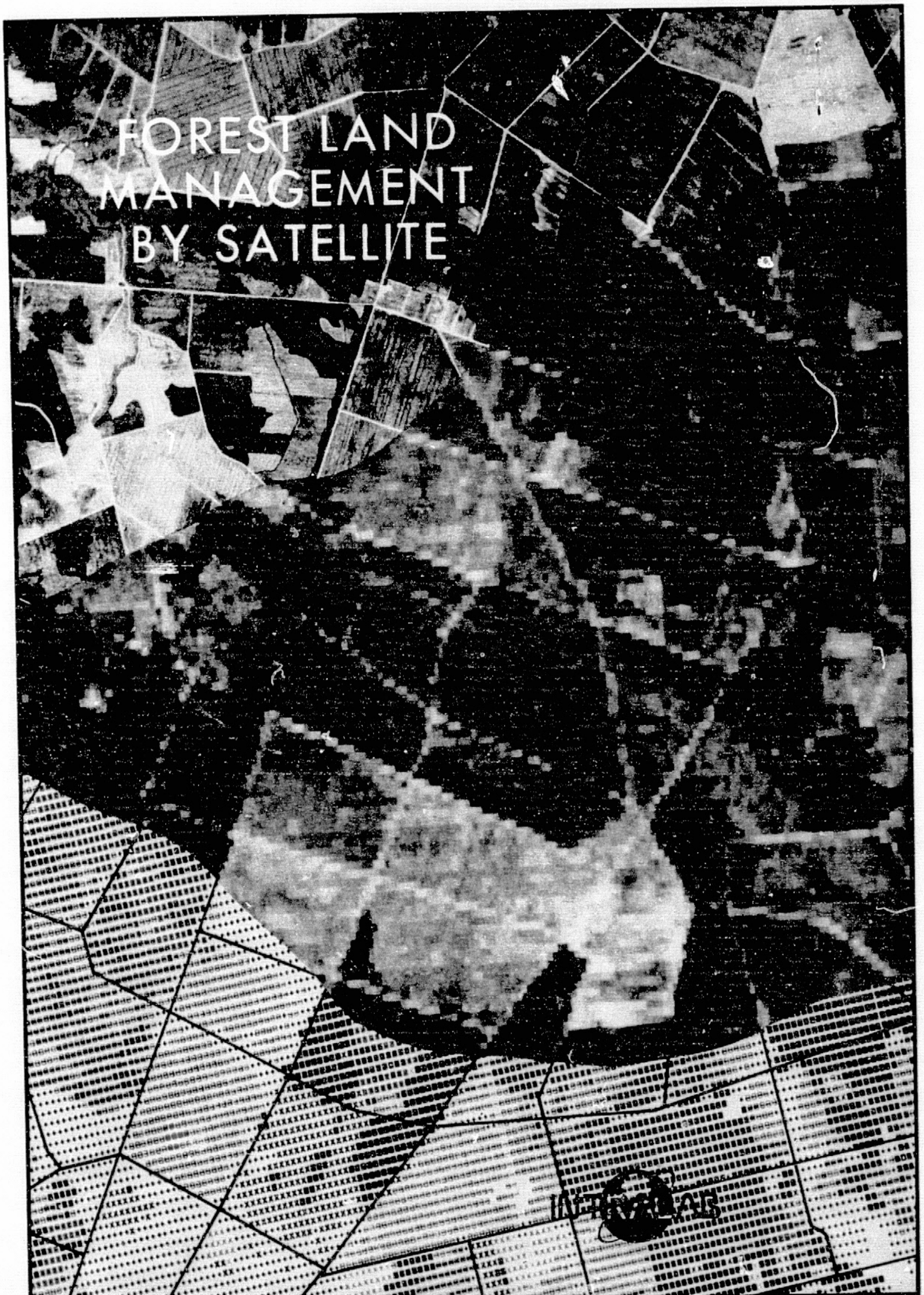

(E78-10038) FOREST LAND MANAGEMENT BY SATELLITE: LANDSAT-DERIVED INFORMATION AS INPUT TO A FOREST INVENTORY SYSTEM (Weyerhauser Co., Plymouth, N. C.) 40 p HC A03/MF A01 CSCL 02F G3/43

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FOREST LAND MANAGEMENT BY SATELLITE:

LANDSAT-DERIVED INFORMATION AS INPUT TO A FOREST INVENTORY SYSTEM

Intralab Project #75-1

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December 1976

Original photography may be purchased from:
EROS Data Center

Sioux Falls, SD

ORIGINAL CONTAINS
COLOR ILLUSTRATIONS

CONTENTS

Table 6

Cost Estimate for Using Landsat Data to Annually Derive Regional (North Carolina) Clearcut Acreages

A.	Landsat Data Procurement Costs	
	Standard Photographic Products	
	up to \$100/scene X 4 scenes = \$400, or Average of \$200	
	Computer Compatible Tapes (CCT's)	
	\$200/scene X 4 scenes = \$800	
	Total Data Procurement Costs (Average)	\$1000
B.	ORSER System Digital Processing Costs*	
	Total Area of Company Holdings in the North Carolina Region – 263,000 hectares or 2630 km^2	
	2630 km^2 @ \$0.35/km^2 = \$920	
	2630 km^2 @ \$0.60/km^2 = \$1580	
	Total Processing Cost – \$920 to \$1580 or Average Processing Cost of	\$1250
	Total Annual Landsat Cost (Data Procurement + Data Processing)	\$2250

*Experience on the ORSER system has generated processing costs ranging from \$0.35/km^2 (\$0.90/sq. mi.) to \$0.60/km^2 (\$1.56/sq. mi.), depending upon such variables as the number of categories mapped, types of final products required, etc.

entire organization. It would be naive to presume that the costs and benefits identified in a sharply focused project in one area can be satisfactorily extrapolated to the broader, often untested, needs of the parent organization. However, these results do form a critical base for a proper evaluation of risk-versus-potential benefit of adopting a new technology.

ABSTRACT

The Weyerhaeuser Company (North Carolina Region) participated in a cooperative project with the Information Transfer Laboratory (Intralab) at National Aeronautics and Space Administration's (NASA's) Goddard Space Flight Center (GSFC). Intralab's primary goal is to provide sufficient information on a specific application of remote sensing technology for a user to make an informed decision to incorporate remote sensing data into routine operations. This project was undertaken to investigate the applicability of information derived from Landsat multispectral scanner (MSS) digital data as supplemental input to a forest inventory system.

Winter and summer Landsat scenes (4 channel) of the North Carolina Coastal Region were analyzed individually, and then registered and merged (8 channel) to take advantage of temporal changes in forest canopy. Best results were obtained through analysis of the summer and 8 channel merged data. Three separable pine categories were successfully extracted, assessing the extent of crown closure and its influence on the amount of ground vegetation that would be sensed by an airborne scanner. By combining this information with existing records and observing the closure advancement over time, forest managers may be able to draw conclusions concerning the growth rate and quality of forest stands. These categories may also be used in the first stage of a stratified random sample to determine stratification and acreages within a stratum. This approach usually has the advantage of maintaining equal precision in forest inventory estimates, at a lower cost. The reliability of the computer classification of the Landsat MSS data was verified by comparison with aerial photointerpretation, with an agreement of 90 percent.

INTRODUCTION

This report describes the technical phase of an Intralab project designed to evaluate and enhance the prospects for adoption of Landsat technology by private industry for routine forest management. The potential "adopter" or "user" in this case is the Weyerhaeuser Company; specifically a group headquartered in the North Carolina Region and represented by Mr. Gerald F. Haver, Planning Coordinator for that region. The names on the title page of this report reflect that the user is an important member of an Intralab project. The Weyerhaeuser Company has participated since its initiation.

The importance of this project to Intralab is that Weyerhaeuser engages in forest practices common throughout the forest industry, and that contemporary satellite systems may provide usable information to support some of those practices. The project's purpose was to explore the application of satellite data to the information needs of the forest industry.

The discovery, testing, evaluation, and decision-making process that all potential adopters of a new technology must conduct is complex. This document synthesizes the discovery and testing experiences of Weyerhaeuser and Intralab in the conduct of a Landsat technology assessment project.

This document provides Weyerhaeuser with a technical performance statement of some of the opportunities for using Landsat data in support of routine management practices. For its part, Intralab has gained additional experience in presenting Landsat technology to a potential user faced with operational information needs. Thus, this joint effort, like all Intralab projects, provides an important learning experience for both parties.

Critical evaluation by the Weyerhaeuser staff has already begun. With the publication of this report, an effective review of the technology can proceed, ending with the user's own critique. This critique will summarize Weyerhaeuser's perspective on what it believes has been learned and, more important, how the company should proceed. While Intralab is encouraged by the results reported in this document, the practical value of these results must be judged by those responsible for making operational decisions. This report will help to guide those responsible for such decisions.

BACKGROUND

Ownership of the 202 million hectares (500 million acres) of commercial forest land in the United States falls into four major categories: national forest, other public ownership, forest industry, and other private. Forest industry holdings amount to approximately 14 percent of total commercial forest land, or approximately 28 million hectares (67 million acres). The Weyerhaeuser Company owns approximately 2.3 million hectares (5.7 million acres), or about 8 percent of the forest industry holdings.

Weyerhaeuser has invested considerable manpower, time, and money in research for improved forest management practices to increase fiber production on all of their company land. For example, in the South the seedling/harvest cycle has been reduced from approximately 45 years to 25 years, while in the Douglas fir region of the Pacific Northwest the cycle on company land is approximately 50 years versus 100 years under natural conditions.

To facilitate the formidable task of monitoring 2.3 million hectares of forest land, at varying stages of growth, over these 25- to 50-year harvest cycles, Weyerhaeuser has decentralized its ownership and management into several regions (Figure 1). The North Carolina Region, containing more that 263,000 hectares (650,000 acres), is a typical example of the regional management concept. Since the project study area was located in this Region, the majority of the remaining discussion will pertain to this region.

To effectively manage the company's multiple-use forest land, a detailed inventory system is essential. The first detailed inventory system began in 1963 with the installation of 6000 Continuous Forest Inventory (CFI) plots. CFI is basically an extensive system of permanent sample plots established, maintained, and periodically remeasured for purposes of deriving representative forest management data for large tracts. In 1969, the company established its first computer-based inventory system, using data for average or typical timber types in various combinations to identify timber volumes and stand locations. Forestry activities such as harvest, site preparation, and regeneration could then be recorded on a stand basis and used for tracking such items as tree growth response to site improvement activities.

As the program developed, the importance of an accurate, up-to-date inventory system became critical. Consequently, the computer-based system was revamped to increase emphasis on individual tree detail to avoid using "average" conditions.

The current inventory system is broken into various overlays based on need. For example, the "stand" overlay contains the data necessary for volume and area calculations; the "ribbon" overlay accounts for road location, streams, and other areas not available for timber production; and the "site" overlay provides the growth-potential data useful for making long-term volume predictions. Once these data are stored on computer files, they can be retrieved in both report form and on computer plot-back maps, individually or by several overlays at a time. As the need arises, overlays can be added or deleted, but most often existing overlays are updated. Updating is performed annually for all activities, such as harvest, regeneration, fire, and insect and disease damage. The source data for these updates are district reports. These reports

Figure 1. A map showing the states within which Weyerhaeuser Company has established timberland regions.

are sent to the Inventory Department in two basic formats: (a) cover sheets which list each block operated on during the year, and which show the number of acres, by block, month, and activity type, (b) compartment maps at a scale of 1:15,840, which show the location and boundaries of all blocks reported for that activity. Aerial photography is then used to check the block boundaries as well as the physical description of any stand.

The ultimate goal of such an inventory system is to provide forest managers with detailed, accurate information regarding the present condition of company forest land. Therefore, the inventory must be kept current to be useful in the planning and implementation of forestry and logging operations. Conventional monitoring techniques, such as ground observations and low altitude aerial photography, can be costly and variable because of the time required to complete data collection over large areas. Newer remote sensing techniques, using small scale data from satellites, may be a logical approach for obtaining supplemental input to forest inventory systems.

OBJECTIVES

The overall objective of this project was to investigate the application of Landsat multispectral scanner (MSS) digital data (Appendix A) as a means of supplementing a forest inventory system. Repetitive satellite coverage may provide a means of monitoring and measuring the changes that may be occurring due to forest management activities such as road building, timber harvesting, and tree planting. Prior to the initiation of this project, however, there was some doubt as to whether satellite data could contribute to the current knowledge of existing forest stands, particularly in the detail necessary on company lands.

Two major questions were identified to test the applicability of Landsat data as a supplement to a forest inventory system. First, could satellite MSS data be used to differentiate between pine stands, hardwood stands, pine-hardwood mixtures, and clearcuts accurately enough to obtain reliable acreage estimates, particularly for the clearcut category? Resolution of this question could result in faster, more efficient updating of harvest activities on company-owned land. Second, could these general categories be divided into various subcategories related to age, vigor, stand density, or other stand characteristics based upon differing spectral reflectance? For example, could the age of the pine stands be broken down into various age classes such as 0 to 6 years, 6 to 20 years, and 20 years and older? This would provide an indication of timber maturity and could facilitate prioritization of stands to be harvested.

Several other interests were identified by Weyerhaeuser as the project progressed and their understanding of the data analysis procedures increased. For example, in view of problems connected with excess water in the North Carolina Coastal Plain, could satellite data be helpful in identifying gross drainage patterns to assist in drainage construction plans? Moreover, since the two currently orbiting Landsats provide data every 9 days, could this information be used to monitor insect and disease infestations? This interest was prompted by the heavy infestation of the southern pine beetle in 1974. In addition, could the affect of adverse weather conditions on tree growth and tree vigor be identified, e.g., could a yellowing (loss of vigor) of the trees be identified to help set up fertilization plans between the normally scheduled periods? Finally, since there is little information known about other private timberland in eastern North Carolina, could satellite data be useful to describe, at least generally, the amount of private timber holdings? Such information could be helpful in developing future wood procurement strategies.

It was obvious that some information relating to these secondary objectives could be obtained by making slight deviations in planned data processing procedures, but no major redefinitions of the primary task objectives were undertaken. As for "assessing" private timber holdings using Landsat data, NASA could not properly participate in any such effort that might appear to give Weyerhaeuser a direct competitive advantage in timber procurement. As the project progressed, certain aspects of the primary and secondary questions were modified to reflect the findings and intermediate results of the research effort.

LOCATION AND DESCRIPTION OF THE STUDY AREA

One of Weyerhaeuser's larger forest tracts in North Carolina, the J&W Tract, encompasses approximately 24,300 hectares (60,000 acres) and lies just south of the western tip of Albemarle Sound (Figure 2). This area falls within the Southern Pine Region, which is essentially co-extensive with the Atlantic Coastal Plain physiographic province. The most prominent vegetational feature of much of this region is evergreen trees growing on the rather low-lying, poorly drained soils. Intensive forest management practiced in the study area for several years has resulted in a full spectrum of forest cover conditions, such as recent clearcuts, various stages of growth following artificial regeneration of pine, and natural stands of both pine and hardwood. Approximately 305 kilometers (190 miles) of logging access roads dissect the study site, and it was hoped that this extensive road system would be helpful for quickly and accurately identifying any given forest compartment within the tract.

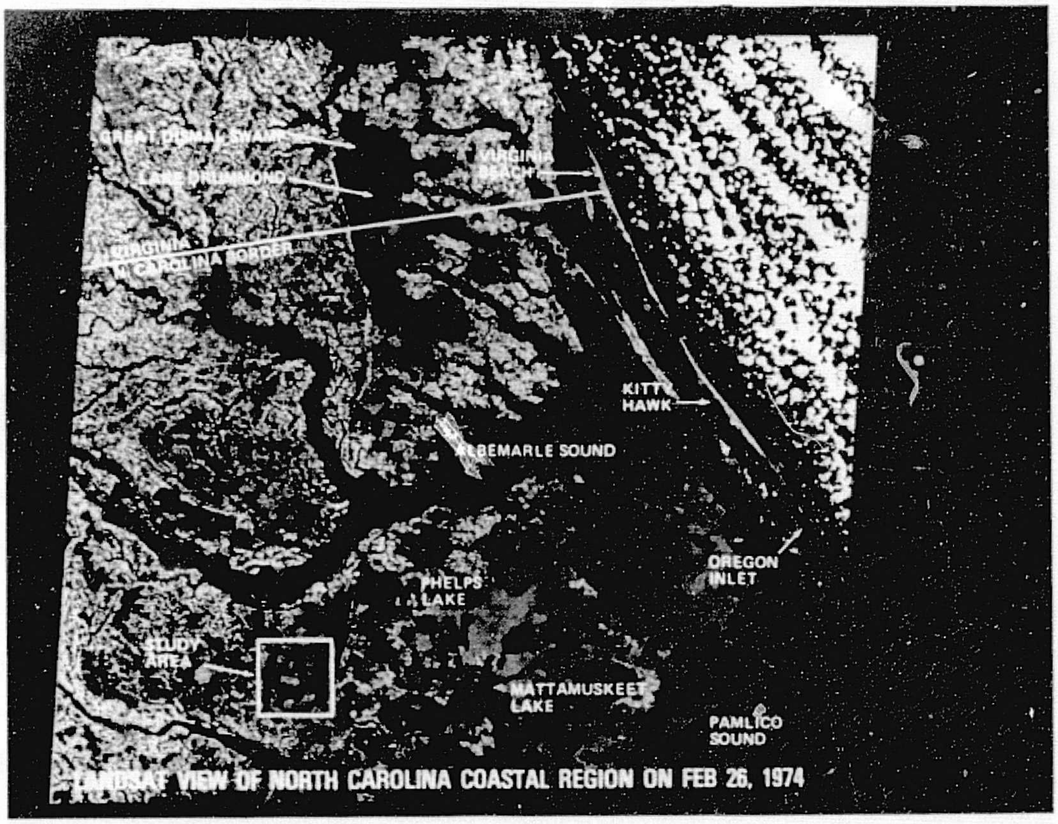

Figure 2. A Landsat view of the North Carolina Coastal Region on February 26, 1974.

DESCRIPTION OF LANDSAT DATA AND SUPPORT MATERIALS

Winter (February 26, 1974/ID#1583-15100; Figure 2) and summer (August 30, 1973/ID# 1403-15134) Landsat-1 scenes of the North Carolina Coastal Region were selected for detailed analysis of the study area. These scenes were selected to take advantage of temporal changes in the forest canopy, as past studies have shown that this approach enhances the separability of hardwood and pine stands. In support of this Landsat coverage, Weyerhaeuser provided: (1) black and white aerial photographs (9-inch by 9-inch stereo pairs) at a scale of 1:75,000 taken on March 15, 1974 (Figure 3), (2) 70-mm color infrared (IR) aerial photographic transparencies in stereo at a scale of 1:36,000 taken during April of 1975, and (3) company maps and records showing stand age and species composition by compartment. Other forms of support materials available were: (a) orthophotoquads prepared by the United States Geological Survey (USGS) from 1:76,000-scale black and white aerial photographs taken April 11, 1974, (b) natural color aerial photographs (9-inch by 9-inch stereo transparencies) at a scale of 1:45,00 taken on February 26, 1975, by the Environmental Protection Agency (EPA).

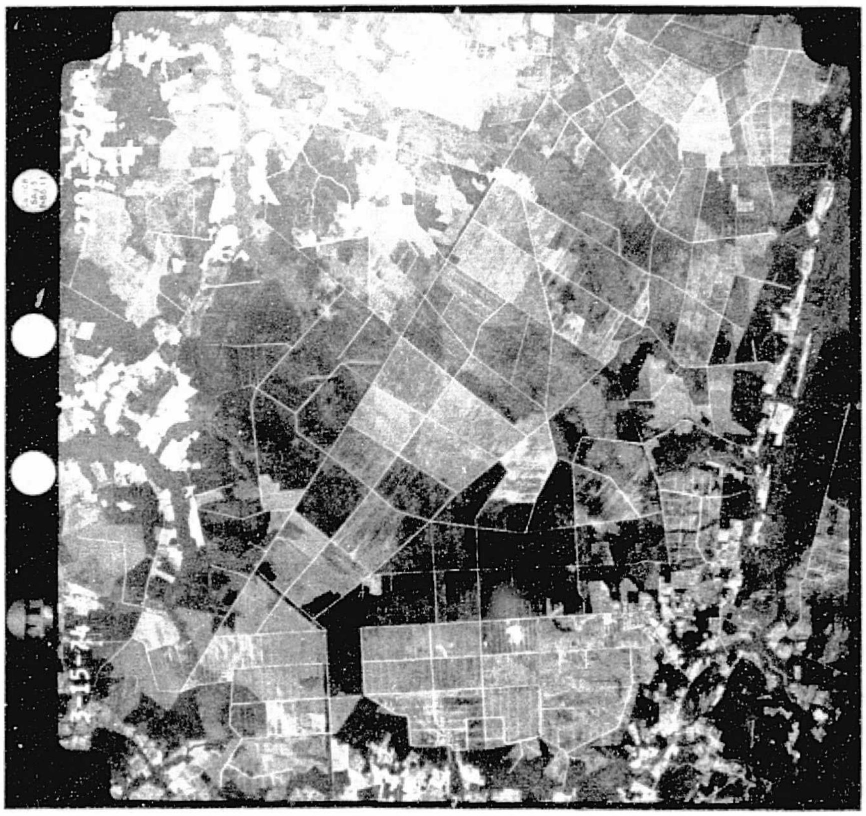

Figure 3. Black and white aerial photograph of the J&W Tract now used by Weyerhaeuser (March 15, 1974).

GENERAL PROCEDURES IN THE ANALYSIS OF LANDSAT DATA

Although Landsat false-color composites (Figure 2) can be useful photointerpretative products when enlarged to appropriate scales, they portray only a fraction of the available information. In recent years numerous digital processing systems have been developed to analyze the Landsat MSS digital data, and thus provide a means for optimum discrimination of selected phenomena. While each of the systems has unique characteristics, they have much in common.

The majority of the computer processing conducted throughout this investigation involved using the system developed by researchers at the Office for Remote Sensing of Earth Resources of the Space Science and Engineering Laboratory (ORSER/SSEL), located on the University Park Campus of Pennsylvania State University (Appendix C). The ORSER system has been implemented on an IBM System 370 Model 168 computer located at the Computation Center on the University Park Campus. This system is not conversational in that the user and the system dynamically interact during processing, but the user can interactively access the system, modify control parameters, and submit jobs for batch processing from Remote Job Entry (RJE) terminals. In this respect, runs are submitted to the Computation Center from Goddard Space Flight Center and output is received at GSFC on an IBM 2780 intermediate-speed remote batch terminal with dial-up capabilities.

The Small Interactive Image Processing System/Video Image Communication and Retrieval (SMIPS/VICAR) (Appendix D) image processing system at GSFC was used at two stages in the investigation to obtain specialized output products. It was used initially to enhance the contrast among MSS digital data values within the study area. This procedure, known as "contrast stretching," greatly improved the quality of the false-color composites generated on a color image recorder. At a later stage in the investigation, the SMIPS/VICAR was used to register geometrically the MSS data from the two Landsat scenes, to allow simultaneous analysis of data collected on the two different dates.

In order to use MSS digital data-processing systems such as ORSER and SMIPS/VICAR, it is usually necessary to define the spectral reflectance characteristics (i.e., spectral signatures) of the various cover types or categories to be mapped. This is generally done by: (a) selecting representative training areas for each category within the study area, (b) finding the mean spectral signatures and other statistics for these training areas, and (c) using these statistics as a basis for obtaining classification output of the entire study area. The standard output is a digital character map with each category of classification represented by a unique symbol selected by the data processor. These maps are then compared with available ground truth to assess overall validity. If discrepancies are noted, successive refinements in classification techniques are then followed until a satisfactory match between the computer-produced maps and ground truth is obtained.

RESULTS

Winter MSS Data

The MSS digital data for the February 26, 1974 Landsat overpass were the first to be analyzed because the Computer Compatible Tapes (CCT's) were already available at GSFC, and it was felt that the hardwood and pine forest canopies would be much easier to delineate in the winter scene.

A SMIPS/VICAR contrast enhancement of the study area (Figure 4) resulted in a color composite photographic product which, depending on the uses, may be easier to interpret than the black and white aerial photographs (Figure 3) now used by Weyerhaeuser. Clearcut areas (i.e., cutover, burned, or otherwise denuded forestland) appear to be almost black in the color composite and are readily identifiable. These clearcut areas are not nearly as obvious in the black and white photographs.

As hoped, the logging roads within the study area were identifiable (Figure 4). This proved to be a tremendous aid in the location and selection of training areas, as any given forest compartment within the tract could be quickly and accurately identified. The fact that the roads did show up may seem surprising, as the nominal resolution of the Landsat MSS is 80 meters (260 feet), yet the road right-of-ways are only 18 to 24 meters (60 to 80 feet) wide. This apparent resolution anomaly can be explained by the abrupt contrast in cover types encountered in the transition from large, homogeneous forest areas to sandy, barren roads (Figure 5).

Use of the ORSER system and the basic procedural steps previously outlined showed that the hardwood and pine forest canopies had distinctive spectral characteristics in the winter scene (Table 1). Spectral signatures were also extracted for clearcuts and areas that had been replanted (i.e., artificial regeneration). However, using the winter data, all attempts to divide any of these broad categories into statistically separable subcategories related to stand characteristics such as age, vigor, or density were unsuccessful.

Summer MSS Data

Following analysis of the winter scene, the August 30, 1973 Landsat data were analyzed using the same procedures. As far as possible, the training areas used in the winter scene were selected again in the summer scene. The extraction of separable hardwood and pine spectral signatures, easily done in the winter scene, was more difficult to obtain from the August data. This problem was not totally unexpected, since the difference in spectral reflectance characteristics should be greatest when there is no hardwood foliage reflecting incoming radiation. As in the winter scene, signatures were also extracted for clearcuts and areas of pine regeneration. Table 1 reveals that the spectral reflectances and standard deviations for all categories are higher for the August data than for 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, hardwood seedlings, stump sprouts, and weeds) with nearly complete foliar development.

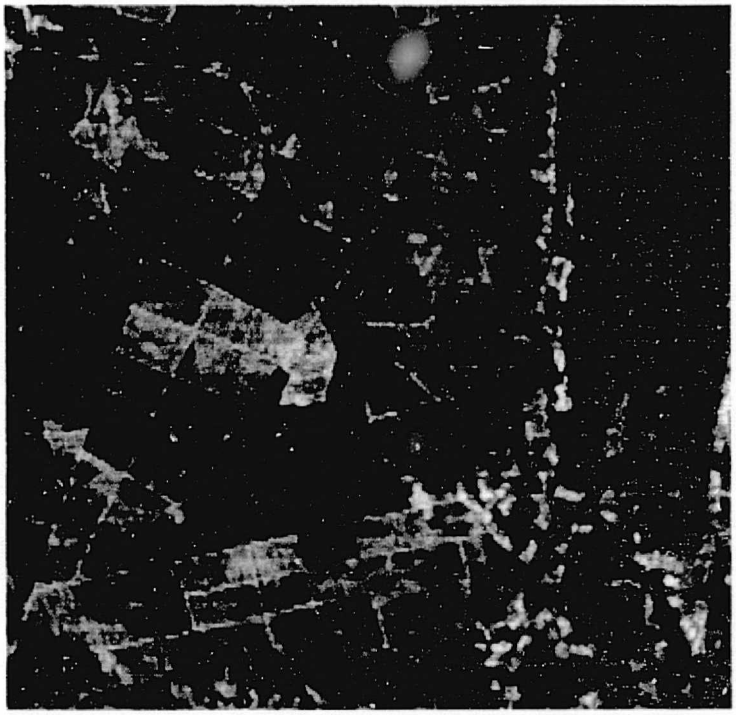

Figure 4. A "contrast stretched" false-color composite of the J&W Tract using February 26, 1974 Landsat data.

At this point, attempts were made to divide the general categories above into subcategories related to stand characteristics. Weyerhaeuser had color-coded a map of the J&W Tract which grouped the various pine stands into the following age classes: 0 to 6 years, 6 to 20 years, and 20 years and older. Representative training areas within each age class were selected, and statistical analyses of the MSS data were done. No noticeable relationship between age and spectral reflectance was noted. Again, this was not totally unexpected, since there are no notable changes in a tree's color (i.e., reflectance) between the ages of 6 and 7 or 20 and 21. Moreover, the size of the trees in any given compartment is more often a function of site index, site preparation, or drainage rather than age.

Because of these results a different approach was taken. Photointerpretation of the various forms of available aerial photography revealed varying degrees of pine crown closure that might be discernible using Landsat MSS data. Three categories of crown closure were outlined on the aerial photography, and each was named and defined. These categories and their descriptions, unique to this study, are listed on the next page.

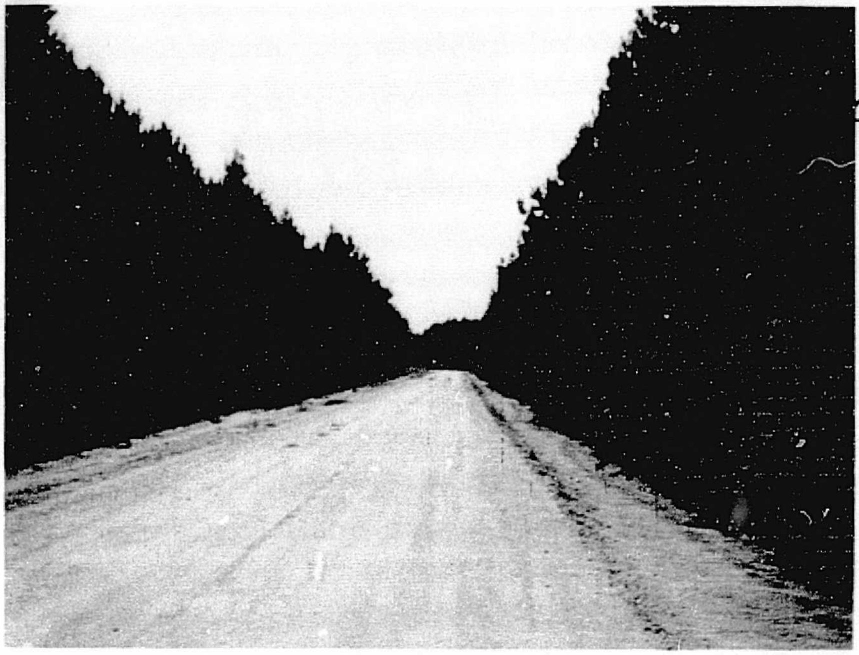

Figure 5. Photograph taken in the J&W Tract showing the abrupt contrast between forest and road.

closed canopy pine – a dense, homogeneous crown cover obscuring all ground vegetation.

partial pine canopy closure – 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.

open canopy pine – 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 category were selected, and statistical analyses of the corresponding Landsat MSS data were done. This time the spectral signatures for each pine subcategory were statistically separable. Close examination of the spectral signatures revealed a rather interesting relationship (Table 1). The response differences between subcategories were minimal in MSS bands 4 and 5, but there was a step-wise increase in reflectance in MSS bands 6 and 7, as the canopy became more open. Figure 6 is a plot showing the relationship of MSS band 6 (y-axis) and MSS band 7 (x-axis), for each of the three pine subcategories. The length of the lines which intersect to form each point in the graph corresponds to the standard deviation of the band 6 and 7 radiance. The increase in spectral reflectance, as the canopy becomes more open, can be explained by the increase in the lush understory vegetation prevalent in the August scene.

Table 1

Spectral Signatures by Season, with Standard Deviation by MSS Band and Number of Observations within Each Training Area

	AUGUST 1973				FEBRUARY 1974				
Category Name	MSS 4	MSS 5	MSS 6	MSS 7	MSS 4	MSS 5	MSS 6	MSS 7	No. of Obs.
Hardwood	25.92	15.72	37.76	44.18	19.03	13.65	19.43	21.92	293
Std. Dev.	1.20	0.94	2.61	2.88	0.86	0.82	1.51	2.44	
Closed Canopy Pine	27.10	16.21	38.74	43.12	18.62	12.13	23.77	26.82	39
Std. Dev.	0.64	0.66	1.29	1.82	0.54	0.77	1.29	1.28	
Partial Closure Pine	27.07	15.97	41.95	48.14	18.44	12.11	24.03	28.36	73
Std. Dev.	0.87	0.78	1.17	1.68	0.78	0.87	1.43	1.38	
Open Canopy Pine	27.72	17.33	44.69	51.66	19.71	14.47	23.47	27.50	236
Std. Dev.	1.06	1.21	1.89	2.74	0.90	1.07	1.86	2.40	
Regeneration	29.40	21.57	42.91	47.02	22.56	21.85	26.42	30.14	129
Std. Dev.	1.18	1.14	2.00	2.52	0.87	0.91	1.57	1.56	
Older Clearcuts	28.63	20.97	31.33	31.46	20.76	17.06	18.85	19.40	104
Std. Dev.	1.48	2.40	2.40	2.28	1.57	2.17	2.47	2.64	
Recent Clearcuts	30.62	25.17	27.32	25.24	20.02	14.85	14.87	14.10	95
Std. Dev.	1.22	1.51	1.81	2.28	1.10	0.93	1.73	2.22	
Change Detection*	28.85	18.38	46.85	52.30	19.23	13.77	12.69	10.62	13
Std. Dev.	0.90	1.39	1.57	1.60	0.73	0.83	1.11	1.26	

*This unique signature, which depicts forest vegetation in August and clearcut (burned) in February, can only be obtained by using temporal data.

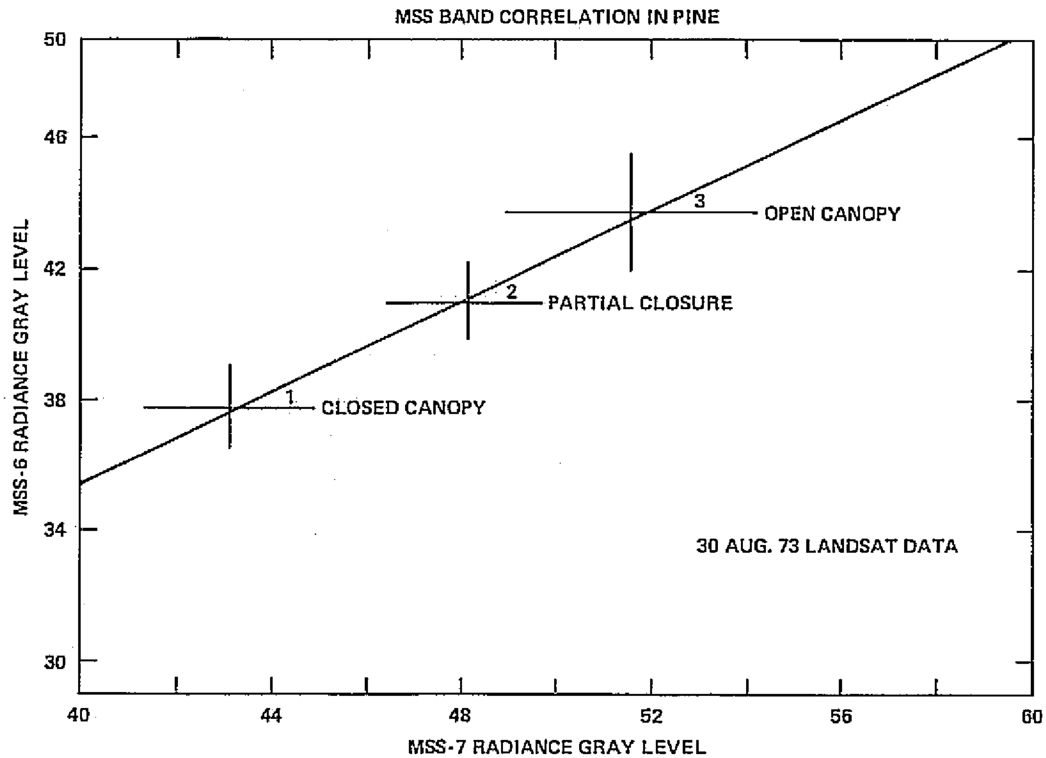

Figure 6. Graph of August MSS bands 6 and 7 showing increase in reflectance as the pine canopy becomes more open.

Although this appraisal of crown closure is not a direct measure of tree age, it could allow a relative assessment of tree size and/or the stocking level (number of stems per acre) of the pine component. By combining this type of information with existing records and observing the closure advancement over time, forest managers may be able to draw conclusions concerning the growth rate and quality of forest stands. In addition, if this subdivision of the pine population were used in the first stage of a stratified random sampling scheme, it could contribute to timber inventory estimates.

In this statistical technique, a population is subdivided into strata, as a preliminary to sampling, such that each stratum is more homogeneous than the population as a whole. A random sample is then taken from each stratum, but the sampling fraction need not be the same for all strata. 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 at each stage in the inventory so that fewer ground sample plots are generally needed.

Temporal MSS Data

In the final stage of analysis, MSS data from the two Landsat scenes were combined to yield 8 channels of temporal data. However, before the two data sets were routinely merged on the ORSER system, they were preprocessed at GSFC using the SMIPS/VICAR system to ensure the best possible registration of selected ground control points common to both scenes.

The training areas previously selected from the individual scenes were used to obtain 8 channel spectral signatures (Table 1). An additional training area was selected to represent the forest stands that were harvested or otherwise destroyed between August 1973 and February 1974. These stands 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 7). The red "X's" in Figure 7 represent areas where drastic changes occurred. The remaining categories represented on the computer classification are defined by the color bar along the left-hand side of the map. The blank areas are unclassified. This does not imply that spectral signatures could not be extracted for these areas, but they represented such a small fraction of Weyerhaeuser's ownership that additional processing was not deemed necessary. For example, the majority of the unclassified areas, which are located along the left fringe of the map, were known to be agricultural fields outside of Weyerhaeuser's ownership. In addition, the location of unclassified areas can be of considerable informational value to the user, as it quickly calls attention to features not represented in the user-selected training areas.

The computer generated map shown in Figure 7, depicting an area roughly the equivalent of the Pinetown NW 7½-minute USGS orthophotoquad, is the final output product for the project. Therefore additional steps were taken to enhance its interpretability. For example, the parallelogram shape is a result of rotation of the output, to compensate for the eastward rotation of the Earth under the satellite during scanning, so that north is now parallel to the y-axis. Other considerations were: (1) scaling the output to approximately 1:24,000 to facilitate comparisons with 7½-minute USGS orthophotoquads, (2) printing the output in colors and tones of color to allow easier recognition of the various categories, and (3) preparing an acetate overlay of the road system to aid user orientation and to facilitate the location of points of interest.

The area outlined in red in the lower portion of Figure 7 is shown enlarged in Figure 8, along with a corresponding frame of color IR aerial photography, so that the reader can easily compare the two remote sensing products. Table 2 summarizes the added advantage of using Landsat temporal data to improve delineation of categories.

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 1974 data, and the pine category breakdown, done only with the August 1973 data, were both accomplished using temporal data.

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

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

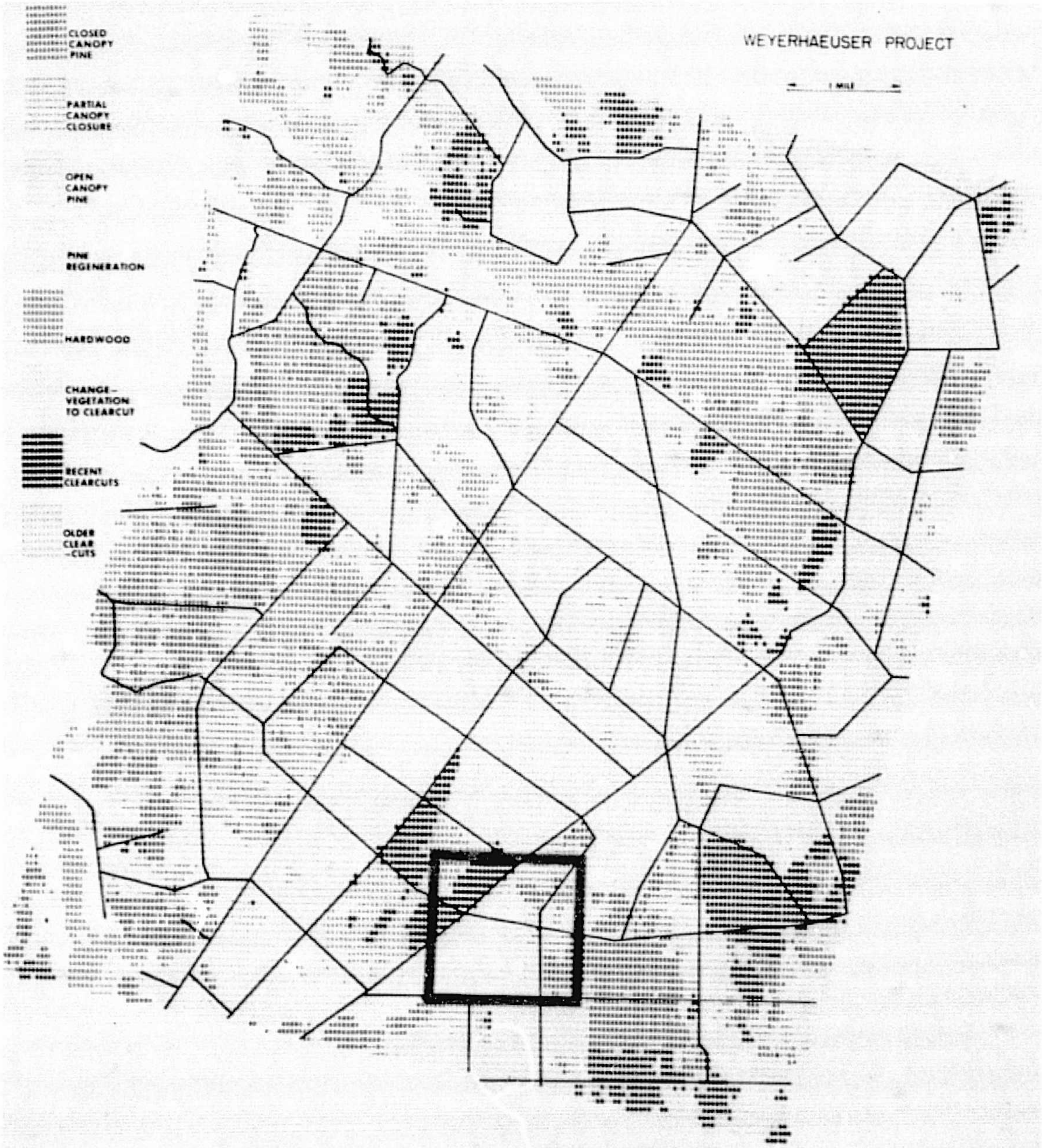

Figure 7. Final ORSER computer classification of the J&W Tract using Landsat temporal data.

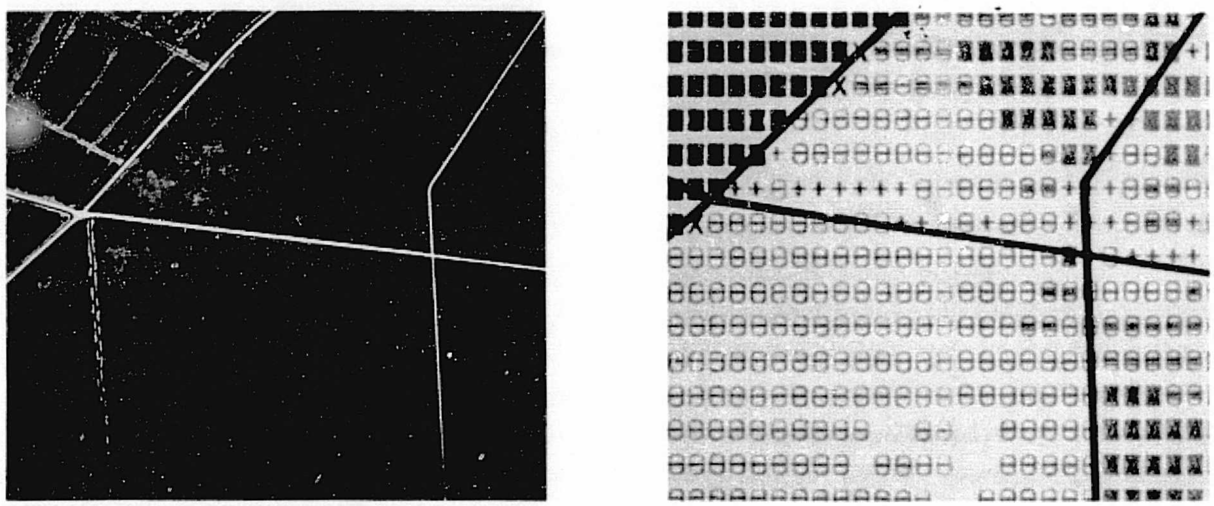

Figure 8. A comparison of color IR aerial photography (left) with a computer classification of Landsat temporal data.

Table 2

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

	Category Delineation		
Category	Feb. 74	Aug. 73	Feb. 74 and 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 February 26, 1974 data, but a breakdown into meaningful sub-categories was not possible.

Reliability of Landsat Classification

The final phase of the investigation was concerned with determining the overall accuracy of category delineation. This is usually done by comparing various forms of ground truth, such as aerial photography, with the computer classification results. Quite often this is a difficult task, since there is seldom adequate aerial photographic coverage available, or other forms of ground truth data collected, within a reasonable time interval of the specific Landsat overpass being analyzed. Even if complete aerial coverage of the desired film-type and resolution were available, there would still be problems 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 0.44 hectare (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 color and color IR aerial photography described in the "Description of Landsat Data and Support Materials" section were the two major forms of ground truth used in this phase of the investigation. They provided coverage of two-thirds, and the remaining one-third of the study area, respectively, and thus a common data base of a given film-type was not available. The general procedure used to compare the aerial photography with the computer classification of Landsat temporal data is described below:

(1) The training areas used to obtain the spectral signatures for each Landsat category were identified on aerial photographs (to serve as a reference for photointerpretation of the entire study area).

(2) An experienced photointerpreter manually classified the entire study area into the various Landsat-derived categories. (NOTE: The older clearcut, recent clearcut, and change categories were all combined into one class called "clearcut.") The method used was direct stereoscopic viewing of the color and color IR transparencies on a light table, with the right-hand member of the stereo pair covered with matte surface Mylar, upon which delineations of the class boundaries were made in pencil. The resulting Mylar overlay was then transferred through a Bausch & Lomb Zoom Transfer Scope onto the 1:24,000 road system overlay. To avoid biasing his decisions, the photointerpreter never referred to either the computer classification map or the contrast stretch enhancement for clarification or comparison.

(3) Using the Landsat scan line and pixel numbering scheme as a grid system, 400 random scan line/pixel coordinates were generated by computer and manually located on the final classification map. Of the 400 random coordinates, 232 points fell within land owned by Weyerhaeuser, which is slightly more than a 1-percent sample of the classified pixels. Of the 168 random coordinates not used, approximately 140 fell in the "unmapped zone," that

results when a parallelogram is enclosed by a rectangular grid. Another 26 points fell along the left-most fringe of the map on land not owned by Weyerhaeuser, and 2 points were dropped due to lack of aerial photographic coverage.

(4) The 1:24,000 Mylar transparency containing the road network and the photointerpretation classification results was overlaid onto the computer map. A third party then made comparisons between the manual and digital classification results at each of the 232 randomly located pixels.

The results of this comparative effort are summarized in Table 3. 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 in agreement. All remaining numbers indicate those points of comparison that 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 94 percent 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 at 70 percent. For individual categories, the percentages of agreement ranged from a low of 54 percent for clearcut, to a high of 94 percent for hardwood. Close examination of the table shows that of those pixels that 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. For certain neighboring categories, such as regeneration and clearcut, the percentage of "overlap" is quite high, and tends to unjustifiably degrade the computer classified results.

In light of this, it is appropriate to include the following discussion of the factors affecting a photointerpreter's delineation of cover categories and their boundaries, as described here by the photointerpreter. In general, the factors fall into two groups: those arising from the interpreter and those arising from the imagery used.

Interpreter-induced Errors

The majority of interpreter-induced errors are a result of inconsistent decision making in the delineation of boundaries in areas of gradual change. In this study, inconsistent delineation within the pine classes presented the greatest problems, even though there were training areas for reference. In general, the breakdown was based upon: *closed*, virtually no ground showing between the trees; *partial*, some, but not much open spacing of trees; *open*, a "thinning out" of tree spacing, ranging from many trees to virtually bare ground; and *regeneration*, sparse, grassy vegetation, plus definite signs of recent human activity such as furrows and/or rows of seedlings. All of this is subjective, of course, and in the zones of transition it was quite difficult to decide on the boundaries between two classes.

Table 3

Results of Comparison Between Air Photo Interpretation and Computer Classification of Landsat Digital Data

Computer Classification of Landsat Data	Photointerpreter Classification of Aerial Photos: Hard-wood	Closed Canopy Pine	Partial Pine Canopy Closure	Open Canopy Pine	Regen-eration	Clear-cut	Com-puter Pixel Count	Percent 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		61	87%
Regen-eration		1	1	17	37	7	63	59%
Clearcut					15	18	33	54%
							162/ 232	70%

Imagery-induced Errors

The color IR, with its better spatial resolution and color tone rendition, provided superior interpretability, but classification was troublesome when color IR was not available. The color photography was taken from a higher altitude and offered less spatial resolution and color separability. Even with the color IR, there was still the probability of gradational error, as that is subjective, but few misidentification errors were possible. With the color, some hardwood/ pine confusion occurred, and it was difficult to determine the state of regeneration of some cleared areas.

Regrouping of Results

In view of the points made in the foregoing discussion, it is appropriate to regroup the results presented in Table 3. Since the greatest potential for error was the subjectivity 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 4 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 3.

Table 4

Results of Regrouping the Data Presented in Table 3

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

*These pixels of disagreement were between the nearest neighbor categories of regeneration and clearcut. See Table 3 for details.

As in Table 3, the values on the diagonal represent agreement. In Table 4, the overall agreement is 90 percent and the agreement for the individual categories of hardwood, pine, and clearcut are 94 percent, 96 percent, and 54 percent, respectively. This regrouping did not alter the results for hardwood or clearcut, but the level of disagreement in the clearcut category is more apparent. This discrepancy can be explained by the fact that the color and color IR photography were taken in February and April of 1975, approximately 18 to 20 months after the August 1973 Landsat coverage, and about a year after the February 1974 overpass, which is ample time for regeneration to have been completed. (NOTE: A major objective of Weyerhaeuser's intensive forest management program is to replant all forest compartments within one year of harvest.)

Although these factors undoubtedly had considerable effect upon the comparison of the manual and digital classification results, the level of disagreement for clearcuts was too large to ignore. As previously stated, one of the major problems was to determine the reliability of acreage estimates which could be obtained using Landsat MSS data, particularly for the clearcut category. To answer this problem, and to support the explanation for the poor level of agreement for the clearcut category, four clearcuts of varying size were selected from the computer map of the J&W Tract. The acreage of each was estimated by counting pixels and multiplying by the acreage per pixel conversion factor of 1.1. These estimates were then compared with the acreage figures in the company forest inventory records, which are calculated by tracing the estimated clearcut boundaries with a Graf-Pen digitizer. Table 5 summarizes the results of this comparison.

These results suggest that computer classification of Landsat data could be used to make reliable acreage estimates of recent harvest activities. The large overestimate for clearcut #4, which may be unacceptable for operational use, was actually felt by Weyerhaeuser personnel to be the result of an underestimate in their own stand records. Such errors are not uncommon in the North Carolina Region due to the human interaction involved in accurately identifying the clearcut boundaries and in placing of the digitizer on these estimated boundaries. (NOTE: All other Weyerhaeuser Regions actually survey their clearcut areas.) In addition, the percentage of error in acreage estimation by any method would be expected to be greater for relatively small clearcuts. Smaller clearcuts are seldom bounded by roads or other distinctive landmarks, making accurate boundary delineation for digitization even more difficult. There is also a greater percentage of border versus total surface area, increasing the probability of "mixed pixels" which might affect classification.

Table 5

A Comparison of Clearcut Acreage Derived from the ORSER Classification of Landsat Data versus Clearcut Acreage Taken from Company Inventory Records

	Landsat Acreage	Inventory Acreage	Percent Error
Clearcut #1	321	295	+ 8.8
Clearcut #2	39	39	0
Clearcut #3	580	580	0
Clearcut #4	51	44	+17.3
Cumulative Results	991	958	+3.4

In summary, the percent agreement between photointerpretation and computer classification of Landsat temporal data was on the order of 90 percent. If the Landsat classification data could have been compared to field data gathered at or near the time of overpass, rather than aerial photographs taken 12 to 20 months after Landsat coverage, an even higher level of agreement may have resulted. Computer processing of Landsat data also provides an important element of consistent delineation based upon spectral characteristics, thus avoiding the inherent variability in human judgment decisions.

A PARTIAL COST ASSESSMENT

An important issue that must be considered in any technology transfer activity is the operational cost to the adopter of using the technology.

The cost assessment presented here does not answer the question of operational costs. We have been working in an exploratory environment to determine the types of information that Landsat might provide a forest manager, rather than to replicate a prescribed information set already assembled by Weyerhaeuser. Some of the costs of an exploratory environment (e.g., education, training, and certain trial and error efforts) will not normally be repeated in an "operational" environment. Furthermore, this report is only a partial statement of the technical performance opportunities discovered in this project. Thus, the cost-to-value (to Weyerhaeuser) ratio for Landsat is highest in this exploratory phase. Although this cost will decrease over time, with the discovery of new applications and with greater familiarity and efficiency on the part of analysts, some cost comparison with existing practices is necessary in order to evaluate properly the prospects for Landsat now and in the future as a forest management tool.

The Intralab and Weyerhaeuser staffs agreed to a cost comparison (excluding salaries and other personnel costs) for annually mapping clearcuts in the entire study region, since this is an important element in Weyerhaeuser's long term forest management plans. Under Weyerhaeuser's High Yield Forestry Program, all cleared lands are artificially regenerated as soon as possible, usually within a year from harvest.

The cost estimates presented in Table 6 were based upon the following guidelines: (1) four Landsat scenes would be necessary to cover the 263,000 hectares (650,000 acres) of company holdings scattered throughout the region, and (2) the required processing (single date optimized for favorable seasonal conditions) would use the ORSER system implemented on an IBM 370/168 computer, at a commerical usage charge of $720 per hour. These two conditions resulted in an annual average cost estimate of $2250.

Weyerhaeuser staff, as a separate effort, concluded that their costs for estimating clearcut acreages for the region run about 15 percent less per year.

The first conclusion one can draw from this assessment is that the cost for Landsat derived information of annual clearcut acreage is competitive with the costs of current company procedures in the North Carolina Region. More important, should regional forest managers attempt to improve upon these procedures, the method tested and reported here is clearly a mission-effective alternative for such a job. It should be remembered, moreover, that "clearcut" is but one of several land cover classes that can be accurately mapped from a single Landsat data set.

This is a necessarily simplistic view of costs, however. The "real" costs of the adoption of a new technology include such factors as integration into existing systems, personnel training, and familiarization. Moreover, these must be weighed not merely from the perspective of a single component (e.g., the North Carolina Region), but rather from the viewpoint of the

Table 6

Cost Estimate for Using Landsat Data to Annually Derive Regional (North Carolina) Clearcut Acreages

A.	Landsat Data Procurement Costs	
	Standard Photographic Products	
	up to $100/scene X 4 scenes = $400, or Average of $200	
	Computer Compatible Tapes (CCT's)	
	$200/scene X 4 scenes = $800	
	Total Data Procurement Costs (Average)	$1000
B.	ORSER System Digital Processing Costs*	
	Total Area of Company Holdings in the North Carolina Region — 263,000 hectares or 2630 km^2	
	2630 km^2 @ $0.35/$km^2$ = $920	
	2630 km^2 @ $0.60/$km^2$ = $1580	
	Total Processing Cost — $920 to $1580 or Average Processing Cost of	$1250
	Total Annual Landsat Cost (Data Procurement + Data Processing)	$2250

*Experience on the ORSER system has generated processing costs ranging from $0.35/$km^2$ ($0.90/sq. mi.) to $0.60/$km^2$ ($1.56/sq. mi.), depending upon such variables as the number of categories mapped, types of final products required, etc.

entire organization. It would be naive to presume that the costs and benefits identified in a sharply focused project in one area can be satisfactorily extrapolated to the broader, often untested, needs of the parent organization. However, these results do form a critical base for a proper evaluation of risk-versus-potential benefit of adopting a new technology.

CONCLUSIONS

The conclusions of this report are presented below, based on the specific results that were produced from Landsat data during the project.

(a) Analysis of Landsat temporal data, specifically the digitally merged winter and summer scenes, provided the best overall classification results.

(b) Comparison of temporal classification results with available ground truth revealed a 94-percent agreement in the delineation of hardwood categories, a 96-percent agreement for the combined pine category, and a greater than 50-percent agreement for each individual pine subcategory.

(c) For the nearly 1000 acres compared, clearcut acreage estimated with Landsat digital data differed from company inventory records by only 3 percent.

(d) Through analysis of summer data, pine stands were successfully classified into subcategories based upon the extent of crown closure.

(e) The maximum spectral separability of hardwood and pine stands was obtained from the analysis of winter data.

(f) Digital enhancement techniques provide false-color composite images which, in many instances, are easier to interpret than conventional black and white aerial photography (See Cover and Figures 3 and 4).

RECOMMENDATIONS

This Intralab project focused on a few specific technical objectives. The results indicate that Landsat-derived information complements traditional forest management information sources. More important, the results should increase the confidence of forest managers in using Landsat for routine inventory programs. A more extensive investigation could more fully answer questions concerning Landsat-derived information for assessing: (1) gross drainage patterns, (2) insect and disease damage in a time frame compatible with establishment of corrective measures or salvage operations, (3) tree growth and vigor as affected by adverse weather conditions, and (4) other parameters which affect forest mangement decisions.

The U.S. Geological Survey's EROS Data Center, in cooperation with NASA, has been implementing technical and administrative improvements to ensure more timely delivery of data products. Further, the Center is preparing to offer to the public a greater variety of data products to serve the varied needs expressed by customers. In support of these initiatives, and in response to our shared experience with Weyerhaeuser, Intralab has three general recommendations to make with respect to public distribution of Landsat data.

1. A serious committment to data delivery times on the order of one week must be made (five working days from receipt of order until order is put in the mail).

2. Certain digitally enhanced photo products (contrast stretched) to facilitate photointerpretation of Landsat images should be routinely available.

3. Geometrically registered data should be made available to allow the merging of two Landsat scenes or the overlay of a scene on existing maps.

While several computer analysis systems are available to Intralab for projects (see Appendixes C and D for two examples), the choice of ORSER provided an excellent first test of a remote batch system. Remote Job Entry terminal access (via telephone hookup) proved to have several advantages for newcomers to Landsat digital processing. As one version of such a system, ORSER offers a flexible, high performance software library, but from the user's standpoint, the complexity of analysis procedures is greatly reduced. The system can be an effective teaching tool, allowing the user to interact with a powerful analysis system from his own facility at a pace consistent with his own schedule and level of experience. Finally, a dial-up system allows the user to examine the application of digital analysis techniques to his operations at minimum institutional risk in terms of capital investment (RJE terminal) and cost of services (hookup and computer processing time). Thus a time share, dial-up environment may be a highly cost-effective mechanism with which to introduce newcomers to Landsat digital analysis techniques.

4. Intralab strongly recommends, therefore, that NASA support the development and thorough testing of Landsat classification software libraries on existing (private sector) national time-share networks, in order that the usefulness of this approach to Landsat digital processing may be tested by the broadest possible range of users.

APPENDIX A

LANDSAT SYSTEM DESCRIPTION

Landsat represents the first satellite data acquisition and analysis system dedicated to a global Earth resource investigation program. There are several major components to the system, but for the purpose of simplifying its operational characteristics from the viewpoint of end users, it can be described in terms of three segments: system characteristics and data acquisition, data organization and distribution, and data analysis. The foregoing report describes specific data analysis techniques, so the remainder of this appendix will summarize the first two components of the Landsat system.

SYSTEM CHARACTERISTICS AND DATA ACQUISITION

The first Earth Resources Technology Satellite (ERTS-1, since renamed Landsat-1) was launched on July 23, 1972 (as of December 1976, it was still operating). Landsat-2 was launched on January 22, 1975. Each Landsat is in a circular (near polar) orbit at an altitude of 920 km (500 nmi). It circles the Earth every 103 minutes, or approximately 14 times per day. The daytime orbital pass is from north to south. From such a vantage point, each Landsat can cover the entire globe, except for the poles, every 18 days. Because of this orbit, a unique feature of each satellite is that it views the Earth at the same local time, approximately 9:30 a.m. at the Equator, on each pass.

The nominal forward overlap between consecutive Landsat images is approximately 10 percent. The sidelap between adjacent orbits ranges from 14 percent at the Equator to 85 percent at the 80° parallels of latitude (Figure A-1). Landsats-1 and -2 were originally phased to provide repetitive coverage over the same area every 9 days. The orbit of Landsat-1 has recently been changed so that the repetitive coverage provided by the two satellites over the same area on the ground is now alternately 6 days and 12 days, instead of 9.

Landsat presently carriers three data acquisition systems: (1) a multispectral scanner (MSS), (2) a return beam vidicon (RBV) or television system, and (3) a data collection system (DCS) to relay environmental data from ground-based data collection platforms (DCP's) to one of NASA's receiving stations on the ground.

The MSS is the primary sensor system and acquires images 185 km on a side in four spectral bands in the visible and near-infrared portions of the electromagnetic spectrum. These four bands are:

Band 4 - 0.5 to 0.6 micrometers Band 5 - 0.6 to 0.7 micrometers	visible
Band 6 - 0.7 to 0.8 micrometers Band 7 - 0.8 to 1.1 micrometers	near-infrared

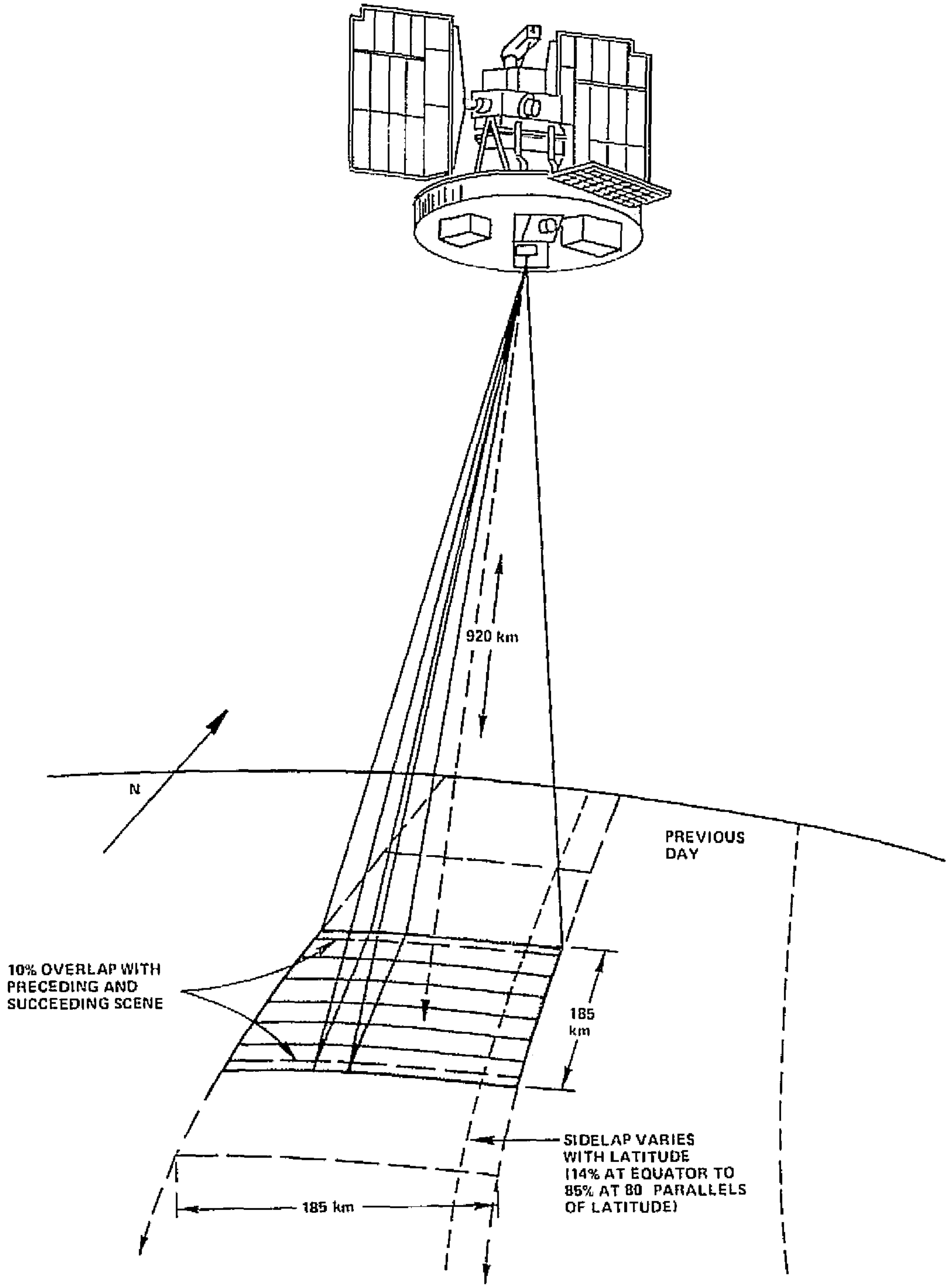

Figure A-1. MSS data acquisition characteristics.

Basically, the MSS consists of an oscillating mirror that scans the ground in a direction perpendicular (west to east) to the satellite orbit path, and a set of focusing optics that transmits the mirror's energy onto detectors filtered for the four spectral bands just described. The output of each detector for each mirror oscillation is a scan line of video data 185 km in length. The motion of the satellite along its orbital path provides for the continuous sequence of scan lines of incoming data that ultimately produce a Landsat scene.

These data are transmitted either directly to NASA receiving stations in Alaska, California, or Maryland (for North America), or stored on a tape recorder for subsequent transmission to the ground (rest of the globe). Several foreign operated stations (Canada, Brazil, and Italy) receive data directly from Landsat, and several new foreign receiving stations are planned.

Landsat photography consists of both paper prints and transparencies (negative and positive), normally produced at a scale of 1:1,000,000 (about 25½ kilometers or 16 miles to the inch), but larger scale products are available from EROS. Figure A-2 is an example of a Landsat black and white print for just one of the four available bands. Part of the annotation has been numbered as a guide to interpreting the image, and the relevant information is as follows:

1. Date on which the scene was acquired by the satellite.

2. Latitude and longitude of center point of the photograph.

3. Band identification, 7 in this instance. One can request individual prints of all four bands or a color composite of any three (usually 4, 5, and 7).

4. Sun elevation and azimuth at the time of data acquisition.

5. Frame identification number, unique for each Landsat scene, in the format 1286-16083-5

   1 = Landsat mission: 1,5 - Landsat-1; 2,6 - Landsat-2; 3, 7 - reserved for Landsat-3

   286 = Number of days from launch to scene acquisition; add 1000 if the Landsat mission digit (above) is 5, 6, or 7.

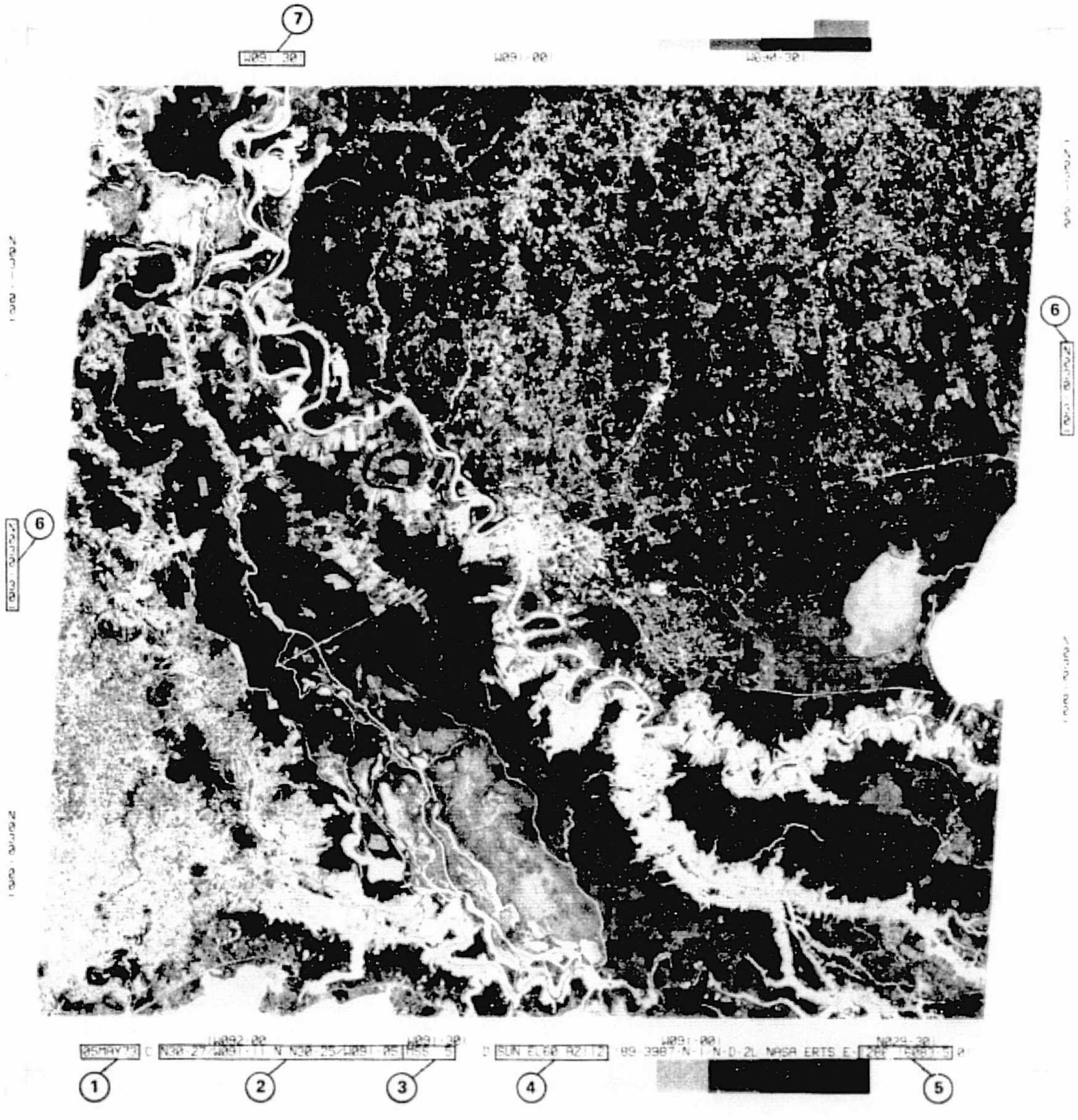

Figure A-2. Landsat black and white print.

16083 = Hours, minutes, and tens of seconds, Greenwich Mean Time, of scene acquisition

5 = Sensor code: 1, 2, 3 = RBV; 4, 5, 6, 7 = MSS

6. Latitude in degrees and minutes. In this instance, 30 degrees, 30 minutes north latitude (measured from the largest bar).

7. Longitude in degrees and minutes. In this instance, 1 degree, 30 minutes west longitude.

DATA ORGANIZATION AND DISTRIBUTION

All data collected by Landsat is processed initially at the NASA/Goddard Space Flight Center's National Data Processing Facility (NDPF) located at Greenbelt, Maryland. The purpose of this processing is to produce archival copies of all data prior to public distribution. The EROS Data Center, administered and operated by the Geological Survey of the U.S. Department of the Interior, distributes all Landsat data to the public[1]. Two basic Landsat data products are available from EROS: CCT's and photographic products.

Computer compatible tapes are generated from the video data transmitted from Landsat. The scan-line data is in the form of a serial stream of discrete digital data values with corresponding ground dimensions of 79 by 57 meters (0.44 hectare or 1.1 acres). The CCT's are standard ½ inch, 7 or 9 track, with either 800 or 1600 bits-per-inch (bpi) packing density.

A Landsat scene is divided into four north/south strips. Thus four CCT's are required for a complete digital tape record of a Landsat scene (Figure A-2). The current cost of a set of four CCT's from EROS is $200.

[1]To place an order, or to request information about Landsat and other remote sensing data products, contact: User Services Unit, EROS Data Center, Sioux Falls, South Dakota 57198, 605-594-6511, Extension 151.

APPENDIX B

GLOSSARY

Canopy—The generally continuous cover of branches and foliage formed collectively by the crowns of adjacent trees and other woody growth.

Clearcut—Removal of the entire standing crop.

Computer Compatible Tapes (CCT's)—Tapes containing Landsat digital data. These tapes are standard 1.3-cm (0.5-in.) wide magnetic tapes in 9-track or 7-track format. Four tapes are required to cover one Landsat scene.

Continuous Forest Inventory (CFI) Plots—An extensive system of permanent sample plots that are established, maintained, and periodically remeasured for purposes of deriving representative forest management data for large tracts.

Contrast (photography)—The ratio of reflecting power between the highlights and shadows of a print. The highest ratio of contrast would be between black and white.

Contrast Stretching—A mathematical procedure used to artificially increase the contrast among Landsat pixels, thus making certain objects in an image stand out sharply.

Digital Classification—Computer manipulation of Landsat MSS digital values singly or in combination, including spatial, temporal, and spectral band relationships for the purpose of representing aggregates of pixels as specific surface features.

False-color Composite—An image created by exposing onto color film three of the four black and white spectral bands in colors other than the original complementary colors. On customary Landsat false color composites, healthy vegetation appears bright red.

Geometric Registration—Superimposition of points on one image with corresponding points on a different image or map of the same scene.

Ground Truth—Information derived from ground data and surveys to support interpretation of remotely sensed data.

Landsat Digital Data—Numbers ranging from 01 to 63 corresponding to the amount of light energy received in each of the four spectral bands for each pixel.

Low Altitude Aerial Photography—Aerial photographs obtained from altitudes of (typically) 15,000 feet or less.

Manual Classification—The identification of features on aerial or orbital photographs by means of photographic recognition elements, namely tone, color, texture, pattern, shape, and size, and combinations of two or more of the recognition elements.

Orthophotoquad—Specially prepared cartographic product resulting from superimposing high altitude photography on standard 7½-minute topographic maps.

Pixel—Picture element; the smallest record of surface reflectance obtained from a sensor system. For Landsat-1 and -2 the dimension of an MSS pixel is 0.44 hectare (1.09 acres). One Landsat frame contains approximately 7×10^6 pixels.

Preprocessing—Processing of raw multispectral data prior to signature extraction and classification. Examples of preprocessing include corrections made for radiometric and geometric fidelity.

Resolution—The minimum area of surface imaged by a sensor system.

Scan Line—The cross-track ground area imaged by a scanner system. For Landsat-1 and -2 MSS, a scan line is 79 m wide by 185 km normal to the orbital track. Thus 2320 scan lines comprise a Landsat scene.

Small Interactive Image Processing System/Video Image Communication and Retrieval (SMIPS/VICAR)—The VICAR System is a digital image processing software system originally developed by IBM Corporation under contract to the Jet Propulsion Laboratory. The SMIPS combines the power and flexibility of VICAR with an interactive processing element so that users can manipulate digital imagery in a sequential (batch) or interactive fashion.

Small Scale Data—Maps or photos having map distance to ground distance ratios of 1:100,000 or smaller.

Stand—A continuous group of trees sufficiently uniform in species composition, arrangement of age classes, and condition to be a homogeneous and distinguishable unit.

Stand Density—A measure of the degree of crowding of trees within stocked areas.

Temporal Data—Data acquired for the same area over a time interval.

Training Area—A recognizable area on a Landsat scene with distinct (spectral) properties useful for identifying other similar areas.

Understory—Any vegetation growing under the forest canopy.

APPENDIX C

ORSER DATA PROCESSING SYSTEM

SYSTEM NAME:	ORSER (Office for Remote Sensing of Earth Resources)
LOCATION:	The Pennsylvania State University (PSU)
CONTACT:	Dr. F. Y. Borden
COMPUTER:	IBM 370/168, IBM 1401
AVAILABILITY:	System can be purchased for minimal cost. No support.
ACCESS:	Remote Job Entry (RJE) (slow speed), Remote Batch Entry (RBE) (medium speed) via telephone dialup.
INPUT:	Standard Landsat CCT's. Must be shipped to PSU.
OUTPUT:	Printer map; (color and overstrike available at PSU); card; DICOMED compatible format; CalComp; Ramtek on-line display at PSU.
MINIMUM USER EXPERIENCE:	General familiarity with key punching or RJE operation. One week training.

CAPABILITIES:

Classification:	(CLASS)	Euclidean distance or angular separation from specified categories
	(CLUS)	Unsupervised clustering
	(PARAM)	Parameter classification, based on pattern-set covariance matrix
	(QUADMAP)	Non-parametric with weights derived from corresponding training programs
	(RATIO)	Classifies ratioed data
Other: (UMAP)	Uniformity mapping	
(NMAP)	Display (printer)	
(LMAP)	CalComp display	
(STATS)	Statistical analysis	

(PRINCOM)	Principle components analysis
(CANAL)	Canonical analysis, using means, covariance for specified categories

COST: $0.20/CPU-Sec. (1976); Program efficiency high.

APPENDIX D

SMIPS/VICAR IMAGE PROCESSING SYSTEM

SYSTEM NAME:	SMIPS/VICAR (Small Interactive Image Processing System/Video Image Communication and Retrieval System)
LOCATION:	NASA/Goddard Space Flight Center
CONTACT:	Hans Moik, Code 933
COMPUTER:	S/360-91
AVAILABILITY:	Software can be purchased from COSMIC, Information Services, 112 Barrow Hall, University of Georgia, Athens, Georgia 30602.
ACCESS:	Batch, CRBE
INPUT:	Standard Landsat CCT's
OUTPUT:	DICOMED, printer-plot 4020 graphics
MINIMUM USER EXPERIENCE:	General IBM operating environment, CRBE, plus familiarity with S/V options and control language. One month training.
CAPABILITIES:	
Classification:	(BAYES) 12 channel, maximum likelihood
	(LOOKUP) 4 channel, table-lookup for Bayesian classifier
	(FASTCLAS) 12 channel, parallelpiped
Other:	(KARLOV) principal component analysis
	(STATLINE, HISTO, HIST2, COVAR) statistical programs for mean and standard deviation on a line, histogram, 2-d histogram, covariance matrix.
	(ASTRTCH2, STRETCH) Contrast stretching
General:	This system has a variety of capabilities relative to other available systems. These can be categorized as:
	Image enhancement
	Radiometric transformations
	Filtering and noise removal
	Geometric corrections and map projections

Fourier analysis

Image correlation and registration

Edge enhancement and extraction

Texture analysis

Image annotation and coloration

Classification and Statistics (as above)

COST:

Cost-Effectiveness: These items are a function of the GSFC computer environment which is not comparable with commercially available systems either in unit cost or turnaround time.