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Use of Manual Densitometry in Land Cover Classification

Reasonably accurate classification of areas in the Cumberland Plateau into useful cover types can be made using manual densitometry data obtained from multi-temporal 1:24 000 scale color infrared and multispectral imagery.

Abstract: *Our study indicates that manual densitometry is a valuable tool for cover classification in regions that include surface-mined areas. Manual spot densitometers were used to obtain land cover signatures for 118 strata from multi-temporal 1:24 000 color infrared and multispectral aerial photographs. Using ground truth surveys, we classified each stratum into one of eight project cover types. Linear discriminant analysis and multi-seasonal imagery led to a reasonably accurate classification system. Distinction between coniferous and deciduous trees is good under prefoliated conditions. However, a combination of foliated and prefoliated conditions is superior to either alone. Undisturbed forest and surface-mined areas are accurately classified from imagery taken during foliated conditions.*

Introduction

A number of research projects have been concerned with development of methodology for objective automated land use classification, forest cover mapping, crop surveys, and soil surveys using remotely sensed data. Highly accurate classification systems have been achieved using data obtained with an airborne multispectral scanner (Todd, Mausel, and Baumgardner, 1973; Coggeshall and Hoffer, 1973; Cipra *et al.*, 1972). These efforts used data collected at one given time. Steiner and Maurer (1968) and Steiner (1970) found, using linear discriminant analysis, that a combination of densitometric variables measured at two or more points in time is more likely to produce correct crop classifications than such a combination measured at one given time. This paper describes the results of a study, conducted by the University of Kentucky Department of Forestry, in cooperation with the NASA Marshall Space Flight Center, which was designed to determine the feasibility of classifying terrain cover types in the Cumberland Plateau region in Kentucky using medium-scale multi-date, multi-type aerial photographs and data obtained from manually operated spot densitometers.

Our main objective was to study the feasibility of classifying land cover, using manually operated spot densitometer data gathered from April and September 1975 color infrared and multispectral aircraft overflight imagery. Secondary objectives included (1) determining the relative utility of the April, September, and combined data sets for land cover classification; and (2) determining the "best" densitometer aperture size to use from the viewpoint of terrain cover classification.

Initially, the eight land cover types de-

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fined in Table 1 were used as the basis for the study. Later Coniferous-Deciduous, Deciduous-Hemlock, and Deciduous types were grouped together as Undisturbed Forest, while the remaining five types were more generally classified as Surface Mined Under Reclamation or Disturbed Forest. Hence, two levels of interpretation intensity were considered.

METHODOLOGY

DATA ACQUISITION

The study area, consisting of 1,332 acres (539 hectares) was located in the Cumberland Plateau of Kentucky. The Cumberland Plateau is sparsely populated, and prominent land uses include hillside farming, forest harvesting, and surface mining for coal. Climax vegetation of the area is mixed mesophytic deciduous forest. The entire study area was forested; however, 18 percent of the study area had been surface-mined and was in varying stages of rehabilitation.

The study area was stratified into 118 field types, ranging in size from 1 to 20 hectares, through a cursory examination of 1:20 000 ASCS panchromatic photographs taken in September 1972. Detailed ground truth information, including species, diameter, total height, and crown closure percent, were obtained for each stratum using a one plot per acre (0.4 hectare) variable plot inventory in forested areas. Species and ground cover percent were recorded for grasses and other non-woody vegetation in reclaimed areas. Each stratum was classified into one of the eight project cover types on the basis of this sample.

Photography consisted of 1:24 000 color infrared transparencies taken on April 7, 1975, and 1:24 000 multispectral and color infrared transparencies taken on September 3, 1975. This imagery provided nonfoliated and foliated ground cover conditions for analysis.

Manual spot transmission densitometers were used to examine all available imagery-wavelength bands of the aircraft transparencies to determine land cover signatures. One densitometer used was a Macbeth TD-528 equipped with interchangeable 1 and 3 millimetre opal glass diffuse and 1 millimetre F.4.5 projection apertures. The TD-528 offered additional signature components through use of the visual, Wratten 93, Wratten 18A, and Wratten 96 filters that were part of this digital display densitometer.

The other densitometer used in this study was a Macbeth TD-500 equipped with interchangeable 1 and 2 millimetre opal glass diffuse apertures and a fixed Wratten 106 gelatin-Corning 9788 glass filter combination.

Data were collected on each aircraft overflight image at an approximate rate of 2.5 samples per hectare, utilizing all combinations of the above apertures and filters. Neither densitometer was equipped with attachments necessary to allow precise geographical positioning and referencing of the imagery. Exact relocation and remeasurement of sampling points were thus impossible. Hence, for each aperture, densitometry samples were taken randomly within the delineated field types. It is well known that image densities depend upon processing, exposure, and atmospheric variables. However, Wiegand (1975) found that it made no difference what density units were used as a data base for final classification accuracy. He found that, if a linear relationship existed, arbitrary digital counts from a single density measuring system were as good as standardized optical density units. This would imply that success with the density algorithms would allow the construction of analogous reflectance algorithms of similar accuracy with broader validity.

DATA ANALYSIS

Discriminant analysis is a multivariate

TABLE 1. DESCRIPTION OF THE EIGHT COVER TYPES USED IN THE ANALYSES.

Type	Description
Coniferous—Deciduous	approximately a 50-50 mix
Deciduous—Hemlock	10-15% Hemlock 80+% deciduous
Deciduous	80+% deciduous, <5% coniferous
Dense Grass 1	85+% grass or non-woody vegetation
Dense Grass 2	65-80% grass
Sparse Grass 1	40-60% grass
Sparse Grass 2	<25% grass
Black Locust-Grass	Black locust overstory with mixed grass understory

statistical method that calculates functions which discriminate between groups in an optimal manner. The discriminant functions calculated by the analysis determine boundaries which produce a set of subspaces, one subspace for each group. The location of the boundaries is such that a minimum number of misclassifications (i.e., individual points lying in the incorrect subspace) occur. A detailed discussion of the mathematics is given by Rao (1973). A major factor involved in assessing the usefulness of the sample linear discriminant functions developed, namely, the accurate estimation of the probabilities of misclassification (error rates) when using the functions to classify new samples, has been neglected by some studies (Steiner, 1970).

Steiner's only estimates of the error rates were obtained by observing the performance of his sample discriminant functions when applied to the set of data *from which his discriminant functions were calculated.* Lachenbruch (1968) has observed that, when applied to a new sample, the observed probabilities of misclassification are usually greater than those computed from the initial sample. He proceeds to show that this increase in the error rates is related to the "shrinkage" of the multiple correlation coefficient, R^2, in new samples. This phenomenon occurs when a set of regression coefficients computed from a sample is used for prediction purposes. In this case the correlation between predicted and observed values in a new sample is found to be less than R. Thus, Steiner's estimates of the error rates may be overly optimistic.

Possibly the most widely used method of estimating misclassification probabilities can be described as follows: If the initial samples are sufficiently large, choose a subset of observations from each group; compute discriminant functions using this subset; and then use the classification results for all or part of the remaining observations to estimate error rates. See Cipra *et al.* (1972); Coggeshall and Hoffer (1973); Todd, Mausel, and Baumgardner (1973); and Baumgardner and Henderson (1973) for examples using this method. Several drawbacks to this method are given in Lachenbruch and Mickey (1968). This method of evaluating the performance of the sample discriminant functions developed in this project was eliminated because very few (<5) observations were present for seven of the eight terrain cover groups associated with the project (Table 2).

A procedure which has the advantages of the foregoing method but which uses all observations without introducing serious bias in the estimates of error rates has been proposed by Lachenbruch (1965). Lachenbruch's procedure, sometimes referred to as a jackknife method, can be described as follows: Take all possible splits of size 1 in one subset (test set) and the remainder in the other subset (training set). This procedure has the effect of successively omitting one observation from the computation of the discriminant functions. Estimates of the misclassification probabilities are then computed by summing the number of cases that were misclassified from each group and dividing by the number in each group. Lachenbruch and Mickey (1968) compared several methods of estimating error rates

TABLE 2. JACKKNIFED CLASSIFICATION RESULTS FOR THE "BEST" SET OF DISCRIMINATING VARIABLES.

Group	No. of Areas	Pct. Correct	Number of Areas Classified into							
			C-D	D-H	DEC	DG1	DG2	SG1	SG2	BLG
C-D	3	100.0	3	0	0	0	0	0	0	0
D-H	3	100.0	0	3	0	0	0	0	0	0
DEC	96	100.0	0	0	96	0	0	0	0	0
DG1	4	0.0	0	1	1	0	0	1	0	1
DG2	4	75.0	0	0	0	0	3	1	0	0
SG1	3	66.7	0	0	0	0	1	2	0	0
SG2	2	50.0	0	0	0	0	1	0	1	0
BLG	3	100.0	0	0	0	0	0	0	0	3
TOTAL	118		3	4	97	0	5	4	1	4

Overall Error Rate (7/118) = 5.9%
Variables Used: April—CIR-1d-93, CIR-1d-96, CIR-1d-18A
Percentage Increases for
CIR-1d-93, CIR-1d-Visual
Tables 2-4 use the following abbreviations for the groups:

C-D = Coniferous-Deciduous, D-H = Deciduous-Hemlock
DEC = Deciduous, DG1 = Dense Grass 1, DG2—Dense Grass 2,
SG1 = Sparse Grass 1, SG2 = Sparse Grass 2,
BLG = Black Locust-Grass

and recommend use of this method, especially when normality is questionable and sample size is small relative to the number of variables. This method seemed reasonable to use with the project data set, considering the number of groups containing fewer than five observations.

DATA PROCESSING

A stepwise discriminant analysis program, BMDP7M, employing the jackknife procedure has been written as part of the BMDP (Biomedical Computer Programs) package developed at UCLA's Health Sciences Computing Facility. BMDP7M performs a multiple group linear discriminant analysis as described by Dixon (1975). Variables used in computing sample discriminant functions are chosen in a stepwise manner. At each step the variable that addes most to separation of groups (largest F value) is entered or the variable with the smallest F value is removed. By specifying contrasts, the user can state which group differences are of interest and, thus, influence variable selection. Prior probabilities may be specified. A variable with an F-to-enter value less than this value cannot be entered into the set of discriminating variables. Similarly, a limiting F-to-remove value may be specified, and an entered variable having an F-to-remove value less than this value may be removed from the set of discriminating variables. Levels (one for each variable) directing the choice of variables in the stepping procedure may be assigned. Variables with lower level numbers are entered first unless their F-to-enter values are less than the threshold value.

At this stage somewhat arbitrary decisions needed to be made concerning use of the options described above since a limitless combination existed. When considering the eight project cover types, it was decided that separation of each pair of groups was of equal importance; so, no special contrasts of groups were used. Limiting F-to-enter and F-to-remove values of 2.00 and 1.75 respectively were specified. Equal prior probabilities of 0.03 were assigned to each cover type except Deciduous which was given a prior probability of 0.79. When dealing only with the two more general terrain types, priors of 0.85 and 0.15 were assigned to Undisturbed and Disturbed Forest respectively.

To eliminate any possible effect of field type size in the discrimination program, each field type was represented in part by a vector of averages of density readings where each average was obtained using a different aperture-filter-machine-film combination. Coefficients of variation associated with these means were also included as suggested by Driscoll *et al.* (1972). Additionally, percentage increases from April to September values were included for the eight available aperture-filter combinations on the color infrared imagery. Finally, ratios of certain values were included in the list of potential discriminators. A list of films, apertures, and films together with their codes as used in describing the results is found in Table 3.

RESULTS

It is well known that stepwise procedures for variable selection usually do not lead to the "optimal" subset of variables. Hence, various large subsets of the variables were entered into the program in an effort to see whether a very few variables might, from these analyses, appear to be of large importance irrespective of the subset entered.

Of the numerous attempts made, the best results produced gave an overall estimated error rate of 5.9 percent when eight land cover types were considered (Table 2). This error rate occurred when the April average densities using color infrared film (CIR); 1 millimetre diffuse aperture (1d); and Wratten 18A, 93, and 96 filters as well as the percentage increases in the CIR-1d-93 and CIR-1d-Visual densities were included in the set of discriminating variables. While this classification may not be the best result achievable if all possible combinations of the variables were to be examined or other program options chosen, it gives an indication of what might be achieved. Excepting the Dense Grass 1 group, no more than one observation in any group was misclassified when using the jackknife method.

A noteworthy observation is that use of ten variables and information from all 118

TABLE 3. PROJECT FILMS, APERTURES AND FILTERS WITH CODES.

Code	Description
CIR	Color infrared film
MS2	Multispectral band 2
MS3	Multispectral band 3
1d	1 mm diffuse aperture
1p	1 mm projection aperture
3d	3 mm diffuse aperture
18A	Wratten 18A filter
93	Wratten 93 filter
96	Wratten 96 filter
Visual	Visual filter
106 + 9788	Wratten 106—Corning 9788 filter combination

TABLE 4. JACKKNIFED CLASSIFICATION RESULTS USING THREE APRIL DENSITIES.

Group	No. of Areas	Pct. Correct	C-D	D-H	DEC	DG1	DG2	SG1	SG2	BLG
			Number of Areas Classified into							
C-D	3	33.3	1	1	1	0	0	0	0	0
D-H	3	100.0	0	3	0	0	0	0	0	0
DEC	96	97.9	0	0	94	1	0	0	0	1
DG1	4	0.0	0	1	2	0	0	1	0	0
DG2	4	50.0	0	0	1	0	2	1	0	0
SG1	3	66.7	0	0	1	0	0	2	0	0
SG2	2	50.0	0	0	0	0	1	0	1	0
BLG	3	33.3	0	0	0	0	1	1	0	1
	118		1	5	99	1	4	5	1	2

Overall Error Rate (14/118) = 11.9%
Variables used: April—CIR-1d-93, CIR-1d-96, CIR-1d-18A

strata to develop the sample discriminant functions led to correctly classifying 117 of the 118 field types. Yet the jackknife estimated overall error rate was 10.2 percent. This discrepancy indicates the circumstances which could cause Steiner's estimated error rate to be overly optimistic since he had only nine observations in each group and used 13 variables when estimating the discriminant functions.

The next consideration was to compare the relative utility to ground cover classification of April, September, and combined data sets. When only variables constructed wholly from April data were permitted to enter the set of discriminating variables, the lowest estimated overall error rate found, when classifying into eight groups, was 11.9 percent (Table 4). This rate was obtained by using average densities obtained with CIR-1d-18A, CIR-1d-93, and CIR-1d-96 film-aperture-filter combinations. Meanwhile, when using only September data, an estimated overall error rate of 12.7 percent using two ratio variables was the best attained (Table 5).

Examination of Tables 2, 4, and 5 reveals the following: (1) the September data set gave no separation of mixed forest types from the Deciduous type; (2) none of the sets was able to classify Dense Grass 1 area correctly; (3) the combined data set offered much higher accuracy in classifying Coniferous-Deciduous, Deciduous-Hemlock, and Deciduous areas than did April or September data alone; and (4) the estimated overall error rate when either set alone was used was at least double that obtained when using the combined data set.

When the broader groupings of Undisturbed and Disturbed Forest were considered, the lowest estimated overall error rate found when using April data was 3.4 percent (Table 6). Likewise, a predicted error rate of 0.84 percent for classification with the September data set was found (Table 6). Variables chosen as discriminators from the April set included average densities ob-

TABLE 5. JACKKNIFED CLASSIFICATION RESULTS USING TWO RATIOS OF SEPTEMBER DENSITIES.

Group	No. of Areas	Pct. Correct	C-D	D-H	DEC	DG1	DG2	SG1	SG2	BLG
			Number of Areas Classified into							
C-D	3	0.0	0	0	3	0	0	0	0	0
D-H	3	0.0	0	0	3	0	0	0	0	0
DEC	96	100.0	0	0	96	0	0	0	0	0
DG1	4	0.0	0	0	1	0	0	1	1	1
DG2	4	25.0	0	0	1	0	1	0	1	1
SG1	3	100.0	0	0	0	0	0	3	0	0
SG2	2	50.0	0	0	0	0	0	1	1	0
BLG	3	66.7	0	0	0	0	1	0	0	2
	118		0	0	104	0	2	5	3	4

Overall Error Rate (15/118) = 12.7%
Variables Used: Sept. – $\frac{\text{CIR-1d-18A}}{\text{CIR-1d-96}}$ and $\frac{\text{CIR-3d-18A}}{\text{CIR-3d-96}}$

TABLE 6. JACKKNIFED CLASSIFICATION RESULTS FOR UNDISTURBED VS DISTURBED FOREST

		April			September		
Group	No. of Areas	Pct. Correct	U	D	Pct. Correct	U	D
Undisturbed	102	100.0	102	0	100.0	102	0
Disturbed	16	75.0	4	12	93.8	1	15
Total	118		106	12		103	15

Overall Error Rate: April = (4/118) = 3.4% September = (1/118) = 0.84%

Variables Used:

April— CIR-1d-93, CIR-1d-96, CIR-3d-93, Coeff. of Variation with CIR-1d-106 + 9788, CIR-1p-18A ÷ CIR-1p-96

September— CIR-3d-93, CIR-3d-93 ÷ CIR-3d-Visual, MS2-3d-18A ÷ MS3-3d-18A

tained with CIR-1d-93, CIR-1d-96, and CIR-3d-93 combinations; the coefficient of variation of densities obtained with the CIR-1d-106+9788 instrumentation; and a ratio of densities obtained using the 1 millimetre F/4.5 projection aperture defined by CIR-1p-18A ÷ CIR-1p-96. The September set of discriminating variables included average densities taken using CIR-3d-93 instrumentation, a ratio of densities defined by CIR-3d-93 ÷ CIR-3d Visual, and a ratio of densities from multispectral imagery bands two and three using the 3 millimetre diffuse aperture and Wratten 18A filter. No combination of variables taken from the combined April and September data gave any further reduction in the estimated error rate. Hence, imagery taken during foliated ground cover conditions appears more useful than that from prefoliated conditions when trying to separate Undisturbed Forest from Surface-Mined Under Reclamation areas.

The best result achieved when types were classified into eight groups was attained using data obtained with a 1 millimetre diffuse aperture. This finding indicates that the 1 millimetre diffuse aperture is superior for this type of terrain cover classification. Also, when the results in Table 2 were considered from the viewpoint of Undisturbed vs Disturbed Forest, it is noted that only two strata have been misclassified for an estimated error rate of 1.7 percent. Thus, little improvement with respect to this level of interpretation is found when both 1 and 3 millimetre apertures are used to gather data.

CONCLUSIONS

Results of this study indicate that, using manual spot densitometry values derived from multi-temporal 1:24 000 color infrared aircraft photography, areas as small as 1 hectare in the Cumberland Plateau in Kentucky can be accurately classified into one of the eight ground cover types defined in this study. When distinguishing between Undisturbed and Disturbed Forest areas is the sole criterion of interest, classification results are highly accurate if based on imagery taken during foliated ground cover conditions.

Multi-seasonal imagery analysis was superior to single data analysis when the eight project cover types are considered. Transparencies from prefoliated conditions give better separation of conifers and hardwoods than do those from foliated conditions.

Evidence also indicates that the 1 millimetre diffuse aperture is the best aperture for the more specific level of interpretation. Little difference among apertures is found when areas are to be classified as either Undisturbed or Disturbed Forest.

This study indicates that reansonably accurate classification of areas in the Cumberland Plateau into useful cover types can be made using manual densitometry data obtained from multi-temporal 1:24 000 scale color infrared and multispectral imagery. Since rugged topography makes field surveys in this area difficult, the methodology herein described may prove helpful in monitoring reclamation of surface mined areas and forest damage due to mining, logging, fire, and other potentially destructive events.

It is felt by the authors that such a system might be well suited for use by distant field offices where no ready access exists to expensive multispectral scanners or to computers. Since labor and travel is quite expensive when making intensive on the ground inspections, this system would allow field personnel the flexibility of segregating potential trouble areas prior to field inspection. Multi-temporal data could be generated by office technicians from low-cost overflight transparencies and converted to computer mode for central office analysis.

Such a system would allow the segregation of "trouble" areas for expensive ground inspections with possible cursory examination of areas of no change or those changing as expected.

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