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Forest land use classification from ERTS-1 imagery

Elvin E. Birth

To the Graduate Council:

I am submitting herewith a thesis written by Elvin E. Birth entitled "Forest land use classification from ERTS-1 imagery." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

John C. Rennie, Major Professor

We have read this thesis and recommend its acceptance:

E. R. Buckner, G. R. Wells

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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We have read this thesis and recommend its acceptance:

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G. R. Wells

Accepted for the Council:

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Vice Chancellor
Graduate Studies and Research

FOREST LAND USE CLASSIFICATION FROM ERTS-1 IMAGERY

A Thesis

Presented for the

Master of Science

Degree

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Elvin E. Birth

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Elvin E. Birth

ABSTRACT

The preparation of thematic maps and tabular summaries defining the maps is basic to forest land use decision making. Because objectives differ according to the decision being made, raw input data should be used to prepare the maps and tables. The Earth Resource Technology Satellite (ERTS-1) collects data over large areas and the data are available to any prospective user.

Minimum collection of ground truth and handling of both ERTS-1 and ground data with a readily available set of computer programs permits classification of land use, forest types and volume classes. Orientation with the ground can be maintained in order to prepare the maps. Frequencies of classifications can be used to prepare tabular summaries.

The classification system used consisted of a computer mapping program, a discriminant analysis classification program and chi-square testing of results. The system was complemented by a forest inventory program. In the discriminant analysis procedure, an option was used which permits user participation by assigning "prior probabilities."

A test of the system in Polk County, Tennessee, using ERTS-1 multispectral scanner channels 6 and 7 data acquired on October 15, 1972, showed acceptable results in classifying

land use and forest type. Results of classifying volume were less acceptable because volume is a continuous function and discriminant analysis is applicable to discrete functions.

The use of aircraft imagery as ground truth for land use classification was acceptable. Aircraft imagery for forest type classification was also acceptable, but forest type classification from ground truth was better when both sets of results were analyzed by the chi-square test of a contingency table.

An important conclusion drawn was that ERTS-1 digital tapes should have been used instead of using photographic reproductions in a microdensitometer. Each generation of data results in some degradation. The most important conclusion drawn was that prospective users of ERTS-1 imagery can construct a system from available computer programs and prepare thematic maps and tables. It is also possible to exert a degree of user control into the system.

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CHAPTER I

INTRODUCTION

The role of the forest land manager is to make decisions regarding forest land use. He should have at his disposal a set of thematic maps, i.e., maps with a theme. With the maps he should have a set of tabular or other statistical summaries defining the several classes shown on the thematic maps. A complete description of forest land requires that the tabular summaries and thematic maps be correlated with geographic location.

The use of forest land may be viewed from more than one objective by the decision maker; thus, the maps and tables should be prepared from raw data as opposed to accepting at face value classifications prepared for some other objective (Anderson, 1971). One of the most common objectives is forest inventory expressed in terms of quantities and qualities of wood products. In its historical sense, forest inventories of large areas have been used to provide for the protection of existing forest resources. Currently, forest inventory is used extensively to plan utilization, development and renewal of forest resources (Kabzems et al., 1972). These purposes may be served efficiently on small tracts of land by ground-based sampling techniques. As the need arises to update inventories more frequently (Neff, 1973), or as the area of land being considered becomes larger in size, it becomes necessary to use additional sources of data that are readily available (Wobber, 1972) and will meet the requirement of raw data. Some objectives of any inventory can be met by use of the raw data in a relatively simple and efficient classification scheme.

The work reported here is an evaluation of the use of ERTS-1 imagery in forest inventory when combined with ground sample data and aerial photography. This work is essentially a test using readily available data, sampling techniques, analysis procedures and data processing.

The threefold objective of this work is to: (1) classify land in (a) nonforest, (b) forest species composition and (c) cubic foot volume per acre classes, (2) test correlations of several sets of raw data with ground conditions and with each other, and (3) develop a systematic and readily available procedure for classification and analysis that may be used to satisfy objectives (1) and (2) or other similar objectives.

CHAPTER II

LITERATURE REVIEW

National, regional and area planning for the development and orderly use of resources has been accompanied by schemes for efficiently handling the vast amount of resource data that may be collected for any large area (Anderson, 1971). Concurrently, systems for the collection of data such as the Earth Resources Technology Satellite (ERTS-1) (Wobber, 1972) and for the correlation of remotely sensed data to ground conditions (Landgrebe, 1972) have also been presented.

In forest land management, aerial photography at medium scales has been used as a common source of data for classifying forest stands by condition class, forest type and volume class. The classification from photographs is followed by on-the-ground sampling to measure volume, type or condition class which are then expanded in proportion to the area in each class as measured on the photographs (Stage and Alley, 1972) and summary tables prepared for the whole area. The current trend to integrate forest land management with overall land and resource development within large but well defined areas has created the need for "in-place" inventories (Neff, 1973) which may be revised easily and adapted quickly to changes, whether or not the changes are directly related to the forest resource.

In order to handle changes over large areas efficiently, automatic data processing (ADP) techniques have either been developed for or adapted to forest land management (Neff, 1973). For area wide forest inventory, sampling techniques have improved to the point of making efficient use of satellite imagery (Langley, 1969). The "in-place" inventory of smaller areas or subunits of forest land still relies on the use of medium-scale aerial photography (Stage and Alley, 1972), though the photointerpretation may be incorporated in an ADP system.

The availability to the public of large quantities of satellite imagery (Wobber, 1972) has not been accompanied by development of systems for classifying the smaller subunits of forest land which are the basis for in-place inventories, though the Laboratory for Applications of Remote Sensing (LARS) system apparently has such capabilities (Landgrebe, 1972). Also, the procedures used for classifying remotely sensed data are commonly specially written routines within an extensive ADP system and are not readily available or adaptable to users outside the system. One classification procedure which has been known for many years (Snedecor and Cochran, 1967) but little used in either forest inventory or handling remotely sensed data is discriminant analysis.

Provided cases can be classified into discrete classes, the discriminant analysis statistical technique can be used to extrapolate new cases into one of several classes (McCutchan and Schroeder, 1973). Discriminant analysis is available to many users as a procedure within the Statistical Analysis System (Service, 1972), a package computer program which has been installed at more than 50 computer centers in the United States and several centers in other countries.

CHAPTER III

TEST SITE

The test site for this study was Polk County, Tennessee, which is located in the southeastern corner of the state. The eastern three-fourths of the county is mountainous, being in the Appalachian Mountains, while the western fourth is gently rolling farmland in the Great Valley.

Polk County was chosen as a test site because it has extensive forested areas suitable for this study and two rivers traversing it, which could be used for registration or the matching of exactly corresponding points on maps. Also, there exists considerable information on its forest resource (T.V.A., 1970).

CHAPTER IV

DATA SOURCES

I. ERTS-1 IMAGERY

Satellite imagery had to be relatively cloud-free at the test site to be usable. Also, to meet a N.A.S.A. contract schedule, only imagery acquired by the satellite before 31 March 1973 was considered. The only set of imagery which met these specifications was acquired on October 15, 1972, with central point coordinates of 34°33'N and 83°57'W (observation identifier 1084-15433). It consisted of $9\frac{1}{2}$ inch black and white negatives of four multispectral scanner (MSS) bands: .5 µm to .6 µm, .6 µm to .7 µm, .7 µm to .8 µm and .8 µm to 1.1 µm. Ground resolution is approximately 2 acres per ERTS-1 element of resolution.

II. SUPPLEMENTARY AIRCRAFT IMAGERY

Medium altitude aircraft imagery was flown on 23 March 1973 by N.A.S.A. using a C-130 aircraft at an altitude of 23,600 ft. (Mission 230). The flight line was in a north-south direction from 35°2.3'N, 84°30.0'W to 35°17.0'N, 84°30.0'W. In addition to infrared scanner imagery (8 µm to 14 µm), four Hasselblad 70 mm cameras were used to obtain coverage with the following film/filter combinations:

	Mean photo scale
Kodak film type #2402 with Wratten filter #25	1:140000
Kodak film type #2402 with Wratten filter #57	1:140000
Kodak film type #2443 with Wratten filter #12	1:140000
Kodak film type #2424 with Wratten filter #89B	1:140000

III. GROUND TRUTH

Fifty-six stands were located on the ground as described under "Procedure" and sampled for type and volume with nine Basal Area Factor 10 (BAF 10) prism points within each sample stand.

CHAPTER V

PROCEDURES

The aircraft imagery was the basis for locating ground plots to obtain field data. Both aircraft imagery interpretations and ground data were used to evaluate the ERTS-1 imagery for use in forest inventory.

I. INTERPRETATION OF AIRCRAFT IMAGERY

Enlargements of the three rolls of black and white photo images were prepared to a size convenient for handling and interpretation. After three days of cursory ground truth collection, it appeared that the forest type could be best interpreted from the #2402 film with #25 filter (2402/25). Three types--pine, hardwood and mixed pine-hardwood--were interpreted on the photographs using a Zeiss Stereopret.

Two scale determinations were made for each photograph using points that could be identified on T.V.A. and U.S.G.S. $7\frac{1}{2}$' quadrangle topographic maps. The Stereopret pantograph was set such that mean photo scale would be enlarged to 1:24,000. Where types were correlated with elevation, the use of mean photo scale for the entire strip would introduce a bias, but examination of the photographs indicated that each of the types existed in roughly equal proportions at all elevations. The result of using mean photo scale was that a portion of the stand areas were inflated in area and an approximately equal portion of the areas were deflated in area.

On the 2402/25 imagery there was little or no difference between types in terms of texture, but the tone for the different types was substantially different. The major streams and a portion of the cleared areas had a distinct tone and could be elminated from the forest acreage. After the interpretation by the three forest types and non-forested areas, each of the interpreted photo models was matched with the appropriate $7\frac{1}{2}$' quadrangle topographic map. It was noted that rivers and power-line rights-of-way were accurately mapped, while roads and fields were less accurately located.

The #2424 film with #89B filter (2424/89B) showed a great deal of texture, including individual tree crowns or groups of crowns; there was little or no tonal variation that appeared to be correlated with type. Nonforested areas, in particular cleared fields, were much more distinct than on 2402/25 imagery, while clear-cut forested areas were less distinct except for reduced texture.

After registration with the 2402/25 imagery, by matching control points, the 2424/89B imagery was interpreted into five different classes of cubic foot volume per acre as follows:

Class 1 -- less than 201 cu. ft. per acre

Class 2 -- 201 to 1000 cu. ft. per acre

Class 3 -- 1001 to 1400 cu. ft. per acre

Class 4 -- 1401 to 2200 cu. ft. per acre

Class 5 -- more than 2200 cu. ft. per acre

Volume class interpretation was done at photograph scale on 0.15" x 0.167" grids representing 10.2 acres on the ground and recorded on a grid chart at 1:24,000 scale and on a list by volume class and forest type. The volume classes used were derived from the T.V.A. July, 1970, Forest Inventory Statistics for Polk County. However, the classes are broad and could have been defined by a few days of reconnaisance level inventory had there been no preexisting volume estimates. The principal use for these classes was to assign a greater intensity of ground plots in the heavier stocked classes where greater within class variance was anticipated. Class No. 3 was defined to include within its range the mean cubic foot volume according to T.V.A. (1970).

Subsequent to the collection of field data, forest type was interpreted from the #2443 film with #12 filter (2443/12). The interpreter was not recently familiar with the forest types of this portion of Polk County. The types were plotted on T.V.A. $7\frac{1}{2}$' quadrangle topographic maps and then transferred to tracing paper.

II. SELECTION AND LOCATION OF GROUND SAMPLES

The desired sampling error (E) at the within test site stage of the inventory was set at 5 percent with a probability of two times out of three. Assuming that the coefficient of variation (CV) of photo-interpreted volume classes would be 40 percent and using formula 1, 64 sample stands were designed to be ground inventoried.

$$\text{Estimated sample number} = (CV)^2/(E)^2 \qquad (1)$$

The distribution of the samples was designed to be equal within forest type but weighted proportional to photo-interpreted volume within volume classes.

Nineteen sample stands were selected in each photointerpreted type by list sampling within the first four volume classes. All six stands interpreted as volume class five were selected for sampling. From the total of 63 sample stands, 56 were measured. The remaining seven stands had been altered after the October 15, 1972, ERTS-1 flight and were excluded from the sample. Since the position of the stand on the list was registered with a specific position of the chart, it was possible to locate these stands on the ground, particularly since both 2424/89B and 2402/25 photography were available to assist in identifying the stands and their location in the terrain.

III. INVENTORY OF SAMPLE STANDS

Within each sample stand, 9 prism points were established from which a subsample of trees to be measured was drawn with 3P sampling. Grosenbaugh (1971) describes this design as APT-3.

The ground inventory consisted of:

a. Locating the center of selected stands.

b. Establishing the central point of a 3-point by 3-point grid with intervals of 2.5 chains; i.e., 9 points on a 5-chain by 5-chain land area.

c. Predicting merchantible heights to a 4" top diameter outside bark in terms of 8-foot sections (half-log intervals) of prism-selected (BAF 10) trees for comparison with the random number list prepared for selecting sample trees.

d. Measuring those trees, including culls, with estimated height equal to or greater than the corresponding random 3-P number and also measuring those trees greater than the maximum height designed in the 3-P inventory to be sampled by comparison with the random number list. A Wheeler pentaprism optical caliper was used to measure the diameter outside bark at numerous points on the merchantible portion of the bole. An engineer's 100 foot tape and clinometer with percent scale was used to measure the length of bole between diameter measurements. The sets of diameter-length measurements were eventually used to calculate cubic foot volume outside bark.

The ground inventory of a 5-chain square area within a stand tended to avoid the edges of stand because the interpretation was based upon a grid approximately 10 chains square. This approach was intended to be comparable to the ERTS-1 imagery microdensitometer scanner-computer system, which was expected to "slice" at levels rather than interpret a continuum of types and volume classes.

IV. SUMMARIZATION OF FIELD DATA

The basal area of pines and hardwoods in a stand was proportional to the number of stems of each species group selected with the BAF 10 prism. When 70 percent or more of the stems were hardwood or pine, the stand was assigned to the hardwood or pine type, respectively; otherwise, it was classified as being in the mixed type (Figure 1).

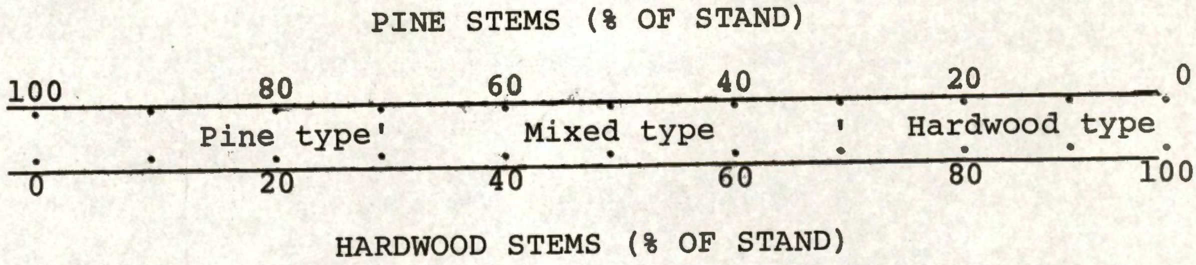

Figure 1. Construction of three forest types from two species groups.

Assignment of ground-visited stands to volume classes was on the basis of formula 2 (Grosenbaugh, 1973) for a point-3P inventory:

$$\text{Volume (cu.ft./acre)} = \frac{BAF}{NP} \times \sum_{1}^{NP} \Sigma H \times \frac{1}{n} \times \sum_{1}^{n} \frac{V}{BA \times h} . \quad (2)$$

Where BAF = basal area factor of prism used in selection of trees, 10 sq.ft./A. in this work

NP = number of sample points per stand, 9 in this work

ΣH = aggregate estimated merchantible height of all prism selected trees at a sampling point

n = number of 3-P selected trees on which stem measurements were acquired

V = merchantible cubic foot volume of 3-P selected and measured tree

BA = basal area of 3-P selected and measured tree

h = height of 3-P selected and measured tree to a 4" top

V. INTERPRETATION OF ERTS-1 IMAGERY

The portion of the four bands of ERTS-1 imagery covering Polk County was scanned with a Technical Operations Scandig Model 25 high speed, digital, x-y scanning micro-densitometer. At sampling points 100 μm in diameter, representing 2.5 acres on the ground, on a 100 μm x 100 μm grid, the optical density was determined on a scale having 256 density levels. The output was stored on magnetic tape with a Kennedy Model 3110 9-track digital tape recorder. Using the computer program OPSCAN (Peach, 1971) gray-scale maps were produced for registration of the bands of imagery, location of ground plots with respect to ERTS-1 imagery and determination of density levels on each band for plot locations. MSS bands 4 and 5 showed too little detail for registration and were discarded.

Two prominent water bodies were used to register the plot location map with the computer maps. Ground plot locations were transferred from T.V.A. $7\frac{1}{2}$' maps to the computer maps. The gray-scale level was read for the element into which each ground plot was located.

CHAPTER VI

ANALYSIS OF DATA

Since the problem was one of classification rather than sampling and estimation, it was appropriate to use the chi-square analysis of a contingency table to test the hypotheses that our classifications, and therefore our thematic maps, were within some stated level of probability (Snedecor and Cochran, 1967). In each case, the null hypothesis was that classes interpreted from ERTS-1 imagery were independent from ground truth classes. Having used this test, the definitive tables or summaries describing the thematic map were then dependent upon the area assigned each class, with the total being within the stated level of probability.

Since the only set of input data available that covered the entire test site was ERTS-1 imagery, these input data were common to all the analyses undertaken, and other sets of input data were included with the ERTS-1 imagery data where appropriate. The gray-scale levels for the points on the ERTS-1 imagery computer maps (Peach, 1971) corresponding to ground plots were examined using discriminant analysis (Hope, 1968). To meet the first objective of the study, discriminant functions were developed to predict land use, species composition and volume class using the species composition and volume classes of the ground plots as training sets. In addition, it was desirable to test other possible correlations of data; i.e., the post-field work classifications of type and volume, in order to indicate where possible improvements in collection of data would result in an improvement of the validity of the final output map and tables. At the same time, it was desirable, in order to maintain an efficient process, to use the same analytic procedure for each of the tests; i.e., discriminant function analysis and chi-square testing.

CHAPTER VII

CLASSIFICATION SYSTEM

To this point, the system consists of:

a. Satellite imagery input,

b. Ground truth inventory input,

c. Computer handling of data,

d. Intermediate (aerial photography) data input, and

e. Discriminant function analysis and chi-square testing.

It is essentially a package system that is readily available to any user and is capable of accepting any one of many data input sources, provided the source can be registered with ERTS-1 imagery.

To this point, however, there is little opportunity for the user of the system to exercise any control over the system output. The only access to the system is through the design of the ground truth inventory and the selection or rejection of whole sets of intermediate input data. At this point it seems appropriate that when the user examines the systematic output, there will be opportunity for an interaction between the user and the system. Since the system itself is relatively simple, and since chi-square testing for validity is a common and widely used test of validity, it is convenient for most prospective users to inject further data and further analytic procedures which will result in final outputs that are of greater use to the decision maker.

The results of any test for correlation of ERTS-1 data and other input data are organized into a two-way table titled "Summary of Classification Performance Using Generalized Squared Distance" in the discriminant analysis routine (Service, 1972). In this table, rows are input data observations while columns are classifications from ERTS-1 data. Misclassifications are recorded off the diagonal, and each misclassification represents an element of the thematic map that will be labelled incorrectly. However, when the column total is equal to the row total for each class, the tabular summary of classes will be correct in spite of misclassification of individual observations. Calculation of chi-square for a contingency table (Snedecor and Cochran, 1967) will give high values for equal rows and columns, but some misclassifications and low values for poor classifications with unequal row-column totals.

Specifying prior probabilities is the tool which permits the user to inject control into the system and is an option available in the discriminant function routine. Reasons for assigning prior probabilities may vary. If the frequencies within classes in the population are unequal and samples are taken at random, there will be unequal numbers of observations in classes. In this case, prior probabilities are set proportional to numbers of observations, and frequency of classification is expected to be proportional to relative frequency in the population. There may be different levels of risk associated with misclassifications, in which case prior probabilities are assigned to minimize overall risks (Hope, 1968).

A chi-square test of the table "Summary of Classification Performance Using Generalized Squared Distance" (D^2) followed by a change in prior probabilities for successive runs will result in determining which of many possible formulas is most appropriate for classification. The criterion for classification is least D^2 (Appendix B) with one of the terms in D^2 being -2 ln (prior probability). The assumption must be that the formula and values appropriate to the control are also appropriate to the remaining elements of ERTS-1 imagery.

CHAPTER VIII

RESULTS AND DISCUSSION

In this work, there are three classifications using seven sets of input data (Appendix A). The first is classification of land use as open, forest and water (Table 1).

TABLE 1

DISCRIMINANT ANALYSIS PREDICTION OF LAND USE CLASS FROM ERTS-1 IMAGERY WITH ACTUAL CLASS FROM #2443 FILM WITH #12 FILTER AND PRIOR PROBABILITIES FROM NUMBER OF OBSERVATIONS

		Predicted Class				Prior
		Open	Forest	Water	Observations	Probabilities
Actual Class	Open	0	16	0	16	0.1882
	Forest	0	54	2	56	0.6588
	Water	0	7	6	13	0.1530
Predictions		0	77	8	85	1.0000

Chi-square = 24.49 with 4 degrees of freedom.
Probability of greater chi-square < 0.005.

The elements of the "forest" column are associated with submatrices described as forest type or volume class. The column "forest" is a prediction of the proportion of land area that is forested in the set of samples that would finally be used to "train" the computer for extrapolating thematic maps and summaries for the whole test site.

The number of digits in prior probabilities varies between tables because some of the classifications are more sensitive to changes in prior probabilities than others.

The probability of a correct classification of a resolution element in forest is 54/56 = 0.964, but the probability of an ERTS-1 imagery element being classified forest is 77/85 = 0.905. To achieve accurate tabular summaries, column probability should equal row probability for each class. To achieve accurate thematic mapping, probabilities of diagonal elements a_{11} through a_{nn} should approach the respective row probabilities. The nearest approach to equal probabilities of diagonal element and row totals is least probability of independence of actual and predicted. Calculated chi-square will be greatest when diagonal elements and row totals are equal.

By an iterative procedure, the user may adjust prior probabilities in the discriminant function routine in order to yield predicted classes approaching actual classes. Increasing the prior probability of any class--and decreasing the prior probability of at least one other class--will tend to increase total number of classifications or predictions in the column associated with the increased prior probability. By successive changes, column totals can be made to equal row totals, and the probability of correct number of predictions in each class will equal 1.0. The procedure is analagous to gaining experience as to the likelihood of any observation falling into a particular class. The iterative procedure for balancing row and column totals may be at the expense of reducing calculated chi-square of the complete set of classifications and increasing the probability of a greater chi-square to a significant level. In order to accept a set of classifications, dual criteria are necessary;

1. For tabular summaries, probability of a greater chi-square equal to or less than 0.05, and
2. For thematic map preparation, a row/column or column/row ratio equal to or greater than 0.90.

One result of assigning prior probabilities is shown in Table 2.

TABLE 2

DISCRIMINANT ANALYSIS PREDICTION OF LAND USE CLASS FROM ERTS-1 IMAGERY WITH ACTUAL CLASS FROM #2443 FILM WITH #12 FILTER AND PRIOR PROBABILITIES ASSIGNED

		Predicted Class				Prior
		Open	Forest	Water	Observations	Probabilities
Actual Class	Open	6	9	1	16	0.30888
	Forest	6	45	5	56	0.35792
	Water	3	3	7	13	0.33320
Predictions		15	57	13	85	1.00000

Chi-square = 25.79 with 4 degrees of freedom. Probability of a greater chi-square < 0.005.

Using the assigned probabilities in a training set for ERTS-1 classification improves overall accuracy of Land Use predictions with no change in significance level. Correct forest classification is 45/56 = P(0.8) of correct forest map elements.

The second classification is forest type from ERTS-1 using as actual classes the ground inventory (Tables 3 and 4),

TABLE 3

DISCRIMINANT ANALYSIS PREDICTION OF FOREST TYPE FROM ERTS-1 IMAGERY WITH ACTUAL TYPE FROM GROUND SAMPLES AND PRIOR PROBABILITIES FROM NUMBER OF OBSERVATIONS

		Predicted Type				Prior
		Hardwood	Pine	Mixed	Obs.	Probabilities
Actual Type	Hardwood	8	1	9	18	0.3214
	Pine	0	1	8	9	0.1607
	Mixed	4	0	25	29	0.5179
Predictions		12	2	42	56	1.0000

Chi-square = 12.05 with 4 degrees of freedom.
Probability of a greater chi-square < 0.025.

TABLE 4

DISCRIMINANT ANALYSIS PREDICTION OF FOREST TYPE FROM ERTS-1 IMAGERY WITH ACTUAL TYPE FROM GROUND SAMPLES AND PRIOR PROBABILITIES ASSIGNED

		Predicted Type				Prior
		Hardwood	Pine	Mixed	Obs.	Probabilities
Actual Type	Hardwood	12	2	4	18	0.247
	Pine	4	2	3	9	0.479
	Mixed	3	4	22	29	0.274
Predictions		19	8	29	56	1.000

Chi-square = 18.14 with 4 degrees of freedom.
Probability of a greater chi-square < 0.005.

photo interpretation from #2402 film with #25 filter (Tables 5 and 6) and the post inventory photo interpretation from #2443 film with #12 filter (Tables 7 and 8).

TABLE 5

DISCRIMINANT ANALYSIS PREDICTION OF FOREST TYPE FROM ERTS-1 IMAGERY WITH ACTUAL TYPE FROM #2402 FILM WITH #25 FILTER AND PRIOR PROBABILITIES FROM NUMBER OF OBSERVATIONS

		Predicted Type				Prior
		Hardwood	Pine	Mixed	Obs.	Probabilities
Actual Type	Hardwood	9	9	1	19	0.3393
	Pine	3	13	1	17	0.3036
	Mixed	6	11	3	20	0.3571
Predictions		18	33	5	56	1.0000

Chi-square = 5.17 with 4 degrees of freedom.
Probability of a greater chi-square < 0.50.

TABLE 6

DISCRIMINANT ANALYSIS PREDICTION OF FOREST TYPE FROM ERTS-1 IMAGERY WITH ACTUAL TYPE FROM #2402 FILM WITH #25 FILTER AND PRIOR PROBABILITIES ASSIGNED

		Predicted Type				Prior
		Hardwood	Pine	Mixed	Obs.	Probabilities
Actual Type	Hardwood	10	4	5	19	0.336
	Pine	4	7	6	17	0.221
	Mixed	5	6	9	20	0.443
Predictions		19	17	20	56	1.000

Chi-square = 5.12 with 4 degrees of freedom.
Probability of a greater chi-square < 0.50.

TABLE 7

DISCRIMINANT ANALYSIS PREDICTION OF FOREST TYPE FROM ERTS-1 IMAGERY WITH ACTUAL TYPE FROM #2443 FILM WITH #12 FILTER AND PRIOR PROBABILITIES FROM NUMBER OF OBSERVATIONS

		Predicted Type				Prior
		Hardwood	Pine	Mixed	Obs.	Probabilities
Actual Type	Hardwood	2	6	2	10	0.1818
	Pine	4	14	2	20	0.3636
	Mixed	3	13	9	25	0.4546
Predictions		9	33	13	55	1.0000

Chi-square = 4.38 with 4 degrees of freedom. Probability of a greater chi-square < 0.50.

TABLE 8

DISCRIMINANT ANALYSIS PREDICTION OF FOREST TYPE FROM ERTS-1 IMAGERY WITH ACTUAL TYPE FROM #2443 FILM WITH #12 FILTER AND PRIOR PROBABILITIES ASSIGNED

		Predicted Type				Prior
		Hardwood	Pine	Mixed	Obs.	Probabilities
Actual Type	Hardwood	0	4	6	10	0.1678
	Pine	5	11	4	20	0.3272
	Mixed	4	6	15	25	0.5050
Predictions		9	21	25	55	1.0000

Chi-square = 9.84 with 4 degrees of freedom. Probabilitiy of a greater chi-square < 0.05.

ERTS-1 forest type predictions with ground sample control show an improvement overall and in significance level when prior probabilities are assigned in the discriminant analysis.

Forest type predictions from ERTS-1 imagery with actual type from photointerpretation of black and white film must be rejected at significance levels less than 0.50.

With #2443 film, only 55 observations are used because an area photointerpreted as open had previously been interpreted on #2402 film as forest and a sample stand assigned.

Classification of forest type with #2443 interpretation as ground truth is acceptable when prior probabilities are assigned. The classification is not as good as when ground samples are used (Table 4, page 27).

The third classification is volume class from ERTS-1 using as actual classes the ground inventory (Tables 9 and 10)

TABLE 9

DISCRIMINANT ANALYSIS PREDICTION OF VOLUME CLASS FROM ERTS-1 IMAGERY WITH ACTUAL CLASS FROM GROUND SAMPLES AND PRIOR PROBABILITIES FROM NUMBER OF OBSERVATIONS

		Predicted Volume Class				Observations	Prior Probabilities
		2	3	4	5		
Actual Class	2-	2	0	7	0	9	0.1637
	3-	0	2	7	0	9	0.1636
	4-	2	0	22	3	27	0.4909
	5-	0	1	8	1	10	0.1818
Predictions		4	3	44	4	55	1.0000

Chi-square = 13.11 with 9 degrees of freedom. Probability of a greater chi-square < 0.25.

TABLE 10

DISCRIMINANT ANALYSIS PREDICTION OF VOLUME CLASS FROM ERTS-1 IMAGERY WITH ACTUAL CLASS FROM GROUND SAMPLES AND PRIOR PROBABILITIES ASSIGNED

		Predicted Volume Class				Observations	Prior Probabilities
		2	3	4	5		
Actual Class	2-	2	0	5	2	9	0.451
	3-	0	3	5	1	9	0.177
	4-	5	5	12	5	27	0.226
	5-	1	1	6	2	10	0.146
Predictions		8	9	28	10	55	1.000

Chi-square = 6.30 with 9 degrees of freedom. Probability of a greater chi-square < 0.75.

and photointerpretation from #2424 film w/89B filter (Tables 11 and 12).

TABLE 11

DISCRIMINANT ANALYSIS PREDICTION OF VOLUME CLASS FROM ERTS-1 IMAGERY WITH ACTUAL CLASS FROM #2424 FILM WITH #89B FILTER AND PRIOR PROBABILITIES FROM NUMBER OF OBSERVATIONS

		Predicted Volume Class					Observations	Prior Probabilities
		1	2	3	4	5		
Actual Class	1-	0	0	0	1	2	3	0.0536
	2-	1	0	1	0	5	7	0.1250
	3-	1	1	2	2	10	16	0.2857
	4-	1	1	2	13	7	24	0.4286
	5-	1	0	0	1	4	6	0.1071
Predictions		4	2	5	17	28	56	1.0000

Chi-square = 16.37 with 16 degrees of freedom. Probability of a greater chi-square < 0.50.

TABLE 12

DISCRIMINANT ANALYSIS PREDICTION OF VOLUME CLASS FROM ERTS-1 IMAGERY WITH ACTUAL CLASS FROM #2424 FILM WITH #89B FILTER AND PRIOR PROBABILITIES ASSIGNED

		Predicted Volume Class					Observations	Prior Probabilities
		1	2	3	4	5		
Actual Class	1-	0	0	1	1	1	3	0.045
	2-	0	1	5	1	0	7	0.141
	3-	1	2	5	5	3	16	0.317
	4-	1	6	4	13	0	24	0.435
	5-	1	1	0	2	2	6	0.062
Predictions		3	10	15	22	6	56	1.000

Chi-square = 22.88 with 16 degrees of freedom. Probability of a greater chi-square < 0.25.

Volume class predicted from ERTS-1 imagery by discriminant analysis with actual classes measured on the ground is not acceptable either with or without assigned prior probabilities.

Volume class 1 is excluded from Tables 9 and 10, pages 30 and 31, respectively, because there was only one ground sample that fell in this class.

Using photointerpreted volume classes as actual classes in discriminant analysis prediction of volume classes from ERTS-1 imagery does not result in acceptable levels of significance.

After the ground inventory was completed, the sample stands were assigned to a new set of volume classes based upon measured volumes because the designed classes had failed to yield predictions at an acceptable level of significance. The new volume classes are:

Class 1--0 to 1350 cu.ft. per acre
(mean = 909 cu.ft. per acre)

Class 2--1351 to 2000 cu.ft. per acre
(mean = 1686 cu.ft. per acre)

Class 3--more than 2000 cu.ft. per acre
(mean = 2565 cu.ft. per acre)

and are used as actual classes for ERTS-1 predictions as shown in Tables 13 and 14.

TABLE 13

DISCRIMINANT ANALYSIS PREDICTION OF POSTINVENTORY CLASS FROM ERTS-1 IMAGERY WITH ACTUAL CLASS FROM GROUND SAMPLES AND PRIOR PROBABILITIES FROM NUMBER OF OBSERVATIONS

		Predicted Volume Class 1	2	3	Observations	Prior Probabilities
Actual Class	1-	4	12	2	18	0.3214
	2-	2	20	1	23	0.4107
	3-	1	8	6	15	0.2679
Predictions		7	40	9	56	1.0000

Chi-square = 11.14 with 4 degrees of freedom.
Probability of a greater chi-square < 0.025.

TABLE 14

DISCRIMINANT ANALYSIS PREDICTION OF POSTINVENTORY VOLUME CLASS FROM ERTS-1 IMAGERY WITH ACTUAL CLASS FROM GROUND SAMPLE AND PRIOR PROBABILITIES ASSIGNED

		Predicted Volume Class 1	2	3	Observations	Prior Probabilities
Actual Class	1-	5	9	4	18	0.5940
	2-	7	11	5	23	0.1609
	3-	6	4	5	25	0.2451
Predictions		18	24	14	56	1.0000

Chi-square = 2.25 with 4 degrees of freedom. Probability of a greater chi-square < 0.75.

Postinventory definition of volume as three classes followed by discriminant analysis prediction of volume class resulted in a 0.025 significance level when prior probabilities were proportional to the number of observations. The level of significance dropped sharply when prior probabilities were assigned.

Of the seven correlations tested, three were partially or wholly acceptable (Table 15) as training sets for extrapolating Polk County, Tennessee, forest land use classes. Raw input data would be ERTS-1 imagery, MSS channels 6 and 7. Gray-scale observations would be measured by the Scandig Microdensitometer and processed by OPSCAN. Following the accumulation of the set of observations,

TABLE 15

SUMMARY OF ACCEPTABLE DISCRIMINANT ANALYSES
PREDICTIONS FROM ERTS-1 IMAGERY WITH
SEVERAL ACTUAL CLASSES

Training Set (Actual Class)	Classes	Prior Prob.	Significance Level	P of correct thematic map elements
	Land Use--			
#2443	Open	0.30888		0.38
film	Forest	0.35792		0.80
#12 filter	Water	0.33320	<0.005	0.54
	Forest Type--			
Ground	Hardwood	0.247		0.67
samples	Pine	0.479		0.22
	Mixed	0.274	<0.005	0.76
	Volume Class--			
Postinventory	0-1350			
volume	cu.ft./acre	0.3214		not
classification	1351-2000			
of ground	cu.ft./acre	0.4107		acceptable
samples	more than 2000			
	cu.ft./acre	0.2679	<0.025	

discriminant analysis using the formula and values (Appendix B) developed by the analysis procedure would be used in the discriminant analysis routine (Service, 1972) to classify each element of resolution.

In Table 15 the classifications that are acceptable are headed "training sets" since these are the sets of observations that would be used with discriminant analysis to extrapolate the tabular summaries and thematic maps for Polk County. For each of the classes within a set, the appropriate prior probabilities are listed. The significance level of each of the sets of observations is well within the 0.05 criterion. In the column headed "Probability of correct thematic map elements," the number is derived from the diagonal element/row total and is an estimate of the probability of a correct classification for any element of resolution from ERTS-1 imagery given its actual class. Interpretation of thematic maps would require that the interpreter be aware that [1.0--Probability of correct thematic map elements] of the elements within an actual class would be mapped as some other class.

No training set meets the dual criteria for acceptance as volume class predictor. However, the set of post-inventory volume classes is acceptable for preparation of tabular summaries when prior probabilities are proportional to number of observations.

CHAPTER IX

CONCLUSIONS

Preparation of thematic maps and tabular summaries requires the use of readily available raw input data for the entire area being studied. ERTS-1 imagery is one such source of data. The system described here for classification of forest land use is not unique. It is organized from individual procedures, one of which permits user participation. Use of the system with ERTS-1 imagery will classify (a) nonforest land, (b) forest type and (c) volume for each element of resolution of the imagery.

The same system, with the same analytical procedures, can be used to test two or more sources of ground truth and compare them with each other. For some purposes; e.g., land use, aircraft imagery alone may be sufficient for ground truth or actual class observations.

For observing ground classes to be used as ERTS-1 training sets, the 9 prism point cluster within a sample stand followed by STX processing (Grosenbaugh, 1971) is quite efficient. For broad classes of land use, small scale photography with #2443 film and #12 filter is acceptable. In this test, small scale photography with #2402 film and #25 filter was not acceptable for constructing a training set for forest type, nor was #2424 film with #89B filter acceptable for constructing a training set for volume class prediction.

The results with ground samples of volume, even when the set of observations was condensed into three classes, were not wholly acceptable. Volume classes are not discrete, and discriminant analysis is a discrete function statistical technique (McCutchan and Schroeder, 1973). A multivariate statistical technique that is appropriate for predicting continuous variables is multiple regression (Snedecor and Cochran, 1967) and it should be tested for volume predictions from ERTS-1 imagery.

As shown in Figure 1, page 15, forest type classes are not discrete. However, the boundaries between classes are distinct enough that imagery observations are classifiable as discrete classes. Volume classes can be described only as a continuum. Forest type classes are actually described by two continuums changing in opposing directions. In the vicinity of any boundary defined, the net change is rapid and the boundary serves well as a limit for two discrete classes.

Polk County terrain and soil differences are such that stands identified on the ground by type or volume class may be smaller in area than the elements of resolution used for either aircraft imagery interpretation or ERTS-1 imagery interpretation. In the case of aircraft imagery interpretation, more than half the cell area in a single type or volume class was the criterion to assign that type or volume class. In the case of ERTS-1 imagery interpretation, the recorded signal is some integrated function of the types or volumes represented on the area being viewed and recorded. In order to retain information, the smallest available unit of resolution should have been used.

Other factors adversely affecting correlations were season of ERTS-1 and aircraft imagery acquisition, photogrammetric control and successive generation of imagery. Both satellite and aircraft imagery should be from a season of little or no change, and both should be acquired in the same season to be best adapted to work of this nature. Better photogrammetric control than that employed in this work is desirable to assure that photointerpreted points are precisely located on the ground and that gray scale density levels read from the computer maps are from the precise locations represented by photographic and ground control. Also, since first generation data in the form of magnetic tapes are available to prospective users, their use in the system would avoid the degradation of imagery due to successive reproductions. Direct use of magnetic tapes in the system would also permit the use of all four multispectral scanner, MSS, channels, since channel to channel registration would then be assured.

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LITERATURE CITED

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APPENDICES

APPENDIX A

TABLE 16

SUMMARY OF INPUT DATA

LAND USE	TYPE (ground)	TYPE (2402/25)	TYPE (2443/12)	VOLUME (ground)	VOLUME (2424/89)	VOLUME (postinv)	MSS CH6	MSS CH7	LEGEND
F	M	H	P	5	5	3	189	157	
F	M	M	M	4	4	3	186	134	
F	M	M	H	5	3	3	192	190	
F	M	H	M	3	4	1	192	166	O--OPEN
F	M	H	P	5	5	3	192	173	
F	M	H	P	3	1	2	181	161	F--FOREST
F	M	M		2	5	1	193	196	
F	M	M	M	3	4	1	168	161	W--WATER
F	M	P	M	3	4	1	188	170	
F	M	H	P	4	3	2	192	174	
F	M	P	M	4	3	2	189	152	H--HARDWOOD
F	M	P	M	2	2	1	192	166	
F	M	P	M	3	4	1	192	174	P--PINE
F	M	H	P	3	2	1	192	192	
F	M	M	M	2	2	1	192	169	M--MIXED
F	M	M	M	2	3	1	192	172	
F	M	P	M	2	3	1	192	168	
F	M	M	M	5	2	3	209	182	Volume--design
F	M	H	P	4	4	2	192	177	
F	M	H	M	2	3	1	250	161	1- less than
F	M	M	M	4	3	2	192	166	200 c.f./A.
F	M	H	H	5	2	3	190	182	
F	M	P	H	4	3	3	198	182	2- 201 - 1000
F	M	P	H	2	1	1	192	182	c.f./A.
F	M	P	H	3	2	1	192	164	
F	M	M	P	4	4	2	197	182	3- 1001-1400
F	M	H	P	5	4	3	192	178	c.f./A.
F	M	H	P	4	4	2	189	169	
F	M	H	P	5	3	3	192	185	4- 1401-2200
F	P	P	M	1	4	1	225	177	c.f./A.
F	P	M	P	2	4	1	181	069	

TABLE 16 (continued)

LAND USE	TYPE (ground)	TYPE (2402/25)	TYPE (2443/12)	VOLUME (ground)	VOLUME (2424/89)	VOLUME (postinv)	MSS CH6	MSS CH7	LEGEND
F	P	M	P	4	4	2	192	156	5- more than
F	P	H	P	4	3	2	180	179	2000 c.f./A.
F	P	H	P	4	4	2	190	180	
F	P	M	P	5	5	3	191	162	
F	P	H	P	4	4	2	192	178	Volume--postinventory
F	P	H	P	4	5	2	187	168	
F	P	M	P	5	5	3	192	160	
F	H	P	P	4	4	2	186	154	1- less than
F	H	M	M	3	4	1	189	182	1350 c.f./A.
F	H	P	M	4	4	3	189	134	
F	H	M	M	4	4	2	181	161	2- 1351-2000
F	H	H	H	3	3	1	192	160	c.f./A.
F	H	P	M	4	3	2	191	161	
F	H	M	M	3	4	1	173	168	3- more than
F	H	P	H	4	4	2	181	157	2000 c.f./A.
F	H	P	H	4	4	2	178	162	
F	H	P	H	4	4	3	187	158	
F	H	M	H	4	3	2	184	166	MSS channels--
F	H	H	M	4	2	2	185	169	gray scale
F	H	M	M	4	1	2	189	169	range 0-255
F	H	P	M	4	3	2	192	162	
F	H	H	P	4	4	3	186	225	
F	H	M	M	4	4	2	169	188	
F	H	M	M	4	3	2	204	172	
F	H	P	M	5	3	3	176	161	
O							169	131	
O							177	185	
O							186	167	
O							206	192	
O							178	166	
O							196	180	
O							192	166	
O							189	173	
O							188	157	
O							192	161	
O							192	175	
O							190	165	
O							192	160	

TABLE 16 (continued)

LAND USE	TYPE (ground)	TYPE (2402/25)	TYPE (2443/12)	VOLUME (ground)	VOLUME (2424/89)	VOLUME (postinv)	MSS CH6	MSS CH7	LEGEND
O							183	190	
O							188	171	
O							172	161	
W							192	180	
W							192	175	
W							225	182	
W							187	190	
W							226	225	
W							218	192	
W							231	250	
W							183	176	
W							225	192	
W							208	175	
W							192	192	
W							186	178	
W							225	227	

APPENDIX B

FORMULA AND VALUES TO BE USED

FOR EXTRAPOLATION

Classification is by least "Generalized Squared Distance" (D^2) with the independent variables being gray scale observations from MSS channels 6 and 7.

$D^2 = g_1 + g_2 + g_3$ where,

> g_1 is the row vector of deviations from mean measures of the two MSS channels times the inverse of the covariance matrix times the column vector of deviations from mean measures of the two MSS channels.
>
> g_2 is zero if the pooled covariance matrix is used or the natural logarithm of the determinant of the within covariance matrix if it is used, and
>
> g_3 is zero if prior probabilities are equal or minus twice the natural logarithm of the prior probability for the group or class.

The values required to calculate the terms g_1, g_2 and g_3 for each class are listed in columns headed "Covariance matrix," "$\log_e$ det Covariance Matrix" and "Prior probabilities" in Table 17.

TABLE 17

VALUES REQUIRED TO CALCULATE THE TERMS g_1, g_2, AND g_3 FOR EACH CLASS

Class	Covariance Matrix		$\log_e$ det Covariance Matrix	Prior Probabilities
Land Use--	Pooled			
Open				0.30888
Forest	389.069	71.119	0	0.35792
Water	71.119	164.525		0.33320
Forest Type--	Within			
Hardwood	335.912	-15.078	9.987	0.247
	-15.078	65.399		
Pine	1215.694	156.806	12.132	0.479
	156.806	172.94		
Mixed	167.167	13.722	10.183	0.274
	13.722	159.352		
Postinventory Volume--	Within			
1	696.265	68.970	12.301	0.3214
	68.970	322.565		
2	92.771	-0.067	8.493	0.4107
	-0.067	52.079		
3	520.981	36.676	10.079	0.2679
	36.676	48.352		

VITA

Elvin E. Birth was born July 10, 1926, in Luzerne County, Pennsylvania. After elementary and secondary schooling in Luzerne County, he entered The Pennsylvania State University in 1943. Following two years in the U. S. Navy, he returned to The Pennsylvania State University and was awarded the Bachelor of Science in Forestry in 1950.

He spent one working season in Alaska and returned to The Pennsylvania State University as resident manager of the Stone Valley Research Forest. In 1955 he moved to Tennessee where he was forester for the Payne-Baker properties on a half-time basis and forest consultant the other half time for clients throughout the mid-South. In 1973 he moved to West Virginia where he is presently head of the Land and Forest Department of the J. P. Hamer Lumber Company.

In 1951 he married the former Shirley A. Moss of Wilkinsburg, Pennsylvania. They have four children: Donald K., Richard A., Terri L. and Randall W. The two eldest are in college, while the last two still reside at home.

He is a member of the Beckley Presbyterian Church, The Society of American Foresters and the American Society of Photogrammetry.