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TIMBER RESOURCES INVENTORY AND MONITORING JOINT RESEARCH PROJECT FINAL REPORT

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NATIONAL SPACE TECHNOLOGY LABORATORIES

TIMBER RESOURCES INVENTORY AND MONITORING JOINT RESEARCH PROJECT

FINAL REPORT

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Section I

INTRODUCTION

This report documents the final results of the Timber Resources Inventory and Management Joint Research Project. The Project was conducted by the Earth Resources Laboratory (ERL), at NASA's National Space Technology Laboratories (NSTL), and by the International Paper Company (IP) Corporate Research Center.

The primary objectives of this project were:

(1) To develop remote sensing analysis techniques for extracting forest-related information from Landsat Multispectral Scanner (MSS) data and Landsat Thematic Mapper (TM) data.

(2) To determine the extent to which International Paper Company information needs can be addressed with remote sensing technology.

International Paper Company is a large-scale forest products industry operating in North America. The company actively manages some 8.4 million acres of forest land. Traditionally, their forest inventory efforts, updated on a three-year cycle, are conducted through field surveys and aerial photography. The results reside in a digital forest data base containing 240 descriptive parameters for individual forest stands.

The information in the data base is used to develop seasonal and long-range forest management strategies. Some examples of forest management activities include:

(1) Monitoring forest resources.

(2) Evaluating forest plantation progress.

(3) Locating forest raw material for developing forest products.

(4) Evaluating insect, disease, or fire damaged stands.

(5) Identifying trends such as high grading.

(6) Monitoring timber trespass.

(7) Assessing stocking program success.

(8) Developing sampling designs for multistage inventories.

Approximately 24% of the forest raw material utilized by IP for developing forest products is harvested from company lands. The remaining 76% is acquired from other lands for which IP has little inventory information. The majority of these other lands are managed by small private forest owners.

Analysis of forest production and management trends is essential to forest managers, who must constantly compare forest raw material production to projected demands. This project will address forest stand condition assessements (species composition, age, and density stratification) and identification of silvicultural activities (site preparation, planting, thinning, and harvest).

Section II

TECHNICAL APPROACH

The project was conducted in phases, with the results of one phase being used to direct research activities for the next. The various phases of the joint research project are presented below:

<u>Phase I (FY83)</u>

- Select study area in cooperation with International Paper Company.
- Establish baseline Landsat MSS performance for use in subsequent comparative analysis.
- Identify parameters contained in IP stand mapping system for use in layered classification and verification of analysis results.
- Acquire Thematic Mapper Simulator (TMS) data over study area.

<u>Phase II (FY83)</u>

- Develop analysis techniques for deriving information from TM data.
  - Forest stand condition.
  - Silvicultural activities.
- Acquire Landsat 4 tm data over study area.

<u>Phase III (FY84)</u>

- Test TMS analysis techniques with Landsat 4 (TM) data.
- Develop TM data analysis techniques requiring geographic registration.
- Conduct a comparative analysis of Phase I (MSS data) and Phase III (TM data).
- Conduct a functional test and evaluate the capability of Landsat 4 TM analysis techniques to provide forest resource information.

<u>Phase IV (FY85)</u>

- Document the results of the analytical methodology and evaluation.

- o Conduct a NASA/IP-sponsored workshop to disseminate project results to the forest products industry.

A. Phase I: DESIGN AND MSS ANALYSIS

This section describes the project study area, selection of data, MSS analysis techniques, and results and discussion.

1. STUDY AREA SELECTION

During the first phase of the project, International Paper Company personnel outlined the criteria for selecting a project study area. The area had to:

- Include intensively forested areas exhibiting a variety of forest management activities.
- Include a variety of merchantable forest stands (slash pine, longleaf pine, loblolly pine, mixed pine-hardwood, mixed hardwood-pine, and hardwood).
- Be an area for which IP inventory information is available.
- Exhibit trends toward converting from unmanaged forest to actively managed forest stands.

A forested study area in Baldwin County, Alabama (Figure 1), was selected using the above criteria. The study area, in southwest Alabama, is part of the Gulf Coastal Plain physiographic region referred to as the Lower Coastal Plain. This particular area is representative of the longleaf-slash pine and oak-gum-bald cypress forest ecosystem found throughout the extreme southeastern United States. The longleaf-slash pine biome is typified by the presence of longleaf pine (*Pinus palustris* Mill) and slash pine (*P. caribaea* Morelet). Other southern yellow pine found throughout the area include loblolly pine (*P. taeda* L.), shortleaf pine (*P. echinata* Mill), and spruce

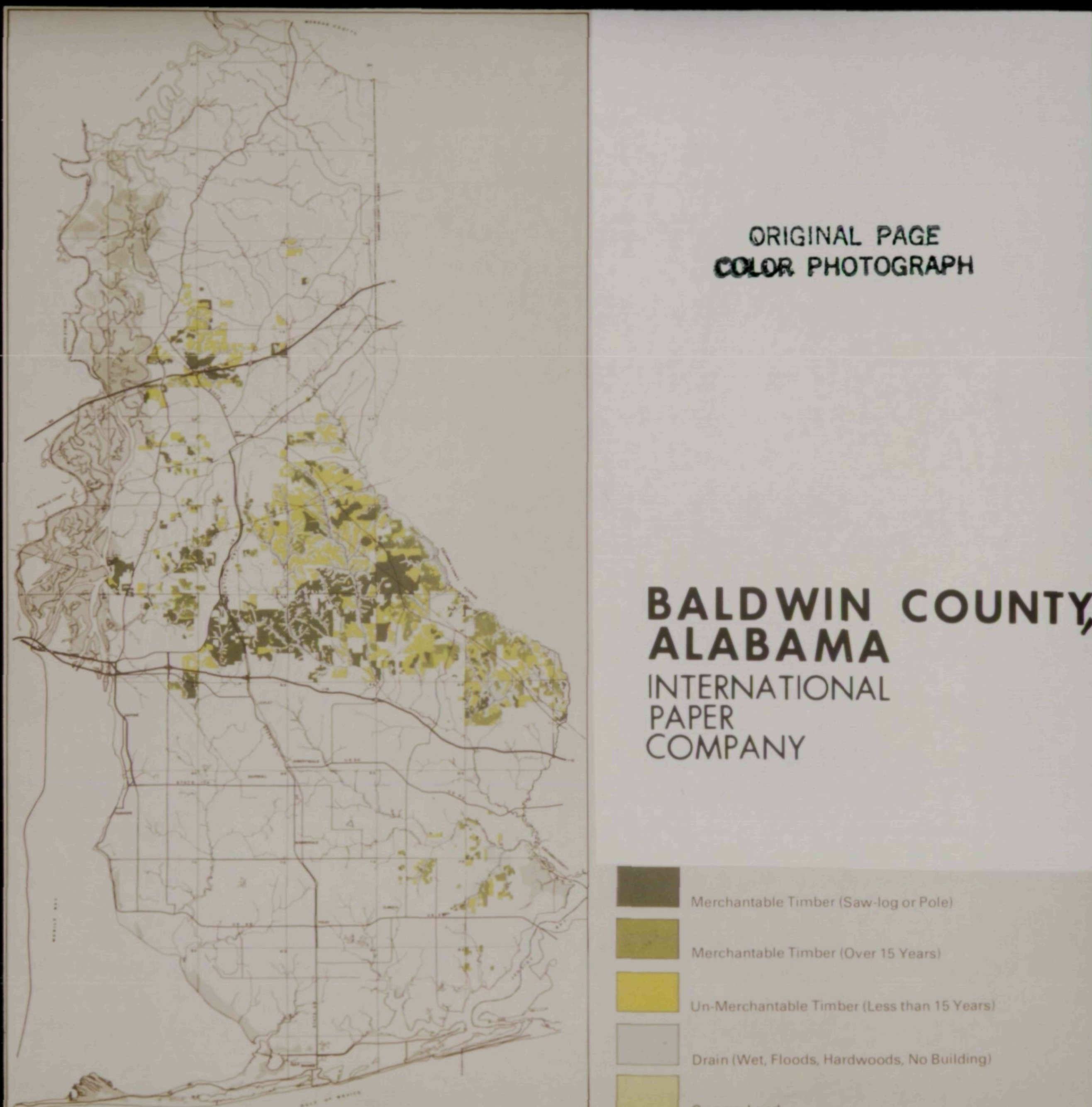

Figure 1. Project Study Area

pine (P. glabra Walt.). The understory components of the longleaf-slash pine forest include various deciduous and evergreen broadleaved plants. Species commonly found in the oak-gum-bald cypress type include various oaks (Quercus spp.), American holly (Ilex opaca Ait), sweetbay magnolia (Magnolia virginicus L.), and sweetgum (Liquidambar styraciflua L.) on the drier sites. The wetter areas include water tupelo (Nyssa aquatica Marsh), red maple (Acer rubrum L.), bald cypress (Taxodium distichum Rich), Atlantic white cedar (Chamaecyparis thoides L.), and various species of ash (Fraxinus spp.).

The topography of the study area is flat to gently rolling, with elevations ranging from sea level to over 200 feet. The lower elevations encompass the major portion of the drainage basins of the Mobile-Middle Tensaw River complex, the Styx River water system, and the Perdido River system. The majority of the upland portion of the study area supports agriculture, with most of the pine forest managed by forest products companies.

The composition of pine stands may range from uneven-aged mixed pine-hardwood forest to even-aged pine plantations. The upland drains contain various species of broadleaved evergreen shrubs, deciduous hardwoods, and from 25% to 75% "turpentine" (old growth) pine. Fire is an important management tool in southern pine production; controlled burning is used to maintain the pine composition in the managed pine stand. A marked difference in understory presence can be noted when comparing burned versus unburned stands (USDA, 1964). In general, the study area contains a diversity of forest types, each maintained with various selections of forest management treatments. Much of the area is managed by IP, thus ensuring the availability of detailed forest inventory information. As a result, the study area is ideal for testing and evaluating various remote sensing techniques useful in forest management.

2. Data Acquisition

Two Landsat MSS scenes were chosen for the study area. A scene imaged

February 23, 1981 (Landsat I.D. 2222415425), was chosen to provide coverage of a winter or dormant condition. During this time period, differences in southern yellow pine and deciduous hardwood species are most dramatic. The February scene also provided a higher sun angle than would have been available in December or January, thereby minimizing shadow problems. A second Landsat MSS scene, imaged July 17, 1981 (Landsat I.D. 2236815410), was selected to provide summer coverage. Most deciduous hardwood species would have mature leaves in July. The most desirable choice was spring (April-May), when most deciduous hardwoods would be in early leafout. However, excessive cloud coverage prevented the acquisition of a spring data set. A combination of a late winter and summer data set was used to maximize spectral separability between the deciduous and coniferous forest types.

3. Data Analysis

All data were analyzed using data processing algorithms available within the Earth Resources Laboratory Applications Software - ELAS (Junkin, et al., 1980). ELAS is a Fortran-based operating subsystem designed to analyze digital imagery data. The flexibility of the ELAS software system allows one to merge segments of digital data collected during different phenological cycles to form multitemporal data sets.

Previous studies analyzing multitemporal Landsat MSS data sets concluded that a combination of Bands 5 (0.6-0.7 micrometer) and 7 (0.8-1.1 micrometers) provided the best overall percent correct vegetation classification (Stoner, et al., 1981; Hixson, et al., 1982). Therefore, to maximize differences in plant appearance (phenotype) and to reduce the amount of data analyzed, one visible band (No. 5) and one near-infrared band (No. 7) were selected from each of the MSS data sets.

Multitemporal analysis requires the registration of the Landsat data sets as the initial phase of data analysis. This technique entails selecting common reference points in the two data sets. Registration of Landsat scenes using this method is accurate to within one pixel (57-79 meters) (Joyce, et al., 1980).

The highest quality cloud-free data set is used as a base for overlaying an additional data set. For the Baldwin County area, the February data set was used as the base. Bands 5 and 7 from each data set were registered to create a single four-channel data set for analysis.

The multitemporal data set (February-July) was used to derive homogeneous spectral classes for the study area. Spectral signatures were developed using the ELAS module SRCH. SRCH develops homogeneous spectral signatures using a 3 x 3 pixel moving window. The results of this unsupervised procedure were used as input to a maximum likelihood classifier. Fifty-five separate spectral classes were developed for the multitemporal data set.

Analysis of the 55 spectral classes indicated that two of the classes contained the majority of the forest types of interest. An ELAS clustering module (WCCL--Within Class Cluster) was used to generate additional statistics by examining each individual pixel previously contained in the two SRCH classes. This technique developed more precise signatures and achieved better pattern recognition for the forest target classes. As a result, nine WCCL spectral statistics replaced the two SRCH forest-related statistics, and 62 spectral statistics were used as inputs to the maximum likelihood classifier to generate the product shown in Figure 2. Ground truth information and IP digital forest inventory information were used to group the spectral classes into 10 land cover categories (Table 1). A general data processing flow diagram (Figure 3) details the steps in data analysis.

4. MSS Accuracy Assessment

Independently of the class naming procedure, ground verification samples were developed for use in determining associated accuracy estimates for each

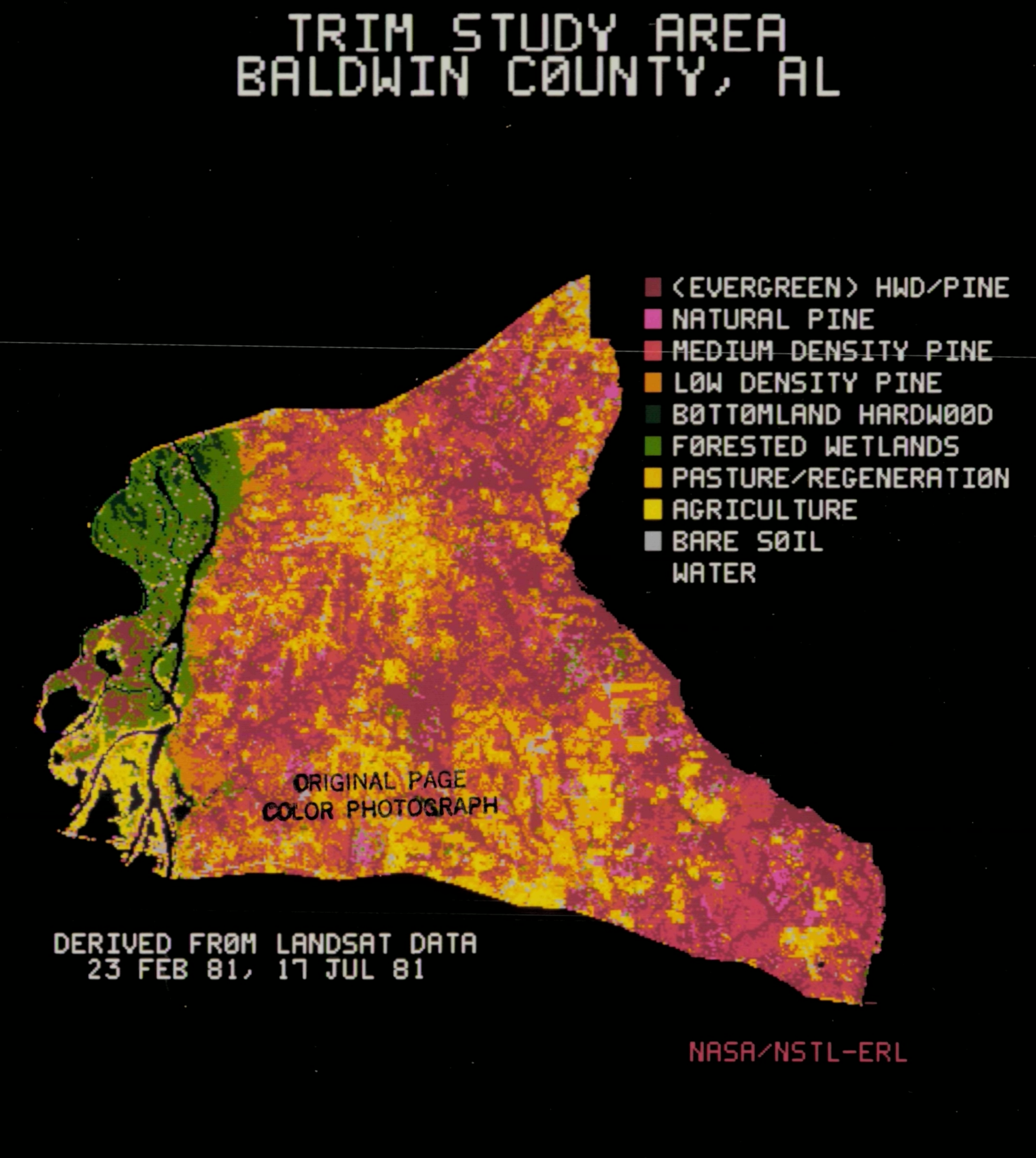

Figure 2. MSS Classification of Study Area

TABLE 1

LAND COVER CATEGORIES AND ASSOCIATED ACREAGE ESTIMATES

FOR TRIM MSS STUDY AREA

LAND COVER CATEGORY	ACREAGE ESTIMATE
Bare oil (sand, mud flats)	4,929
Agriculture-Urban	15,587
Pasture-Pine Regeneration	51,005
Low Density Pine	47,658
Medium Density Pine	78,092
Natural Pine (Longleaf)	17,035
(Evergreen) Hardwood/Pine	123,739
Bottomland Hardwood	3,098
Forested Wetlands	30,120
Water	18,378
TOTAL	389,644

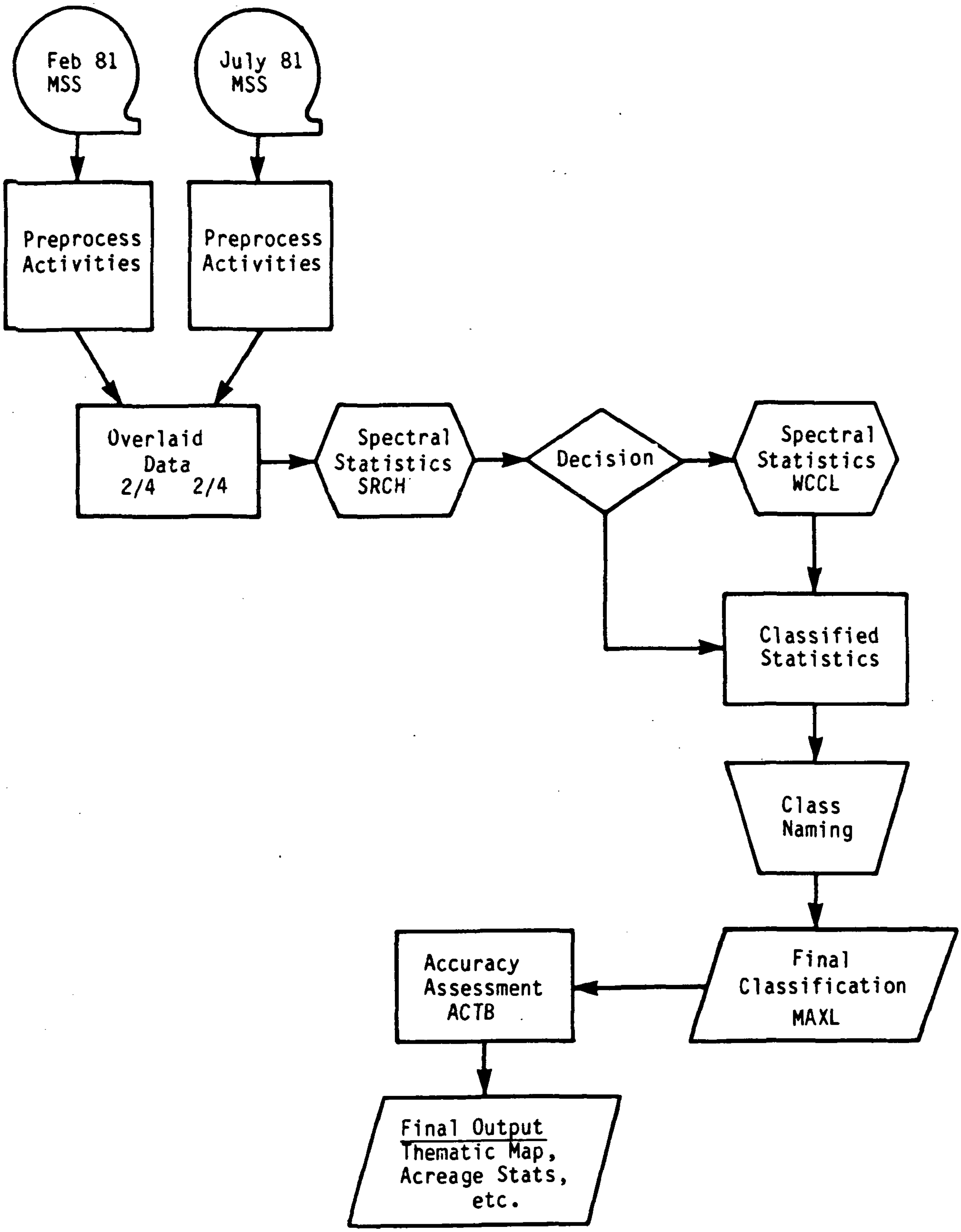

Figure 3. Data Processing Procedures for Producing Final Classification Results of a Multitemporal MSS Analysis

surface category. The verification samples were delineated onto U.S. Geological Survey (USGS) 7-1/2-minute topographic maps and digitized to provide a separate data plane. The ELAS module ACTB (Accuracy of Classification Table) was used to correlate ground truth to the classification, based on comparing the classified data to the known surface composition of the verification samples. Table 2 presents the results from the accuracy assessments of the data relating each surface cover type to the others.

MSS analysis resulted in a final output product presenting seven "forest" associated vegetated communities. However, due to the spectral and spatial limitation of the data, no land cover category satisfied the information requirements set forth by the project goals. Pine regeneration could not be consistently separated from native pasture. Two categories of pine (medium density and low density) were identified. However, the composition of the stands could not be determined as to species. The natural pine stands, for the most part, were composed of longleaf pine stands of uneven age and density. In some cases, mixed stands of longleaf and slash pine were included in the natural pine category. The evergreen hardwood/pine category was composed of very dense evergreen broadleaf understories with various densities of pine (25-75%) in the overstory. This category was composed primarily of the upland drains and lower portions of forested slopes. Bottomland hardwood and forested wetlands were adequately described.

B. PHASE II: THEMATIC MAPPER SIMULATOR ANALYSIS

1. Data Acquisition

Simulated Thematic Mapper (TMS) data were collected in lieu of satellite data for a portion of the study area. TMS data were used to examine

TABLE 2

MSS CLASSIFICATION ACCURACY MATRIX

REMOTE SENSING DERIVED CLASSES*

GROUND TRUTH DERIVED CLASSES	(EG)H/P 1	MD/PINE 2	LD/PINE 3	N/PINE 4	B/HWD 5	F/WETLD 6	PAST/PL 7	AGRI 8	B/SOIL 9	WATER 10	TOTAL PIXELS
1	389 74.52	51 9.77	19 3.64	0 0.00	0 0.00	0 0.00	54 10.34	9 1.72	0 0.00	0 0.00	522
2	34 3.85	727 82.24	77 8.71	2 0.23	0 0.00	0 0.00	35 3.96	2 0.23	7 0.79	0 0.00	884
3	27 6.40	46 10.90	344 81.52	0 0.00	0 0.00	4 0.95	1 0.24	0 0.00	0 0.00	0 0.00	422
4	12 1.49	4 0.50	104 12.95	587 73.10	0 0.00	33 4.11	63 7.85	0 0.00	0 0.00	0 0.00	803
5	0 0.00	0 0.00	0 0.00	0 0.00	487 83.82	94 16.18	0 0.00	0 0.00	0 0.00	0 0.00	581
6	0 0.00	0 0.00	0 0.00	0 0.00	4 2.31	168 97.11	0 0.00	0 0.00	0 0.00	1 0.58	173
7	170 10.16	306 18.29	78 4.66	6 0.36	0 0.00	3 0.18	1077 64.38	16 0.96	17 1.02	0 0.00	1673
8	34 3.53	31 3.22	86 8.94	0 0.00	0 0.00	2 0.21	94 9.77	711 73.91	4 0.42	0 0.00	962
9	0 0.00	0 0.00	2 1.53	0 0.00	0 0.00	2 1.53	41 31.30	2 1.53	84 64.12	0 0.00	131
10	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	1557 100.00	1557

*(EG)H/P-Evergreen Hardwood/Pine; MD/PINE-Medium Density Pine; LD/PINE-Low Density Pine; N/PINE-Natural Pine; B/HWD-Bottomland Hardwood; F/WETLD-Forested Wetlands; PAST/PL-Pasture/Pine Plantations; AGRI-Agriculture; B/SOIL-Bare Soil; Water

classification approaches during the time period prior to TM data availability. MSS classifications were tested using TMS data and validated using TM data. The NASA/NSTL/ERL Thematic Mapper Simulator is an aircraft-borne sensor capable of producing, in a simulated form, Landsat 4 TM data. Primary considerations contributing to the utility of the TMS were spatial and spectral fidelity, radiometric sensitivity, and atmospheric path length perturbations (Flanagan, et al., 1982). A summary of TMS specifications and TM responses is presented in Table 3.

TMS data were collected February 23, 1982, and September 9, 1982. The aircraft altitude (12,000m) necessary for a 30x30m pixel at nadir--the normal instantaneous field of view (IFOV) for the TM satellite--results in geometric distortions at larger angles of look. As a result, only the center 60 degrees (30 degrees on either side of nadir) was used in analysis. It should be noted that the TMS bands are numbered in the sequence in which they occur in the electromagnetic spectrum and do not have the same number assignments as the TM bands. Also, the analysis of TMS data was made with no adjustments for the resolution difference in Band 7 (10.30-12.30 micrometers). Band 7 resolution was maintained at 30 meters.

2. Data Analysis

For the purpose of understanding TM data characteristics, preliminary data processing was accomplished on the February TMS data set. A standard unsupervised technique was used to analyze a small area selected from the center 60 degrees of the flight line. The six reflective bands of data were used in the analysis.

A total of 47 spectral signatures were developed using the SRCH analysis approach. The results of the classification were analyzed using ground truth data, IP timber stand maps, and color infrared photography. The TMS classification was not geographically referenced. As a result, an empirical

TABLE 3

TM SPECIFICATIONS AND TMS RESPONSE

LANDSAT 4 TM SPECIFICATIONS			NASA/NSTL/ERL TMS RESPONSE		
Band	Spatial[a]	Spectral[b]	Band	Spatial[a]	Spectral[b]
1	30	0.45 - 0.52	1	5-33	0.46 - 0.52
2	30	0.52 - 0.60	2	5-33	0.53 - 0.60
3	30	0.63 - 0.69	3	5-33	0.63 - 0.69
4	30	0.76 - 0.90	4	5-33	0.77 - 0.90
5	30	1.55 - 1.75	5	5-33	1.53 - 1.73
7	30	2.08 - 2.35	6	5-33	2.06 - 2.33
6	120	10.40 -12.50	7	5-131	10.30 -12.30

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a. Meters; b. Micrometers

analysis was completed with regards to classification success.

Loblolly pine was spectrally distinct from the other southern yellow pines as a result of a lower response in the near infrared channel (Channel 4, 0.76-0.90 micrometer). Recently burned pine stands were also delineated from unburned stands. Regenerated pine plantations differed from site prepared areas. In some cases, differing techniques of site preparation were noted; e.g., push and burn and double disked.

Preliminary analysis of TMS data indicated possible success in discriminating some forest types and silvicultural activities. All categories were verified using ground truth data and color infrared photography.

C. PHASE III: THEMATIC MAPPER DATA ANALYSIS

1. Data Acquisition

The TM data used in this study were collected on January 15, 1983 (Scene ID 40183-15545), and coincided with Path 21, Row 39, of the Landsat Worldwide Reference System. A study area encompassing 145,000 acres (58,725 hectares) and including forest types representative of the Gulf Coastal Plain was identified.

2. Data Analysis

Prior to data processing, it was determined that Channel 6--the thermal IR channel (10.40-12.50 micrometers)--would not be used to derive spectral signatures. At present, little is known about the thermal emissivity characteristics of Channel 6 relative to the reflectance energy properties of the other channels. The resolution of these data is 120m as opposed to the 30m data contained in the other channels. Additionally, the data contained in Channel 1 (0.45-0.52 micrometer) were not available due to parity errors within the raw data tapes. As a result, data processing was restricted to the information contained in TM Channels 2 (0.52-0.60 micrometer), 3 (0.63-0.69

micrometer), 4 (0.76-0.90 micrometer), 5 (1.55-1.75 micrometers), and 7 (2.08-2.35 micrometers). The means, standard deviations, coefficients of variation, and correlation matrix for the five channels of data used in analysis are listed in Table 4.

Data processing was initiated with the development of spectral signatures using a 3x3 pixel moving window signature development program module called SVCP. SVCP is a modification of the SEARCH (SRCH) unsupervised sliding window spectral signature development algorithm in ELAS. Both SRCH and SVCP develop spectral statistics after locating homogeneous 3x3 pixel areas within the data set. SVCP differs from SRCH in that it permits the user to define spectral homogeneity independently for each channel of input data using various input parameters (i.e., standard deviation, coefficient of variation, and scaled distance).

Fifty-two spectral statistics resulted from the five channels of TM data input to SVCP. The data were then classified using these spectral signatures as inputs to a maximum likelihood classifier.

An initial examination of the classification showed that the majority of the forested area could only be separated according to the following forest cover categories: (1) an overstory of pine with a dense broadleaf evergreen understory; (2) an overstory of mixed pine-hardwood in the upland areas; and (3) a dense overstory of mixed hardwood-Atlantic white cedar with scattered pine located in the bottomland areas.

Data analysis continued with the delineation of polygons to define pure stands for each target timber type (i.e., slash pine plantations, loblolly pine plantations, natural pine stands, and mixed hardwood-cedar stands). The polygons for each target category were merged and statistics computed for each. Channel means, standard deviations, and the coefficients of variation for each category are presented in Table 5. A plot of the channel means for

TABLE 4

MEANS, STANDARD DEVIATIONS, COEFFICIENTS OF VARIATION, AND CORRELATION MATRIX FOR TM DATA USED IN THE STUDY

Channel	2	3	4	5	7
Means	22.33	22.25	35.44	38.96	16.72
S.D.	4.95	6.44	10.56	18.18	9.23
C.V.	0.22	0.29	0.30	0.46	0.56
Correlation	1.00				
Matrix	0.95	1.00			
	0.49	0.40	1.00		
	0.60	0.67	0.68	1.00	
	0.64	0.73	0.55	0.96	1.00

TABLE 5

MEANS, STANDARD DEVIATIONS, AND COEFFICIENTS OF VARIATION OF PURE POLYGONS FOR EACH TARGET FOREST TYPE

Slash Pine Plantations

Channel	2	3	4	5	7
Mean	19.45000	16.45000	42.80000	23.05000	8.30000
S. D.	0.55470	0.81650	1.42325	1.10940	0.94733
C. V.	2.85193	4.96351	3.32535	4.81302	11.41363

Loblolly Pine Plantations

Channel	2	3	4	5	7
Mean	18.97058	16.08824	34.82353	26.61765	9.38235
S. D.	0.52223	0.71774	0.71774	1.33712	0.87039
C. V.	2.75286	4.46127	2.06108	5.02342	9.27687

Natural Pine Stands

Channel	2	3	4	5	7
Mean	21.33673	20.50000	38.94897	34.11224	13.23469
S. D.	0.73218	0.96858	2.26811	2.31979	1.32385
C. V.	3.43153	4.72477	5.82329	6.80047	10.00287

Hardwood-Cedar Stands

Channel	2	3	4	5	7
Mean	18.50000	15.57692	33.57692	26.53847	9.69231
S. D.	0.66332	0.91652	1.42829	1.37113	0.69282
C. V.	3.58554	5.88380	4.25377	5.16658	7.14815

each target type indicated that the greatest spectral separation could be accomplished using the information in Channels 4 and 5 (Figure 4). Consequently, SVCP was employed to extract spectral information utilizing only data values contained in those channels. Thirty-seven spectral statistics were developed from the two channels of TM data input to SVCP and the data were classified using these spectral signatures.

A close examination of the two-channel classification indicated improvements in forest stands delineation as compared to the five-channel classification. Young pine plantations and medium-aged pine plantations were separated. Moreover, pine plantations could be separated from natural uneven-aged pine stands. Homogeneous spectral statistics could not be developed, however, for some important timber types due to their relatively small size and irregular arrangement on the landscape (e.g., upland drains, stands transcending from pine to hardwood, and small areas of pine regeneration within other stands).

To extract spectral information for small timber stands, a pixel-by-pixel signature development program in ELAS called Within Class Cluster (WCCL) was employed. Signature development was directed to only those pixels that were initially classified as a forest land cover. Non-forest-related pixels in the raw two-channel TM data were not utilized in the pixel-by-pixel signature development process. The spectral signatures from SVCP and WCCL were collected and the data were classified, yielding 43 spectral classes.

Classes were named using recent aerial color infrared photography, ground truth resulting from field visits, and digitized timber stand maps provided by IP. The 43 spectral classes were systematically aggregated into six specific categories as a result of the class naming procedure. The six categories of land cover identified from the classification were: (1) medium-aged slash pine--this related primarily to dense even-aged plantations 10-20 years old;

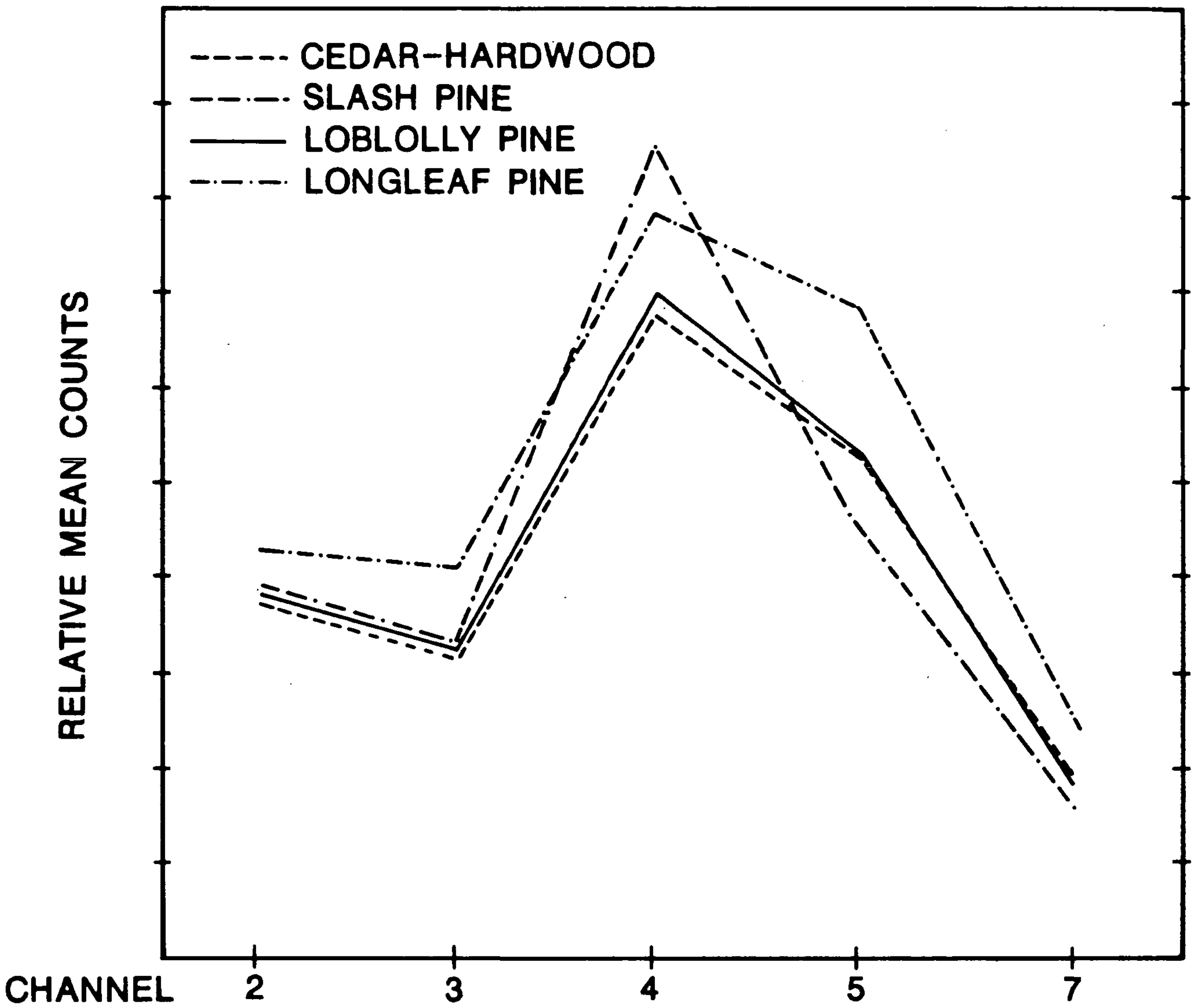

Figure 4. Channel Means Plotted for Forest Types Using TM Data Imaged January 15, 1983

(2) medium-aged loblolly pine--this class encompassed even-aged stands; (3) young pine, which coincides with pine regenerated areas less than 5 years old; (4) natural pine, predominantly uneven-aged stands of longleaf and loblolly pine; (5) hardwood-pine, consisting of hardwood stands with scattered pine; and (6) non-forest.

Upon close examination of each category, confusion was discovered between medium-aged loblolly pine and Atlantic white cedar-hardwood stands. Due to similarities in plant spectral characteristics, the two stand types could not be differentiated strictly within the spectral domain. With the spatial information in the data and a knowledge of the riverine preference of Atlantic white cedar-hardwood, a separation was accomplished. The ELAS modules POLY (polygon selection) and PGUD (polygon update) were utilized to delineate stands of Atlantic white cedar-hardwoods, using an image display device, and to revise the classes confused with loblolly pine. All pixels previously classified as loblolly pine, but actually Atlantic white cedar-hardwood, were identified as a new class.

Scene-to-map registration was performed using several control points within the TM data set which were correlated with base map coordinates. The TM scene was rectified by correlating TM line and element coordinates with the corresponding Universal Transverse Mercator (UTM) coordinates (northing/easting) of the map base. The Landsat TM data were resampled with an ELAS nearest neighbor rectification algorithm (Graham, 1977) to a 30m grid cell size. Registration was accomplished to within one pixel (29m RMS) of the data set.

Analysis of accuracy was conducted using the matrix presented in Table 6. Each class was assessed for accuracy using digitally formatted ground data polygons mapped from aerial photography, timber stand maps, and verified ground truth. The ground data polygons were established using the same

TABLE 6

PERCENT CORRECT BY SPECTRAL CLASS AND NUMBER

OF PIXELS CLASSIFIED CORRECT BY VERIFICATION CATEGORY

SPECTRAL CLASSES

Ground Verification Category	Loblolly Pine	Young Pine	Slash Pine	Natural Pine	Hardwood Pine	Percent Correct
Loblolly Pine	304	0	9	68	0	79.6
Young Pine	0	4673	0	120	1	96.8
Slash Pine	1	0	1230	15	0	98.5
Natural Pine	3	911	41	3401	7	77.9
Hardwood Pine	10	0	0	71	268	76.6
				Percent correct overall		88.4

criteria established for class naming and entered into a multichannel, georeferenced data file. ELAS module ATCB (Accuracy of Classification Table) was used to relate each class in the digital classification with a table containing the digital ground data. (Note: The ground data polygons used in the accuracy assessment were defined as homogeneously as possible in land cover content to facilitate the computation of a "true" accuracy statistic. As a result, across-stand variance was at a minimum within each accuracy assessment polygon). The following classes were assessed using ACTB: (1) slash pine, (2) loblolly pine, (3) young pine, (4) natural pine, and (5) hardwood-pine.

Highest classification accuracy was achieved for slash pine at 98.5% correct. Slash pine is the major planted timber species in the area, with an average density of 1,000 stems per acre. Medium-aged plantations of slash pine exhibit very smooth, uniform, nearly closed crowns. Understory encroachment is usually prevented with periodic applications of controlled burning. Slash pine is more reflective in the infrared bands than loblolly pine due to physiological differences in the plants.

The estimated classification accuracy for young pine less than 5 years old was 96.8% correct. The understory composition for these areas is largely native grasses with scattered shrubs. The majority of the spectral overlap found in this class was with natural pine stands. An explanation for this spectral overlap is provided by a close examination of the ground data polygons, revealing a few remaining parent trees within the stands.

Loblolly pine stands were classified 79.6% correct. Many of the uneven-aged natural pine stands are composed largely of loblolly pine mixed with longleaf pine. The spectral indistinction between some loblolly pine classes and natural pine classes apparently was responsible for the misclassification.

Natural pine classes, composed of uneven-aged mixtures of longleaf and loblolly pine, produced a classification accuracy of 77.9% correct. An examination of Table 6 reveals that 20.9% of the misclassification results from a confusion with young pine. Typical stands of natural pine have open canopies which result from lower densities of uneven-aged pine. The spectral measurements made between the pine crowns in the more open stands are similar to the spectral responses in young pine regeneration. The areas between the pine crown, therefore, are regenerating in young pines.

The hardwood-pine class was the most difficult class to define and, as a result, it provided the lowest classification accuracy achieved (76.6% correct). Hardwood-pine stands range from upland areas of hardwood with mixtures of pine to upland drains with scattered pine in the overstory and a dense understory of broadleaf evergreen trees and shrubs. The majority of misclassification (20.3%) occurred in areas where the upper canopy contained a greater amount of pine. Consequently, these areas were misclassified as natural pine. The overall percent correct for classification of slash pine, young regenerated pine, loblolly pine, natural pine, and mixed hardwood-pine was computed at 88.4%.

Silvicultural activities were identified and noted during various field activities. The following were identified as forest management practices within the study area:

- Site Preparation
  - Raking
  - Push and Burn
  - Chopping
  - Double Disking
- Planting

- Seed Tree Regeneration
- Prescribed Burning
- Timber Stand Improvement (TSI)
- Precommercial Thinning
  - Selection Cutting
  - Row Extraction
- Harvesting
  - Clear Cutting
  - Selection Cutting

Upon close examination of the TM classification, it was noted that some of the silvicultural activities could be correlated with spectral classes in the TM analysis. Site preparation and harvesting (clear cutting) were silvicultural activities that were consistently identified. These forest management procedures usually result in large areas with a uniform surface composition.

The other silvicultural activities (seed tree regeneration, planting, prescribed burning, timber stand improvement, and precommercial thinning) result in areas producing a large variation of spectral measurements. As a result, these silvicultural activities could not be consistently delineated from other land cover categories.

Site prepared areas are those from which all vegetation has been removed prior to planting activities. These areas were delineated from other forest management activities with the exception of very recent planting activities. In addition, one method of site preparation (double disking) was separated from the other methods. Double disking is a very intensive method of site preparation and closely resembles plowed agricultural fields. (There were no plowed agricultural fields in the study area during the time of TM data acquisition).

Harvested areas where a clear cutting technique was employed were delineated and established as a separate category of silvicultural activities. These areas are typified by the presence of necrotic forest slash and the absence of living vegetation. They were classified during a time period beginning two to three weeks after harvest was completed and ending prior to site preparation activities.

In summary, some silvicultural activities (i.e., site preparation and clear cut harvest) were identified using classified TM data. However, the correlation of silvicultural activities to remotely sensed data is very difficult due to the dynamic nature of these activities. When a harvest operation is initiated, the harvest, site preparation stage, and replanting activities may be completed very rapidly. The identification of silvicultural activities using satellite-acquired data is dependent on knowing the exact activity and stage of activity at the time of data acquisition. Future studies analyzing TM data for assessments of silvicultural activities must consider methods for closely correlating data acquisition and ground truth activities.

Section III

CONCLUSIONS

Results from analysis of MSS data provided an MSS baseline classification for TM comparison. An overall accuracy of 79% correct was achieved for some forest associations and, in one case, gross density levels. A multitemporal analysis was successful in distinguishing some pine hardwood mixes. However, the large presence of a heavy evergreen understory added problems in distinguishing pine stands from pine/hardwood and hardwood/pine upland drains. The forest stand information requirements set forth as project goals were not accomplished using MSS data. Spectral and spatial characteristics of MSS did not provide adequate information for distinguishing timber stand species composition (monoculture pine), stand age and density stratification, or silvicultural activities.

The analysis of TM data conducted here offers some interesting results regarding improvements in forest stand mapping. The capability exists with the TM to spectrally identify inter-forest category variations for which homogeneous spectral areas could be identified both in the data and on the ground. For example, it has been possible to discriminate forest stands of slash pine, young pine, loblolly pine, and natural pine with TM data. In addition, some silvicultural activities (site preparation and harvest) were identified using TM data. Similar analysis of MSS data had limited results with only broad categorization of pine forest possible. The more dynamic spectral characteristics of the TM, however, require more spectrally uniform ground truth for accurate evaluation. It is evident from this study that the previously used methods for gathering ground truth information, developed for analysis of MSS data, must be modified to compensate for the improved characteristics of the TM.

Acceptable results can be achieved by utilizing standard pattern recognition techniques for developing spectral signatures from TM data. However, it is apparent that as the target land cover type becomes more complex and heterogeneous (e.g., stratified mixtures of pine-hardwood, transition forest stands, and damaged stands) both spectral and spatial attributes of the TM must be incorporated in analyses. Ultimately, techniques must be developed incorporating textural and contextual information with spectral signature development to derive definitive forest-related information from TM data.

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