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SPECTRAL RESPONSE CURVE MODELS APPLIED TO FOREST COVER-TYPE DISCRIMINATION

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ABSTRACT

Digital brightness values for several coniferous cover types and associated background features (primarily snow and leafless hardwoods) were obtained from Landsat-3 multispectral scanner data acquired on February 26, 1979. Although most cover types exhibited an exceptionally large range of brightness values, each displayed a characteristic set of spectral response curves. The brightness values in each of the four Landsat MSS bands were modeled for the coniferous types and showed that the magnitude of change in reflectivity from band 5 (red light) to band 6 (near-IR) provided a measure for discriminating the cover types.

Training-site signatures from areas of relatively pure cover types were used as the foundation of the model. Subsequently, pixel brightness values for various spatial mixtures of cover types were generated by the model. The near-constant, relatively small difference between the band 5 and band 6 brightness values for the background features resulted in (BV6-BV5) values for the coniferous types that not only discriminated among species, but also were sensitive to stocking levels. Compared to traditional training site data, the array of response curves predicted by the model provided a more complete description of the spectral reflectance continuum for each cover type.

I. INTRODUCTION

The inventory of forest resources, including the monitoring of changes to the forest, is of vital concern to foresters and other natural resource managers. The potential of remote sensing systems to provide a cost-effective inventory tool is currently of interest to a variety of natural resources management agencies. The Landsat system in particular has generated interest from both the scientific community as well as resource managers.

Several studies have been conducted on the use of Landsat data for mapping forest resources in Michigan. An attempt to map tree species groups from June data, using automated recognition techniques, did not produce a classification with acceptable accuracy (Roller and Visser, 1980). A study utilizing visual interpretation of winter Landsat imagery, with snow cover on the ground, to map scattered woodlots obtained accuracies ranging from 74.0 to 98.5 percent (Karteris, Enslin, and Thiede, 1981). Finally, the visual interpretation of Landsat computer enhanced imagery of an April (leaf-off) scene provided overall classification accuracies between 73 and 81 percent, whereas individual species interpretability accuracies ranged from 32 to 95 percent (Franklin, Hudson, and Ramm, 1983).

Current research, which is the subject of this paper, has been directed toward the development and evaluation of computer-implemented classifications for the identification and characterization of coniferous forest types in Michigan's northern Lower Peninsula.

II. CHARACTERISTIC RESPONSE CURVES FROM LANDSAT MSS DATA

Landsat-3 multispectral scanner (MSS) data, acquired on February 26, 1979 (E-30358-15471), were used to obtain digital brighness values (BV) over a variety of sites in Michigan's northern Lower Peninsula. At this date, there was an average of 58.4 cm of snow on the ground as reported from 17 stations, ranging from 38.1 to 93.4 cm (NOAA, 1979). Almost all of this snow fall occurred prior to several days before the Landsat overpass.

As a result, virtually all non-forest cover types, including inland lakes, exhibited the spectral response of snow. Although the hardwood forests were leafless, their extensive mass of trunks and branches provided a substantially different reflector compared to the underlying snowpack. The coniferous forests, primarily red pine (Pinus resinosa), jack pine (Pinus banksiana), pine mixtures, and swamp conifers (primarily northern white cedar, Thuja occidentalis), provided the only green-foliage reflectances in the entire scene.

Digital brighness values were obtained from a total of 136 training sites. Each site was characterized on the basis of photo-interpretation of color infrared imagery (1:24,000 scale) and subsequent field verification. The individual sites were chosen to represent as many different stand conditions occurring on the various major landform types as possible. The three pine types included both plantations and natural stands.

Most of the coniferous cover types exhibited an exceptionally large range of brightness values (Table 1), although individual training sites were reasonably homogenous and seldom had a range of over 10 digital counts for a single band. In contrast, the hardwood training sites had a large total range of BV's but were much more variable -- ranges from 15 to 25 BV's were not uncommon for a single band. Snow covered areas, on the other hand, exhibited the smallest range of BV's; band 5 was saturated (BV=127) in all but a few cases while band 6 typically had a range of fewer than five digital counts.

The mean brightness value for each training site was utilized to plot spectral response curves for individual cover types (Figure 1). While still exhibiting a large overall range of brightness values, the spectral response curves display a discernable pattern. Coniferous training sites (red pine, jack pine, pine mixtures, and swamp conifers) representing highly stocked stands had the lowest spectral responses. The shape of these curves, for example the three lowest red pine curves on Figure 1a, follows that of "typical" green vegetation; they exhibit a slight decrease from band 4 (green light) to band 5 (red light), a substantial increase from band 5 to band 6 (near-IR) and a moderate increase from band 6 to band 7. The curves for coniferous vegetation contrast sharply to those for hardwoods and snow which exhibit an increase from band 4 to band 5; a near-constant, relatively small difference between band 5 and band 6; and a moderate to substantial decrease from band 6 to band 7. The coniferous training sites exhibiting higher mean spectral responses represent stands with varying degrees of stocking. As stocking decreases, more of the area mapped as coniferous forest is composed of snow, and occasionally hardwoods, which contribute to the spectral response of the stand. Therefore, the brighter coniferous BV's are the result of the combined reflectance of the conifers and snow (or hardwoods) -- the lower the stocking level, the higher the brightness.

III. SPECTRAL RESPONSE CURVE MODELS

Analysis of the mutispectral, reflectance patterns exhibited by the coniferous cover types and the background features led to the development of spectral response curve models. Training-site signatures from areas of relatively pure cover types were used as the foundation of the model. The brightness values corresponding to mixtures of various cover types were predicted by summing the average spectral response for each cover type weighted by its spatial

Table 1. Summary of Landsat MSS Training Sites.

Cover Type	Range of Brightness Values				Number of Sites	Sample Size (Pixels)
	Band 4	Band 5	Band 6	Band 7		
Red Pine	8-80	2-91	17-95	26-74	26	1015
Jack Pine	7-76	5-90	14-90	17-70	30	1341
Mixed Pine	11-55	8-67	18-75	20-60	22	1056
Swamp Conifers	3-43	8-45	16-46	19-42	22	1646
Hardwoods	22-94	20-110	24-112	24-86	23	1519
Snow	97-127	114-127	112-127	81-103	13	1277
All	3-127	2-127	14-127	17-103	136	7854

extent in the instantaneous field of view (IFOV):

$$BV_M = \sum_{i=1}^{k} P_i \overline{BV}_i$$

BV_M = predicted brightness value of the mixture of cover types (for a single band)

P_i = proportion of cover type (i) in the IFOV

$\overline{BV}_i$ = average brightness value for the pure cover type (i) (for a single band)

k = number of cover types in mixture

As an example, the mean brightness values for snow and pure red pine can be utilized to predict pixel brightness values for various spatial mixtures of these two types representing various stocking levels of red pine. The general shape and progression of the response curves, as generated by the model (Figure 2), is similar to those which were obtained from training-site data (Figure 1a). To illustrate the predictive value of the model, mean spectral response values from training site data were analyzed. The red pine cover type represented by curve A (Figure 1a) had mean brightness values of 40.9, 44.2, 52.8, and 45.2 for bands 4, 5, 6, and 7 respectively. According to the model just presented, the percent of snow (S) and red pine (PR) can be calculated as follows:

$$P_S = \frac{BV_M - \overline{BV}_{PR}}{\overline{BV}_S - \overline{BV}_{PR}} \quad \text{and} \quad P_{PR} = 1-P_S$$

Curve A would therefore represent an area composed of approximately 75% red pine and 25% snow. The actual brightness values predicted from the model for this particular combination (curve A on Figure 2) are 41.0, 40.0, 51.0, and 46.3.

Compared to traditional training-site data, the array of response curves predicted by the model provides a more complete description of the spectral-reflectance continuum for each cover type. In addition, the model helps explain the large range of BV's and characteristic sequence of response curves exhibited by the coniferous cover types. As stocking decreases, more of the stand reflectance is contributed by background features, predominately snow, which have moderate to large increases in brightness values from band 4 to band 5. This has the effect of increasing the brightness value difference between band 4 and band 5 for lower-density conifer stands and they lose their characteristic red light "dip." The large drop in brightness values from band 6 to band 7 for hardwoods and snow accounts for a similar decrease noted for lower-density conifer stands. The near-constant, relatively small difference between the band 5 and band 6 brightness values for the background features have little effect on the shape of the response curves for confiers. Throughout a large range of stocking densities (>25%) the response curves for conifers maintain their characteristic band 5 (red light) to band 6 (near-IR) rise. In fact, the dampening of this band 5 to band 6 rise could be used as a measure of stocking levels.

IV. FOREST COVER-TYPE DISCRIMINATION

The utility of the spectral response curve models arise from their application to forest cover-type discrimination. The predicted brightness values from areas containing a mixture of conifers and background features showed that the magnitude of change in reflectivity from band 5 to band 6 provided the most consistent measure for discriminating among the cover types.

In order to test this hypothesis, a portion of the Landsat scene was classified using data from only these two bands. Because of the predicted characteristic increase in brightness values from band 5 to band 6 for conifers, compared to the relatively flat response for background features, the value obtained by subtracting BV5 from BV6 was used to classify the test area. The (BV6-BV5) data provided discrimination accuracies of 77.9% for individual cover types and 87.8% for all conifers vs. non-coniferous forest categores, compared to 79.4% and 86.4% obtained with a maximum likelihood classification. When the (BV6-BV5) data were analyzed in conjunction with the absolute band 6 brightness values, the accuracies (80.6% and 88.7%, Table 2) exceeded those obtained by the maximum likelihood classification (Table 3). In addition to comparable or improved accuracies, the two-band techniques ran more than 10 times faster than the maximum likelihood, or other, algorthms.

Two approaches for implementing this model as a classification technique are presently being investigated. One uses a look-up table based on sample training data; the second is an unsupervised clustering of the two-dimensional data set (BV6-BV5, BV6).

Table 2. Landsat classification performance, (BV6-BV5, BV6) data.

Cover type map	Red pine	Jack pine	Pine mixtures	Non-forest	TOTAL	Percent correct
	Number of Pixels Classified as --					
Red pine	4497	177	28	665	5367	83.8
Jack pine	358	733	37	552	1680	43.6
Pine mixtures	811	199	56	145	1211	4.6
Swamp conifers	130	133	7	68	338	0.0
Non-Forest	757	405	5	13292	14459	91.9
TOTAL	6553	1647	133	14722	23055	
Percent correct	68.6	44.5	42.1	90.3		80.6

Table 3. Landsat classification performance, maximum likelihood.

Cover type map	Red pine	Jack pine	Pine mixtures	Non-forest	TOTAL	Percent correct
	Number of Pixels Classified as --					
Red pine	3701	222	146	1298	5367	69.0
Jack pine	203	709	77	691	1680	42.4
Pine mixtures	498	202	265	246	1211	21.9
Swamp conifers	113	105	50	70	338	0.0
Non-Forest	528	274	20	13637	14459	94.3
TOTAL	5043	1512	558	15942	23055	
Percent correct	73.4	46.9	47.5	85.5		79.4

V. CONCLUSIONS

Spectral response curve models can be used to evaluate and explain the characteristic spectral responses of coniferous forest types on a snow-covered, winter Landsat scene. Predicted brightness values indicate that the magnitude of change in reflectivity from band 5 (red light) to band 6 (near-IR) provides a measure for discriminating between the various cover types. Data from just these two bands (BV6-BV5, BV6) will produce classification accuracies similar to those obtained by maximum likelihood classifier, but require less than one-tenth of the computer time to process. The use of these models in forest cover-type discrimination should provide resource managers with a powerful, cost-effective tool which will help to meet their informational needs.

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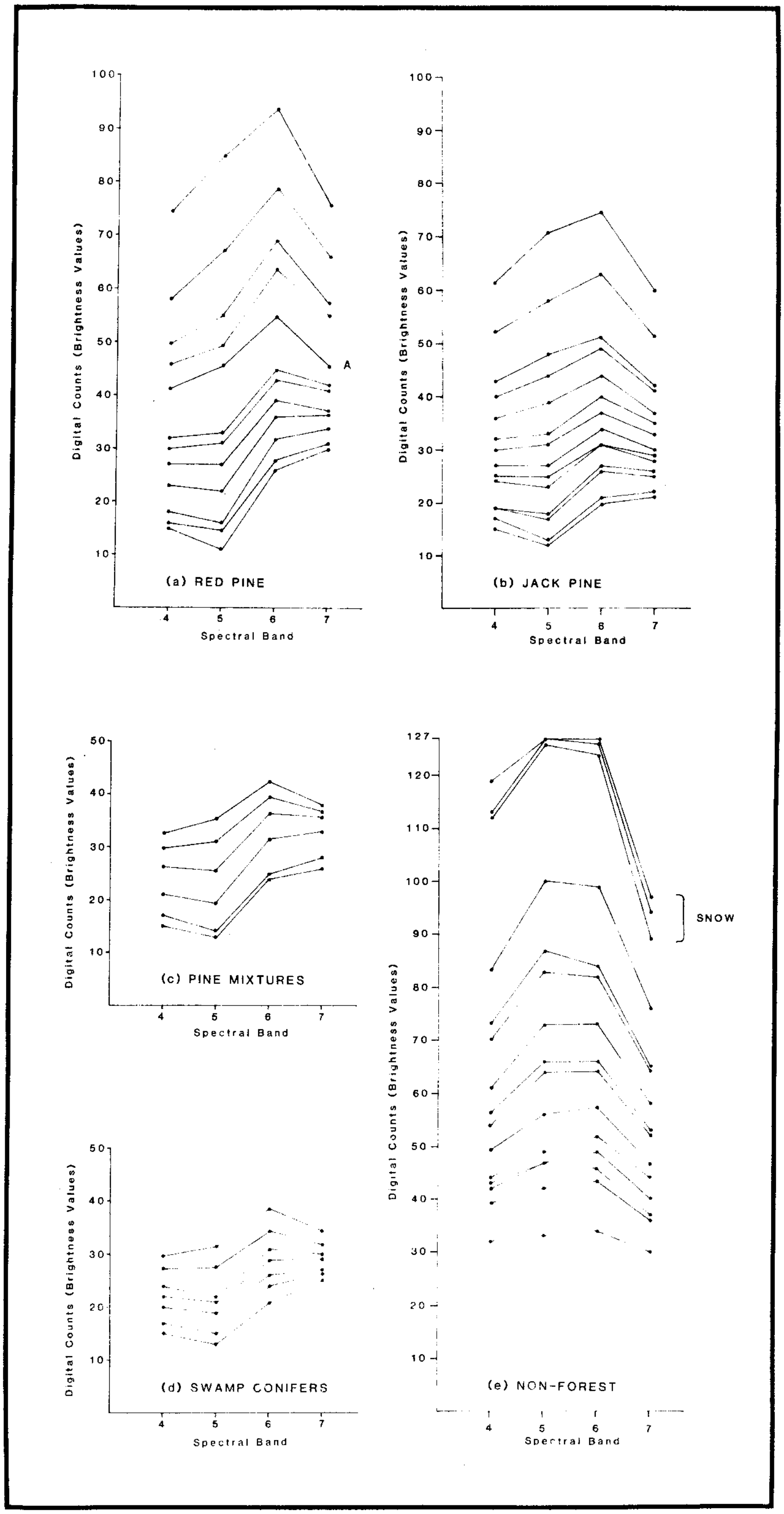

Figure 1. Mean Spectral Response Curves.

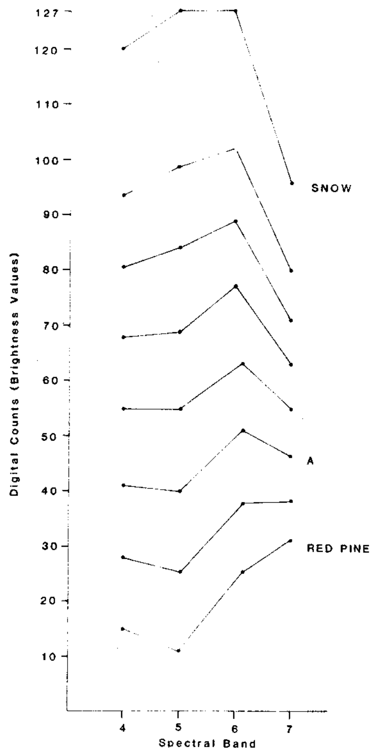

Figure 2. Spectral Response Curve Model for Red Pine.