, moderate defoliation and healthy forest are separable only in MSS 7. The results for aspect category indicate very low separability in MSS 4 and 5. This was expected since the variation in those bands due to aspect was not significant. The results for MSS 6 and 7 indicate that three aspect groupings are separable. N/NW and S/SE form the low and high ends of the range, respectively. W/SW and E/NE fall in between; they are separable from either end of the range, but not from one another.

It is important to note that results from the multiple range test refer to the separability of the sample populations, not individual pixels. In addition, this test examined canopy condition separability without regard to aspect. The next step in the analysis examined canopy condition separability in each aspect category from the perspective of discriminating (classifying) individual pixels. In order to obtain a graphic display of the spectral overlap or separability of the three canopy conditions, two-dimensional plots were produced of the sample mean values, plus and minus one standard deviation, for each canopy condition in the following band pairs: MSS 7 versus MSS 5, and MSS 6 versus MSS 4. Plots were produced for each aspect and for the overall statistics (Figure 9). Examination of the plots for the overall statistics reveals the problem with separating moderate defoliation and healthy forest. The moderate defoliation ellipse is almost entirely embedded within the healthy forest ellipse, i.e., the spectral space occupied by moderate defoliation falls within the larger region of spectral space occupied by healthy forest. Accurate classification of pixels which fall into this region would be impossible. A visual assessment of the plots for the individual aspect categories reveals essentially equivalent situations. Moderate defoliation falls largely within the healthy forest spectral space on every aspect. In every MSS 7 versus MSS 5 plot, however, the spectral space occupied by heavy defoliation was distinct. Heavy defoliation was not as separable from the other canopy conditions in the MSS 6 versus MSS 4 plots.

Examination of the plots provided a qualitative assessment. In order to quantify the findings, two separate classifications, described in the previous section, were performed. If moderate defoliation and healthy forest were more separable on an individual aspect than they were overall, then the layered classification should have produced superior results. An automated, pixel-by-pixel comparison of the two classified images to the forest canopy condition reference image revealed that the layered classification technique actually produced slightly lower accuracy figures than the standard technique. In both cases, three-fourths of the heavy and moderate defoliation pixels, and one-half of the healthy forest pixels agreed with the reference image. For heavy defoliation, most of the disagreement was due to errors of commission with healthy pixels in the reference image which fell along the border of the forest/non-forest mask (i.e., spectrally mixed pixels). The difference in classification accuracy between moderate defoliation and healthy forest was due to two factors: the size and position of the spectral space occupied by these two canopy conditions and the assignment algorithm employed by the maximum likelihood classifier. Since the spectral region for moderate defoliation is embedded within the spectral region for healthy forest, many healthy forest pixels which fall within the moderate defoliation region are misclassified as moderate defoliation (i.e., there is a higher probability of pixel assignment to the smaller population which is spectrally embedded within the larger population). Confusion would occur less frequently in the other direction.

These combined results lead one to conclude that moderately defoliated areas and healthy forest are not separable using Landsat MSS data, even when potential effects on sensor response due to terrain aspect variability are taken into account. The spectral responses of these two forest classes are too similar. However, Talerico, et al.[7] have reported that these two forest cover conditions can be delineated using air photointerpretation techniques, which implies that they must be texturally and/or spectrally distinct. This leads one to the conclusion that the Landsat MSS spectral bandwidths and spatial resolution are inadequate for differentiating these cover types. Perhaps the improved spectral, spatial and radiometric resolution capabilities to be provided by the Landsat-D Thematic Mapper will be adequate, but additional work on textural classification techniques may also be necessary.

Results from this study also indicate that heavily defoliated areas can be reliably delineated from either moderate defoliation or healthy forest using Landsat MSS data and techniques to mask out non-forest areas. Thus, Landsat does provide a relatively low-cost, standardized data base for monitoring heavy defoliation of deciduous forest stands by the gypsy moth caterpillar.

VIII. SUMMARY AND CONCLUSIONS

This study was undertaken to develop a better understanding of the interrelationships among severity of defoliation, slope orientation (aspect), and spectral response, as recorded by the Landsat MSS. The availability of high spatial resolution digital terrain data, in the form of DEM data tapes provided by the USGS Digital Applications Team, was extremely vital to this research effort. The DEM data were found to accurately represent the topographic conditions in the study area.

Based upon the statistical analyses of the spectral response data, which were carefully summarized by aspect category, canopy condition and pooled for overall statistics, the following conclusions can be drawn:

• for Landsat scenes dominated by dense vegetative cover, spectral response in the visible bands (MSS 4 and 5) is only slightly affected by terrain variability, while spectral response in the near infrared bands (MSS 6 and 7) can be significantly altered;

• significant variations in forest canopy conditions are manifested in the spectral response recorded in all four MSS bands;

• both forest canopy condition and aspect produced significant variation in MSS data;

• MSS 5 and MSS 7 are the best pair of bands to use to separate heavy defoliation and healthy forest, based on the two-dimensional spectral plots;

• heavy defoliation is separable from both moderate defoliation and healthy forest, but moderate defoliation and healthy forest cannot be consistently separated from one another even when accounting for any confounding effects on sensor response due to aspect; and

• for this study, the integration of digital terrain data with Landsat MSS data did not significantly improve or alter results in comparison to results derived without terrain data.

Although these results were not totally positive from the perspective of successfully separating healthy forest and moderate defoliation, a better understanding of the effects of terrain variability upon sensor response was obtained. Additional research efforts are currently underway at GSFC to improve our understanding of scene reflectance dynamics and the monitoring of forest disturbances.[5,12] The data set created in this research effort will be further utilized to evaluate proposed radiation transfer models that are designed to correct for topographic effects on sensor response prior to classification.

IX. ACKNOWLEDGEMENTS

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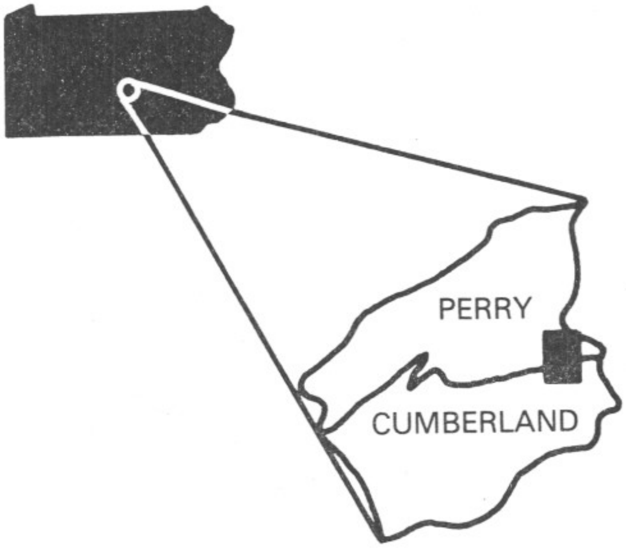

Figure 1. Location of the study area. The study area consists of the Wertzville 7.5' topographic quadrangle, and is illustrated above by the black rectangular box which straddles the Perry/Cumberland Co. line in central Pennsylvania.

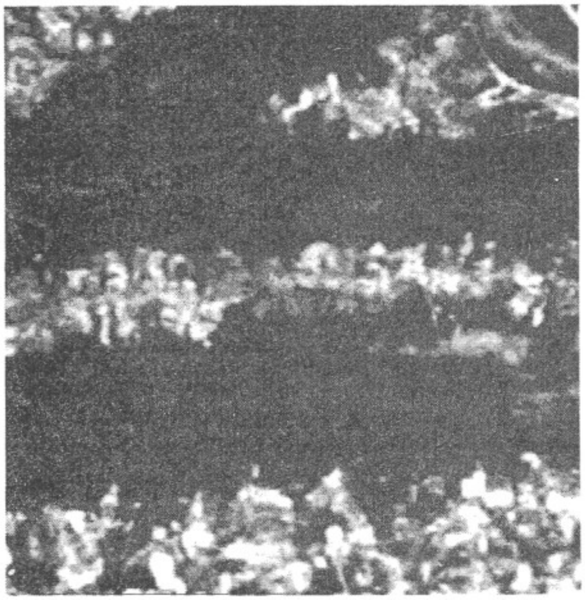

Figure 2. MSS Band 5 Rendition of the Wertzville Quadrangle. The 27 June 1977 MSS 5 image of the Wertzville quadrangle, shown above, was recorded during peak defoliation conditions. Areas of heavy defoliation show up as lighter tones of gray along the ridges.

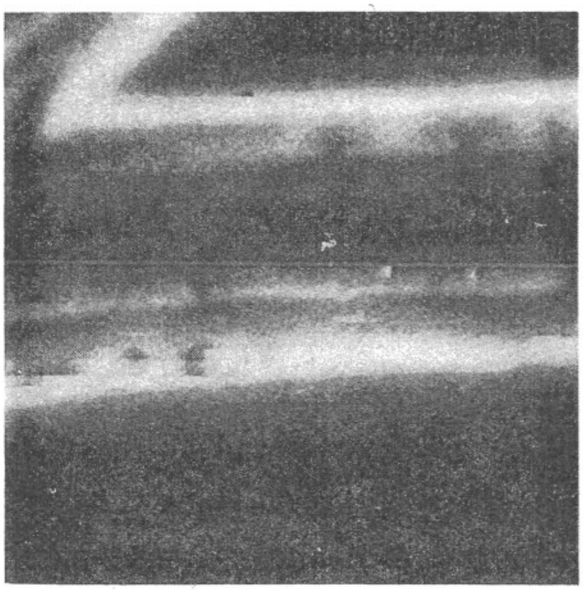

Figure 3. Digital Elevation Model Data. The image above provides a visual representation of the DEM data of the Wertzville quadrangle. Lighter tones of gray represent higher elevations; darker tones represent lower elevations.

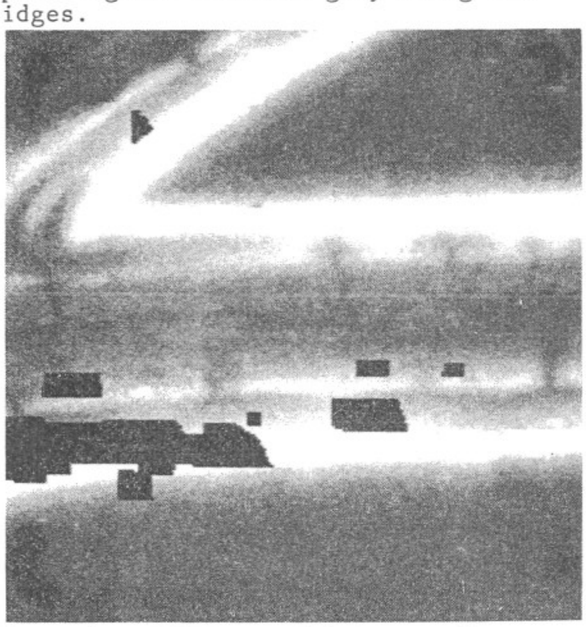

Figure 4. DEM Data with Areas of Discontinuity Removed. Areas of elevation discontinuity within Figure 3 were removed from consideration by assigning a zero value to the affected pixels.

Figure 5. Forest Canopy Condition Reference Image.
The image above illustrates the ground reference data. Black = non-forest; light gray = healthy forest; medium gray = moderate defoliation; and dark gray = heavy defoliation.

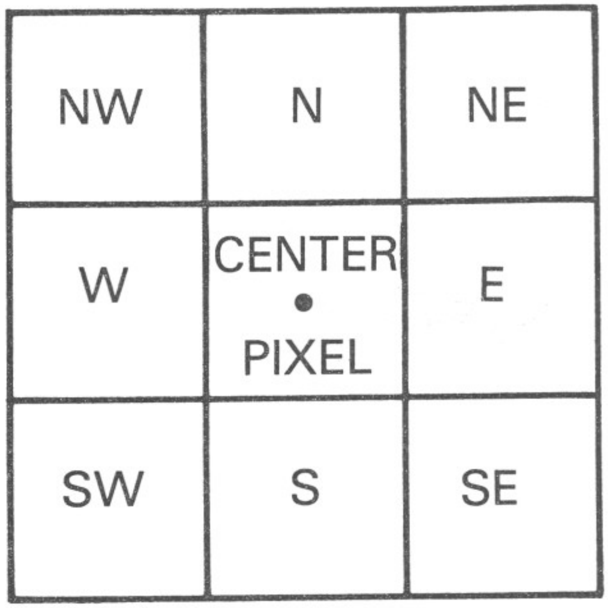

Figure 6. Aspect Category Assignment Matrix.
This drawing illustrates the decision criterion utilized to assign an aspect category to each pixel. The elevation of the center pixel was compared to the elevation of the eight sourrounding pixels.

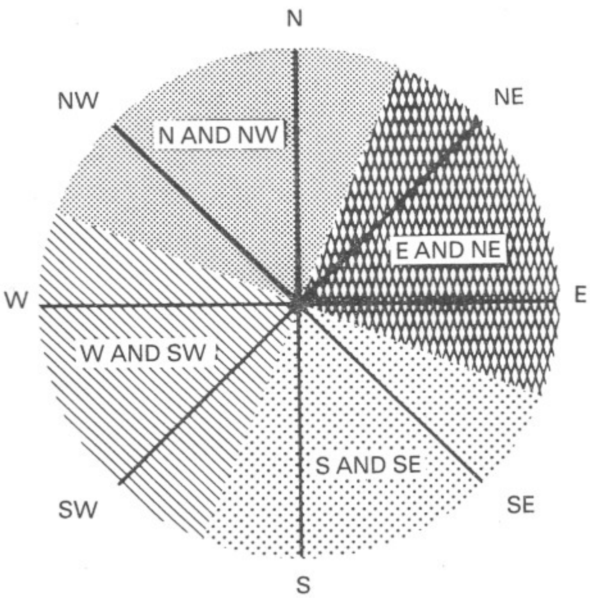

Figure 7. Aspect Categories Utilized in Tabulation of Results.
This drawing illustrates the four aspect categories utilized for the tabulation of results in this study. These categories were grouped on the basis of the predominant ridge pattern in the study area.

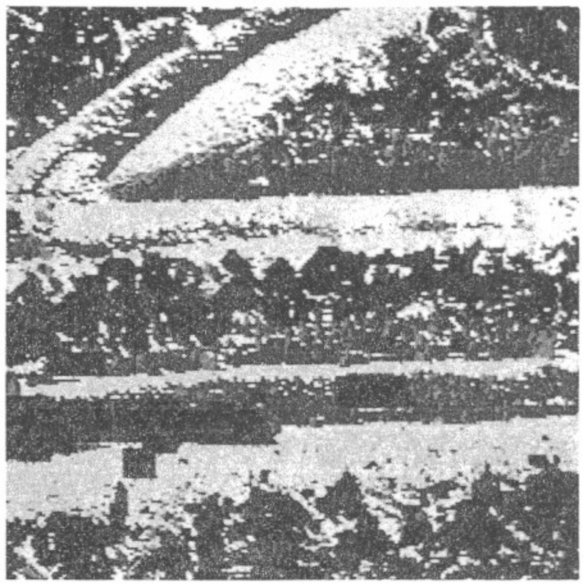

Figure 8. DEM Data Delineated by Aspect Category.
By applying the decision rules discussed and illustrated in Figure 6 and 7, the DEM data were subdivided into aspect categories as shown above. Black = non-study area; dark gray = N/NW; medium-dark gray = E/NE; medium-light gray = S/SE; and light gray = W/SW.

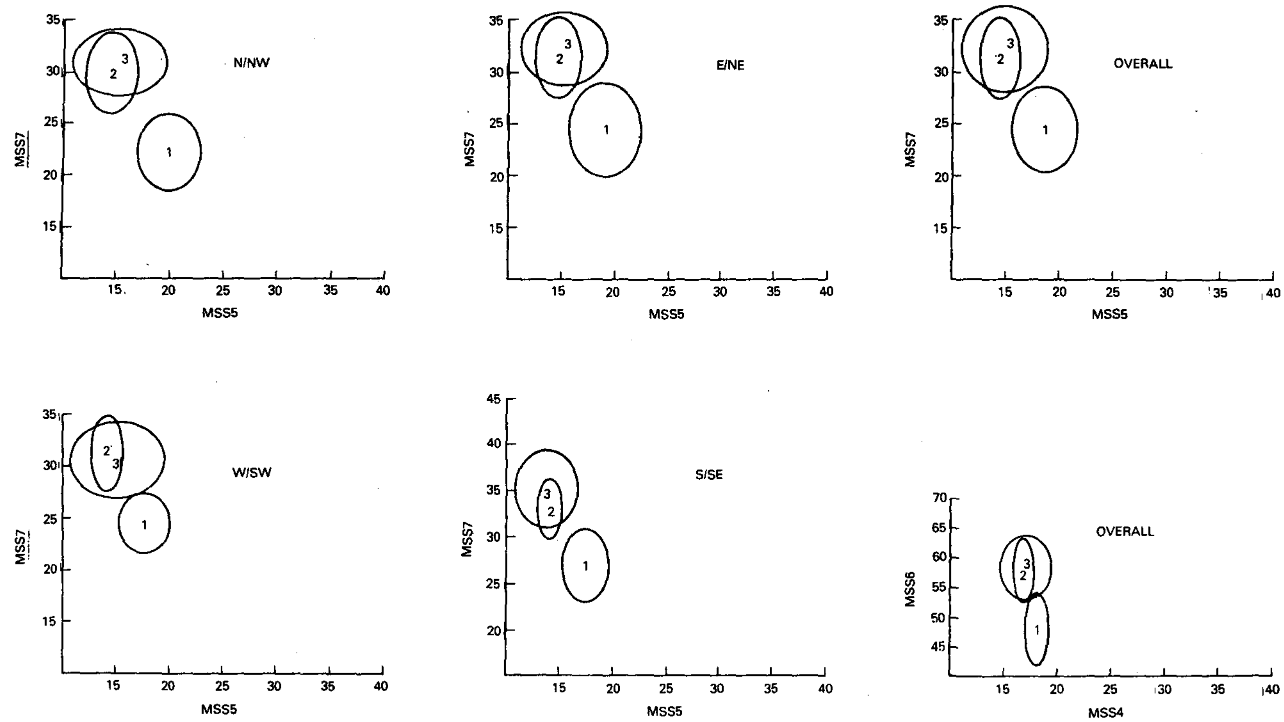

Figure 9. Two-Dimensional Spectral Response Plots.
The spectral response space of each canopy condition class is identified by the number at the center of each ellipsoid: 1 = heavy defoliation; 2 = moderate defoliation; and 3 = healthy forest.

Table 1. Summary Statistics.

Canopy Condition	ASPECT	n	MSS4 μ	MSS4 σ	MSS5 μ	MSS5 σ	MSS6 μ	MSS6 σ	MSS7 μ	MSS7 σ
Heavy Defoliation	NNW	60	18.37	.92	19.83	2.89	43.93	5.75	22.03	3.60
	ENE	60	18.25	1.13	18.98	3.51	47.27	7.02	24.18	4.59
	SSE	60	17.93	1.01	17.37	2.32	52.02	5.36	26.78	3.95
	WSW	60	17.78	.87	17.70	2.24	47.92	4.50	24.18	2.85
	Overall	240	18.08	1.01	18.47	2.96	47.78	6.41	24.30	4.16
Moderate Defoliation	NNW	60	16.78	1.01	14.37	2.42	55.42	5.44	29.60	3.87
	ENE	60	17.07	.94	14.57	2.17	57.58	5.28	31.12	3.73
	SSE	60	16.68	.87	14.05	1.23	60.23	4.57	32.87	3.24
	WSW	60	16.73	.84	14.20	1.54	57.70	4.83	30.92	3.54
	Overall	240	16.82	.93	14.30	1.91	57.73	5.32	31.13	3.79
Healthy Forest	NNW	60	17.03	2.70	15.15	4.29	56.27	3.42	30.62	3.08
	ENE	60	17.38	2.39	15.08	3.98	58.85	4.67	31.98	3.61
	SSE	60	16.60	2.12	13.72	2.86	62.13	5.62	35.02	4.21
	WSW	60	17.15	2.74	15.12	4.32	55.83	4.15	30.32	3.55
	Overall	240	17.04	2.52	14.77	3.95	58.27	5.18	31.98	4.08

Table 2. ANOVA Results.

Using the data in Table 1, a two factor univariate analysis of variance (ANOVA) was performed to determine whether canopy condition and/or aspect produced significant (α=.05) variations in the spectral response data. The value for the F statistic, and its associated probability, are summarized by MSS band for each factor.

		MSS4		MSS5		MSS6		MSS7	
	D.F.	F	Prob.	F	Prob.	F	Prob.	F	Prob.
Canopy Condition	2	49.61	.0002	61.51	.0001	99.90	.0000	150.86	.0000
Aspect	3	3.73	.0800	3.44	.0923	14.68	.0036	19.67	.0017
Canopy Condition*Aspect	6	0.82	.5527	2.30	.0333	3.19	.0043	2.08	.0531

Table 3. Student-Newman-Keuls Multiple Range Test.

The Student-Newman-Keuls multiple range test was applied to the sample data (Table 1) to determine which canopy conditions or aspect categories produce separable MSS data populations. If two or more adjoining factors are not separable (α=.05), they are underlined.

Channel	Canopy Condition Groupings			Aspect Category Groupings			
MSS4	Moderate Defoliation	Healthy Forest	Heavy Defoliation	SSE	WSW	NNW	ENE
MSS5	Moderate Defoliation	Healthy Forest	Heavy Defoliation	SSE	WSW	ENE	NNW
MSS6	Heavy Defoliation	Moderate Defoliation	Healthy Forest	NNW	WSW	ENE	SSE
MSS7	Heavy Defoliation	Moderate Defoliation	Healthy Forest	NNW	WSW	ENE	SSE