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BIOGRAPHICAL SKETCH

Darrel Williams is a Forestry Specialist with the Earth Resources Branch at NASA's Goddard Space Flight Center, and discipline scientist for GSFC's Information Transfer Laboratory (Intralab). He received his B.S. and M.S. in Forest Resources from the Pennsylvania State University. Since 1972 his research has involved digital image processing of remotely sensed data, as applied to the Agriculture/Forestry/Range discipline. He is a member of the ASP, SAF and AFA.

ABSTRACT

An investigation was undertaken to determine if a consistent stratification of a Southern pine forest could be obtained by using Landsat multispectral scanner data to assess crown closure. Winter and summer Landsat scenes of the North Carolina coastal region were analyzed individually and then registered and merged to take advantage of temporal changes in the forest canopy. Three levels of pine crown closure were accurately delineated. The applicability of this stratification as supplemental input to a forest inventory system is also discussed.

CONTENTS

ILLUSTRATIONS

TABLES

A CANOPY-RELATED STRATIFICATION OF A SOUTHERN PINE FOREST USING LANDSAT DIGITAL DATA

INTRODUCTION

Since Landsat multispectral scanner (MSS) data became available in July of 1972, numerous investigations have been undertaken to analyze its potential for operational applications in forestry. The results, in general, have been similar to those reported by Kan and Dillman (1975); namely, that Landsat MSS data can be effectively used to separate the forest features of softwood, hardwood, and regeneration with accuracies in the order of 70 to 80%. One noteworthy investigation went a step further however, and demonstrated the utility of incorporating Landsat data into the first stage of a multistage sampling scheme designed to estimate timber resource inventories. The predominately old-growth timber in the Plumas National Forest in California was stratified into subclasses related to timber volume using photointerpretation and computer processing of Landsat data, and this approach resulted in equal precision in estimation at a 44% cost savings in comparison to conventional methods (Nichols et al., 1974). Thus, using Landsat data, major economic benefits will be realized in areas where the forest can be consistently subdivided into strata prior to sampling, such that each stratum is more homogeneous with respect to the variable being measured.

Using conventional aerial photography, variables such as tree height, crown diameter, crown closure, crown area and the number of trees per unit area have been measured and used by forest-land managers to obtain reliable estimations of timber volume (Thorley, 1975). However, assessment of the canopy-related variables is the only feasible approach to a consistent stratification using Landsat data, particularly in view of the 80 meter resolution. Thus, an investigation at GSFC's Intralab was undertaken to determine if a consistent stratification of a Southern pine forest could be obtained by using Landsat MSS data to assess crown closure.

THE STUDY AREA

A 24,300 hectare (60,000 acres) commercial forest in North Carolina's Southern Pine Region was chosen as the study area (Fig. 1). Intensive forest management practiced in the study area for several years has resulted in a full spectrum of forest cover conditions, such as clearcuts, various stages of growth following artificial regeneration of pine, and natural stands of both pine and hardwood. Black and white, color, and color IR aerial photography were available, as well as detailed maps and records showing stand age and species composition by compartment.

METHODS

Winter (26 Feb. '74/ID# 1583-15100) (Fig. 1) and summer (30 Aug. '73/ID# 1403-15134) Landsat-1 data were analyzed individually and then registered geometrically and merged in order to take advantage of temporal changes in the forest canopy. Computer processing was accomplished using the Penn State ORSER system (McMurtry et al., 1974), with the standard analysis approach of selecting training areas, obtaining spectral signatures and other statistics for these areas, and then classifying the entire study area based upon these statistics. Geometric registration of the two Landsat scenes was accomplished using the SMIPS/VICAR system (Moik, 1976).

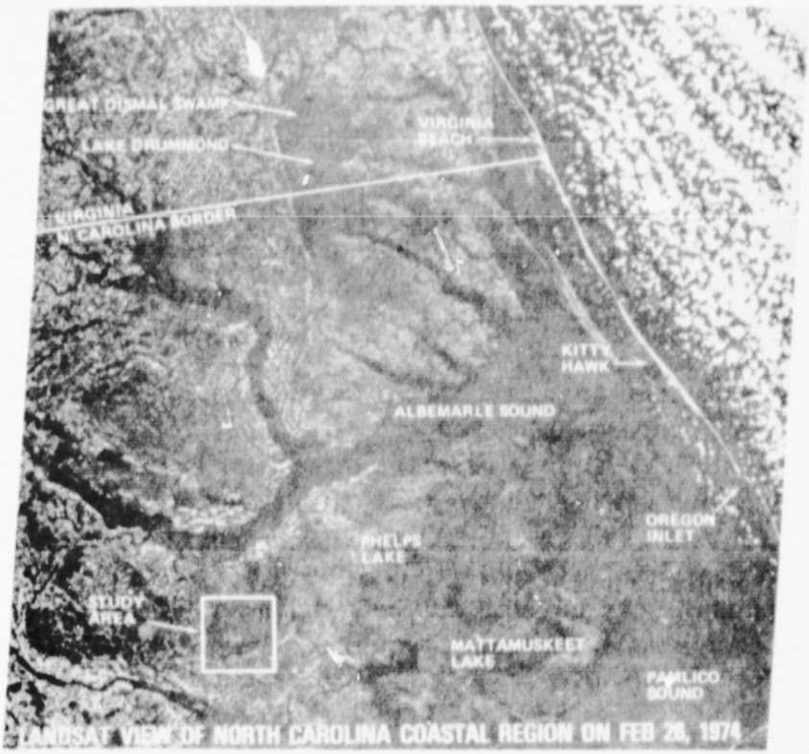

Figure 1. A Landsat View of the North Carolina Coastal Region on Feb. 26, 1974. (NOTE: The original was the standard 1:1,000,000 color composite.)

RESULTS

WINTER MSS DATA

As expected, the hardwood and pine forest canopies had quite distinctive spectral characteristics in the winter scene. Spectral signatures were also extracted for clearcuts and areas of pine regeneration. All attempts to subdivide any of these broad categories into spectrally separable subcategories related to crown closure or other stand characteristics were unsuccessful using the winter data.

SUMMER MSS DATA

Next, the 30 Aug. '73 Landsat data were analyzed, and to the extent possible, the training areas selected in the winter scene were again used. The extraction of separable hardwood and pine spectral signatures, straightforward in the winter scene, was rather difficult to obtain from the August data. This was not totally unexpected since the difference in spectral reflectance characteristics should be greatest when these is no hardwood foliage reflecting incoming radiation. As in the winter scene, signatures were also extracted for clearcuts and areas of pine regeneration. It should be noted that the spectral reflectance and standard deviations for all categories were higher for the August data than the February data, primarily because a higher sun angle results in greater illuminance of the summer scene, and because of the abundance of lush vegetation (e.g. grasses, weeds, hardwood seedlings and stump sprouts) with nearly complete foliar development.

Again, attempts were made to further stratify the forest canopy. Photointerpretation of the various forms of available aerial photography revealed varying degrees of pine crown closure which might be discernible using Landsat MSS data. Three different categories of crown closure were outlined on the aerial photography, and each was named and defined as follows:

<u>closed canopy pine</u> — a dense, homogeneous crown cover obscuring all ground vegetation.

<u>partial pine canopy closure</u> — crowns smaller in size, such that small openings in the crown canopy exist, and some ground vegetation would therefore be sensed by an airborne scanner.

<u>open canopy pine</u> — crown development such that nearly equal amounts of forest canopy and ground vegetation would be sensed by an airborne scanner.

Several training areas for each new category were selected and statistical analyses performed. This time the spectral signatures for each pine subcategory were statistically separable. The signatures revealed a rather interesting relationship in that the response differences between subcategories were minimal in MSS bands 4 and 5, but there was an increase in reflectance in MSS bands 6 and 7, as the canopy became more open. This increase in spectral reflectance can be explained by the increased influence of the lush ground vegetation prevalent in the August scene.

Although this appraisal of crown closure is not a direct measure of individual tree variables, it could allow a relative assessment of average tree size and/or the number of trees per unit area. By combining this type of information with existing records and observing the closure advancement over time, forest-land managers may be able to draw conclusions concerning the growth rate and quality of forest stands. In addition, this stratification of the pine population could be used to obtain a more representative sample for timber inventory estimates.

Consider, for example, the widely accepted sampling approach known as stratified random sampling. In this statistical technique, a population is subdivided into strata prior to sampling, such that each stratum is more homogeneous with respect to the population variable being assessed. A random sample is then taken from each stratum, often with the sampling fraction proportional to each stratum's share of the entire population. In comparison to a simple random sample, this approach usually has the advantage of maintaining equal precision in estimation at a lower cost. A cost reduction is realized because the stratification optimizes the selection of representative samples so that fewer ground plots are generally needed.

TEMPORAL MSS DATA

In the final stage of analysis, MSS data from the two Landsat scenes were registered geometrically to yield 8 channels of temporal data. In addition to the training areas previously selected, statistics were obtained for a forested site which had burned during the six month time lapse between August and February. Forest stands which were harvested, or otherwise destroyed during the six month interval, were expected to have unique spectral signatures because of the lush vegetation present in August and the lack of vegetation in February. This assumption was verified when a classification of the study area was performed using temporal spectral signatures. Figure 2 is a portion of the computer classification of the study area using Landsat temporal data. It shows all of the categories delineated during the investigation. Table 1 summarizes the advantage of using temporal data.

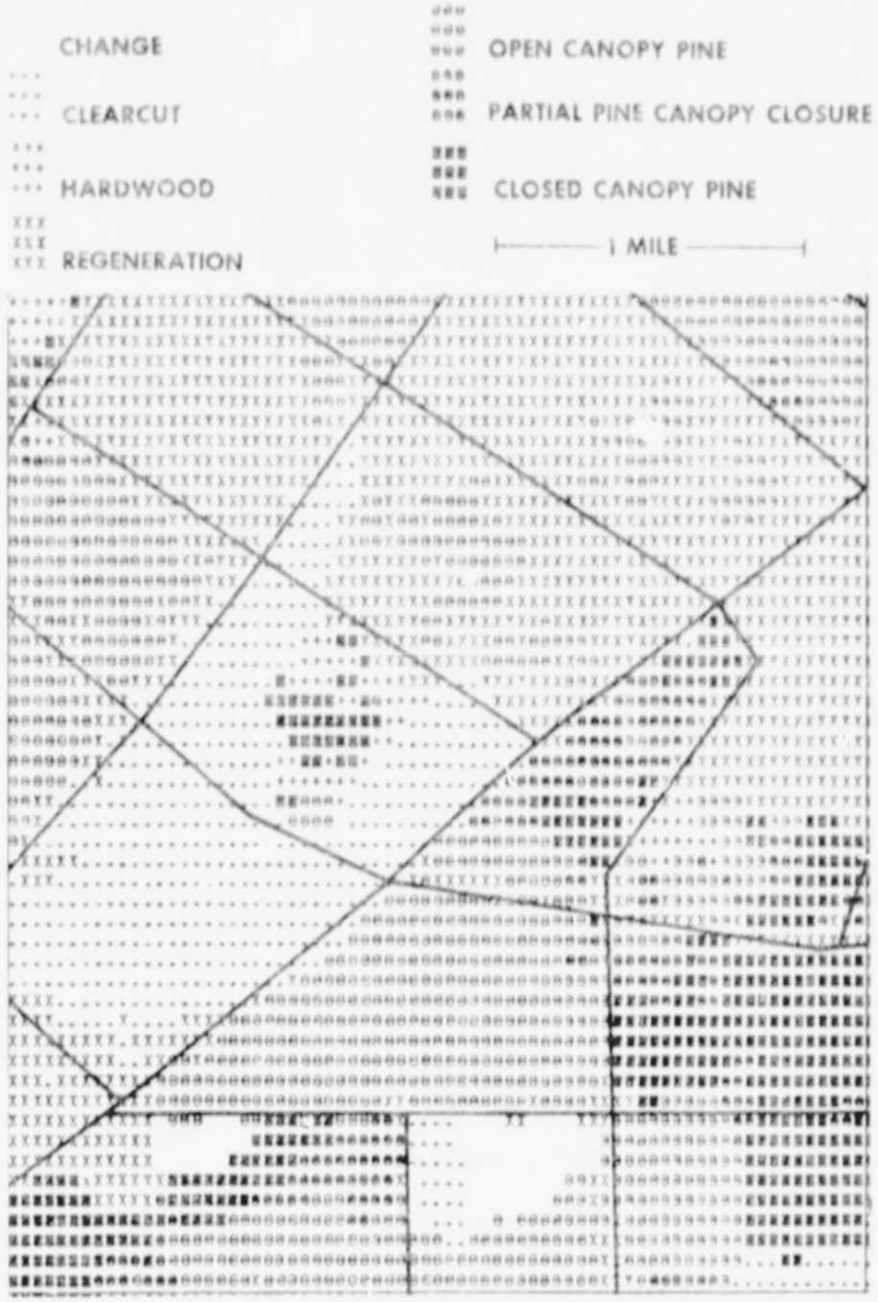

Figure 2. A Portion of the Computer Classification of the Study Area Using Landsat Temporal Data.

Table 1

A Summary of the Categories Delineated Using Winter, Summer and Temporal Data Sets

Category	Category Delineation		
	Feb 74	Aug 73	Feb 74 + Aug 73
Hardwood	YES	NO	YES
Closed Canopy Pine	NO*	YES	YES
Partial Crown Closure	NO*	YES	YES
Open Canopy Pine	NO*	YES	YES
Regeneration	YES	YES	YES
Clearcut	YES	YES	YES
Change (veg. to clearcut)	NO	NO	YES

*An overall pine category was extracted using 26 Feb. '74 data, but a breakdown into meaningful subcategories was not possible.

In reference to the table, the following observations and/or conclusions can be made:

(a) The separation of hardwood and pine, achieved mainly with February '74 data, and the pine category breakdown, achieved only with the August '73 data, were both accomplished using temporal data.

(b) Change detection (e.g. from forest vegetation to clearcut) can easily be obtained from the temporal data, allowing rapid updates in harvesting activities, or catastrophic events such as fire.

(c) Analysis of temporal data results in a higher order classification, as more vectors (i.e. 8 vs. 4) are incorporated into the decision-making process. Thus, computer analysis of temporal data should result in improved classification accuracy, as long as care is taken to insure proper registration of the data.

RELIABILITY OF LANDSAT CLASSIFICATION

The final phase of the investigation was concerned with determining the reliability of category delineation using Landsat data. Color and color IR aerial photography, which provided coverage of two-thirds, and the remaining one-third of the study area, respectively, were interpreted and compared with the computer classification results. There are problems with such comparisons however, because photointerpreter delineations should not be considered as "absolute ground truth". Variables are always involved due to interpreter fatigue, his ability to detect gradual changes in cover types and his ability to make consistent decisions. In addition, differences may occur due to Landsat's "averaging of conditions" over 1.1 acre samples versus high resolution photography where individual tree crowns may be observable. For these reasons, comparisons should be expressed in terms of the percentage of "agreement", and not the percent "correct".

The general procedure used to compare the aerial photography with the Landsat classification was: (a) photointerpreter delineation of categories using the previously selected training areas as a reference; (b) transferral of these delineations onto mylar which was then overlaid onto the computer classification; and (c) comparison of the two classifications at 232 randomly located points (i.e. slightly more than a 1% sample). Table 2 summarizes the results of this comparative effort. The photointerpreter classifications appear across the top and the computer classification of Landsat data appears along the left-hand side of the table. The numbers on the diagonal, running from upper left to lower right, represent those pixels which were in 100% agreement. All remaining numbers indicate those points of comparison which did not agree. For example, reading across the first row, labeled hardwood, one can see that of the 32 randomly selected pixels classified as hardwood by the computer, 30 agreed with the photointerpreter classification, while 2 pixels were classified differently by the photointerpreter; namely one each into the partial and open canopy pine categories. This is expressed as a 94% agreement for the hardwood category. By summing the numbers on the diagonal (162), and dividing by the total number of random comparisons (232), the overall agreement for all categories was calculated to be 70%. For individual categories, the percentages of agreement range from a low of 54% for clearcut, to a high of 94% for hardwood. These results look unfavorable and excellent, respectively. However, close examination of the table will reveal that of those pixels which do not agree, the vast majority fall into nearest neighbor categories on either side of the diagonal. This can be expected due to the subtle differences one must observe to distinguish between, for example, the more advanced stages of partial pine canopy closure and the less dense areas of closed canopy pine. In fact, the photointerpreter stated that consistent delineation within the pine classes presented the greatest problems, and in the zones of transition it was quite difficult to decide on the boundaries between classes. For certain neighboring categories, such as regeneration and clearcut, the percentage of "overlap" is quite high, and tends to degrade unjustifiably the computer classification results.

Table 2

Results of Comparison Between Air Photo Interpretation and Computer Classification of Landsat Digital Data. (NOTE: The computer classification was arbitrarily chosen as the basis of comparison in the tabulation of results below.)

Photointerpreter Classification of Aerial Photos

Computer Classification of Landsat Data	Hard-wood	Closed Canopy Pine	Partial Pine Canopy Closure	Open Canopy Pine	Regen-eration	Clear cut	Com-puter Pixel Count	% Agree-ment
Hard-wood	30		1	1			32	94%
Closed Canopy Pine		9	5	2			16	56%
Partial Pine Canopy Closure		6	15	5	1		27	56%
Open Canopy Pine			3	53	5		62	87%
Regen-eration		1	1	17	37	7	63	59%
Clearcut					15	18	33	54%
							162/ 232	70%

REGROUPING OF RESULTS

In view of the points made in the foregoing discussion, it is appropriate to regroup the results presented in Table 2. Since the greatest potential for error was the subjectiveness involved in delineating the various pine classes, the four pine-related classes of closed, partial, open and regeneration were combined into one class called pine. Table 3 below shows the results of this regrouping effort. No new photointerpretation was done; the results were just regrouped as indicated by the bold lines in Table 2.

Table 3

Results of Regrouping the Data Presented in Table 2

Manual / Computer	Hardwood	Pine	Clearcut	Computer Pixel Count	Percent Agreement
Hardwood	30	2		32	94%
Pine		160	7*	167	96%
Clearcut		15*	18	33	54%
				208/ 232	90%

*These pixels of disagreement were between the nearest neighbor categories of regeneration and clearcut. See Table 2 for details.

Once again, the values on the diagonal represent agreement. In this case, the overall agreement is 90%, while the agreement for the individual categories of hardwood, pine, and clearcut are 94%, 96%, and 54%, respectively. It is obvious that the regrouping did not alter the results for hardwood or clearcut, but the level of disagreement in the clearcut category is more glaring. This discrepancy can be explained by the fact that the color and color IR photography was flown in February and April of 1975, approximately 18 to 20 months after the Aug '73 Landsat coverage and about a year after the Feb '74 overpass, which is ample time for regeneration to have been initiated in this intensively managed commercial forest.

SUMMARY

A stratification of a Southern pine forest, based upon an assessment of crown closure, was obtained by computer analysis of summer and temporal Landsat digital data. Computer processing of Landsat data provides an important element of consistent, repeatable stratification based upon spectral characteristics, thus avoiding the inherent variability in human decision-making. The reliability of the classification in this investigation was verified by a comparison with aerial photography, and the agreement was in the order of 90%. Similar demonstrations of successful stratifications of forests would be a giant step toward establishing Landsat as a bona fide operational alternative for forest-land managers.

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