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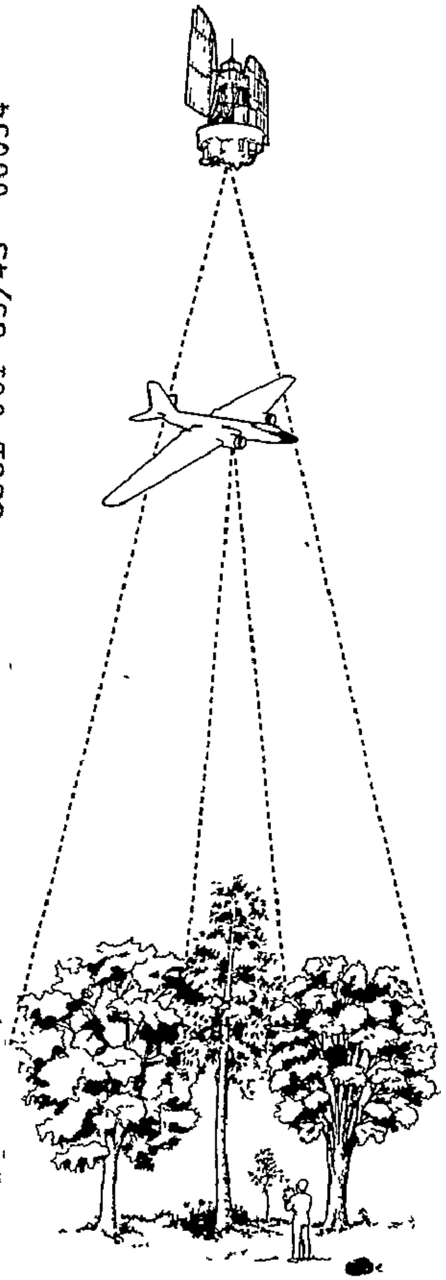

TEN-ECOSYSTEM STUDY (TES) SITE III,
ST. LOUIS COUNTY, MINNESOTA, FINAL
REPORT

J E Weaver
Lockheed Electronics Company, Inc.
Systems and Services Division
Houston, Texas 77058

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J. E. Weaver
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16 Abstract
This report presents the results and conclusions of the analysis which was carried out in St. Louis County, Minnesota, Site III of the Ten-Ecosystem Study. The purpose of the analysis was to determine the level of detail that can be detected using Landsat data and to determine the accuracy at which that level can be detected when using training fields selected in a limited area (10 percent) of the site. A probability of correct classification of 73 percent for Level II was attained using training fields from the limited area. The criteria for performing a Level III classification were not met.

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PREFACE

The Ten-Ecosystem Study is a supporting research and technology project sponsored by the Nationwide Forestry Applications Program, a cooperative effort of the National Aeronautics and Space Administration and the U.S. Department of Agriculture, Forest Service. This cooperative program is designed to sponsor research and development on the application of remote sensing analysis techniques to problems arising from the need to inventory, monitor, and manage forests and rangelands, including the assessment of the impact of insect damage on forest stands.

The Ten-Ecosystem Study was designed as an automatic data processing study using Landsat data, supporting color-infrared aerial photographs, and ancillary information to obtain an inventory of forest, grassland, and inland water in selected sites representing each of the 10 ecosystems.

The primary objectives of the study were to

- Investigate the feasibility of classifying forest, grassland, and inland water areas by administrative boundaries in the 10 ecosystems of the United States by the use of state-of-the-art automatic data processing remote sensing technology
- Identify processing problems and recommend specific solutions for individual sites or ecosystems
- Recommend the definition and requirements of an integrated automatic data processing system to support a nationwide forest and grassland applications system verification test

The secondary objectives of the Ten-Ecosystem Study included:

- Determining type mapping accuracies at two different levels of hierarchy in the ecosystems

- Establishing the season or seasons that offer the greatest potential for type mapping in each ecosystem
- Providing the U.S. Department of Agriculture, Forest Service, with project findings, and conducting evaluation workshops

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1. INTRODUCTION

This report documents the work done on the Ten-Ecosystem Study (TES) Site III in St. Louis County, Minnesota. This site is one of nine being analyzed; it is believed to be representative of the Northern Conifer Ecosystem, as defined by the Ten-Ecosystem Study (TES) Investigation Plan (ref. 1).

Site III (figure 1-1) covers an area of 360 000 square hectometers (890 000 acres) in the northeastern portion of Minnesota, within St. Louis County. The determination of the two best seasons or dates for automatic data processing (ADP) analysis was based on an evaluation of six Landsat transparencies. The data processing consisted of two phases: the separability study and the simulated inventory study. The former was designed to establish the level of classification detail possible using Landsat multispectral scanner (MSS) data. The latter was designed to determine how successfully ADP technology can extend limited ground truth for large area inventories. Classification results from the simulated inventory were analyzed to determine map classification accuracy and feature proportion accuracy.

This site was classified into four Level II features (ref. 1): softwood, hardwood, grassland, and water. If accuracies from the separability phase were 90 percent or above, an investigation of the feasibility of performing a Level III classification would be made.

The following sections present a description and analysis of the study site; the technical approach used; and the final results from preliminary site evaluation, preprocessing, processing, postprocessing, and final evaluation of the overall results at Site III.

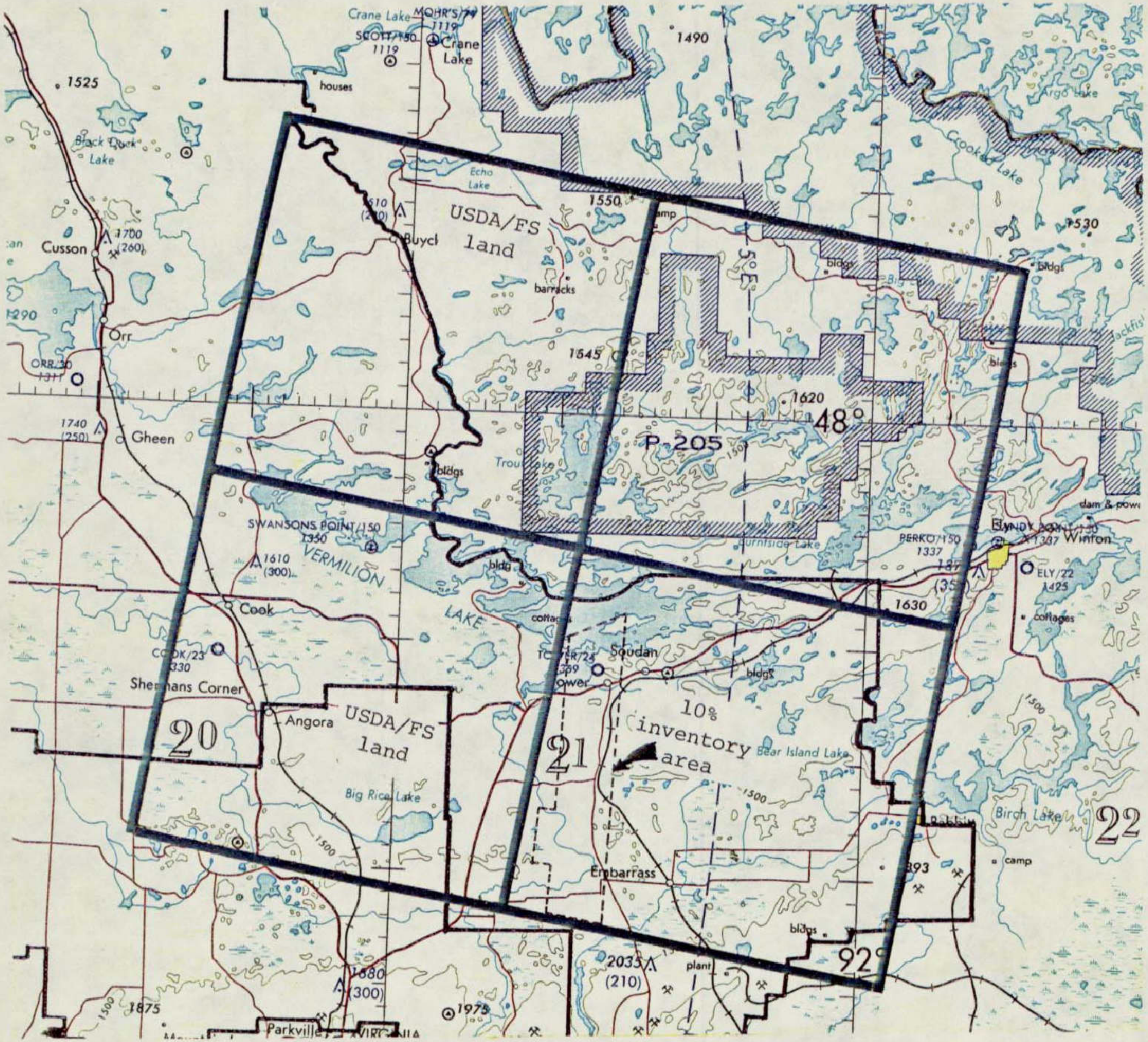

Figure 1-1.- TES Site III Study Site. (The site is divided into four quadrants in order to facilitate the I-100 analyzer.)

2. SITE ANALYSIS

2.1 INTRODUCTION

Before starting the analysis of the site, it was necessary to learn as much about the area as possible. This was accomplished in three ways: by studying literature, maps, photographs, and data relative to the cultural, physical, and biological nature of this ecosystem; by making field inspections of the site; and by communicating with U.S. Department of Agriculture (USDA), Forest Service, personnel who worked in the area. In addition, it was necessary to ascertain which of several portions of Landsat data were acquired and used as a basis for making this determination. The following sections describe the procedures and methods used to learn about the area. Also presented herein are the results of the literature search and the determination of the best data set.

2.2 PROCEDURES

2.2.1 AIRCRAFT IMAGE ANALYSIS (MANUAL)

Six primary frames and their stereographic mates, at a scale of approximately 1:120 000, were used to cover the study area that was to be interpreted manually. The six frames were obtained from an overflight of the National Aeronautics and Space Administration (NASA) aircraft during Mission 345, August 1976. They were contained on roll 2 and included frames 8, 10, 19, 21, 35, and 37.

The basic concept was to interpret the aerial photographs to determine all of the recognizable classes and to use this information to devise a classification hierarchy (Level II). In this way the classifications identified from the Landsat imagery could be compared with the aerial interpretation (table 2-1). Several interpreters were employed so that a general concensus of recognizable features could be obtained. A stereographic example of these aerial photographic classifications is illustrated in figure 2-1.

TABLE 2-1.– CLASSIFICATION LEVELS

Level I	Forest		Nonforest	
Level II	Softwood	Hardwood	Grassland	Water
Level III	Pine Spruce Pine-spruce mix	Aspen Birch Aspen-birch mix Black ash	Pasture Wet grass Dry grass	Census Noncensus

2.2.2 LANDSAT IMAGE ANALYSIS (MANUAL)

Six Landsat frames (dates) covering the study area were available. To determine which of these provided the best data for the ADP analysis, one of the previously interpreted frames of photography taken from high-altitude aircraft was selected to be used as a basis with which to compare the Landsat frames. It would have been impracticable to attempt to use more than one aircraft frame because of the time element. The selected frame covered an area believed to be a good representation of the ecosystem being investigated. The approximate area of the frame (frame 8, NASA Mission 345) was outlined on each of the Landsat frames. Using the Bausch and Lomb Zoom Transfer Scope, each delineated frame 8 area of each Landsat frame was enlarged approximately 4.5 times and interpreted separately using the same hierarchy (Level II) of classification used on the aircraft frames.

LEGEND

1 - Hardwood	5 - Water and bogs
2 - Conifers	9 - Clearcut
3 - Hardwood-conifer mixed	10 - Mixed rock and hardwood
4 - Range and grassland	13 - Clouds and cloud shadow

Figure 2-1.– A stereographic example of aircraft photograph classification.

The categories manually classified and delineated on the Landsat images were water, hardwood, softwood, and grassland. These categories provide a Level II hierarchy of classification, as shown by table 2-1.

2.2.3 SITE DESCRIPTION

Site III is located in the northeastern portion of Minnesota and in the northeastern quarter of St. Louis County. Its area of coverage is 360 000 square hectometers (890 000 acres). The locations of the site corners are approximately 48°14'N – 92°41'W; 48°06'N – 91°51'W; 47°36'N – 92°02'W; and 47°41'N – 92°47'W (figure 1-1). This site was selected because it should be representative of the Northern Conifer Ecosystem which consists primarily of spruce, balsam fir, aspen, and jack pine species. Pine is found on the drier soils, and spruce is found on the poorly drained areas. Aspen is found in the regenerated areas, with balsam fir growing as the lower canopy. The forest economy of this area is oriented mainly toward industries using small sizes of forest products for such things as pulp, posts, chemicals, and mine timbers.

2.2.4 CLIMATE

The temperatures in this area range from -45° C (-49° F) in winter to 43° C (110° F) in summer. The annual precipitation is about 64 centimeters (25 inches), 55 percent of which occurs in the months of May through August. The abundance of inland lakes in Minnesota probably has some effect on the local climate. During the growing season, there is sunshine during 70 percent of the daytime hours. This amount of sunshine reduces the effect of the long winter temperatures in limiting the forest growth.

2.2.5 GEOLOGY AND TOPOGRAPHY

Most of the site is tableland which ranges in elevation from approximately 366 meters (1200 feet) near the Canadian border to 549 meters (1800 feet) near the town of Babbit or around the northeastern end of the Mesabi Range. North of the Mesabi Range, the topography is characterized by linear bluffs and ridges. Vermillion Lake occupies a large portion of the west-central portion of the site, and numerous small lakes are scattered throughout the entire site. North of Lake Vermillion and Lake Birch, glacial drift is very scanty on hills and ridges.

The terrain south of the Mesabi Range covers a portion of the old glacial lake bed commonly called glacial Lake Upham or glacial Lake St. Louis.

In the district between the Mesabi Range and Vermillion Lake, there are rough and very stony strips interposed by nearly plain areas that are partly sand and gravel and partly stony drift similar to that in the moraines. On the Mesabi Range the drift is in places so thickly set with boulders as to form a pavement.

In the east-central portion of the site and trending northeast to southwest, the oldest rock exposure (Keewatin greenstone) in the state can be found. North of this strip are found the granites of the Vermillion batholith, and south are the Giants Range granites.

Another rock exposure is the Knife Lake Series; it is in the west-central portion of the site and is about 29 kilometers (18 miles) wide. The Knife Lake Series occurs as argillaceous slates, cherty slates, tuffaceous slates, graywackes, micaceous schists, gneisses, and conglomerates.

The Virginia slates, greenish gray in color, are found in the southwest portion of the site and lie conformably on the Biwabik Formation. The Biwabik is recognized as a ferruginous chert with a granular texture; it consists of chert, iron silicates, iron oxides, and carbonates which weather to limonite and hematite (ref. 2).

2.2.6 SOILS/VEGETATION RELATIONSHIP

The area soils are classified as Gray-Brown Podzolic, but soil moisture plays an important part in determining sites for different tree species. The driest soils are predominantly sands and are occupied by jack pine, red pine, white pine, and scrub oak or scrub live oak. Mesic soils may support stands of northern hardwoods. Hydric soils are largely organic or gley loams on clays. Depending on the depth of mineral soil and drainage, the latter soils support black spruce, tamarack, elm, and red maple. Poorly drained mineral soils support stands of spruce, balsam fir, and white cedar, in contrast to the pines and northern hardwoods of better drained sites.

On moderately sloping terrain of the northern half of the site, the soils are classified as spodosols. The subsurface horizons have an accumulation of unstratified materials of organic matter plus compounds of iron with rocks, usually. In the southern half of the site the soils are classified as alfisols; this implies a high pH. These soils have gray-to-grown surface horizons and subsurface horizons of clay accumulation. Usually they are moist, but they may become dry during the warm season. In some areas, a clay horizon may occur within 30 centimeters (2 feet) of the surface (ref. 3).

2.2.7 VEGETATION

The forests of St. Louis County, Minnesota, extend over a great percentage of the total land area, and a large portion of this forest land lies within the boundaries of the Superior National Forest. The TES site within the county includes a wide variety of resource situations resulting from combinations of ownership and a variety of land management policies including state and county, private, national forest, and wilderness.

Site III was selected as an example of the Northern Conifer Ecosystem, which is characterized by a combination of spruce-fir forest (*Picea-Abies*), conifer bog (*Larix-Picea-Thaja*), and Great Lakes pine forest (*Pinus*).

The spruce-fir forest is composed of balsam fir and white spruce as dominant species; it also includes other components of maple, birch, ash, aspen, balsam poplar, pine, and cedar. The conifer bog is composed of dominant species of black spruce, tamarack, and white cedar; it includes other components of maple, willow, alder, Laborador-tea, sphagnum, and a variety of bog plants. The pine forest is composed of jack pine, red pine, and remnants of white pine; it includes other components of aspen, birch, oak, maple, dogwood, and hazel.

The Northern Conifer Ecosystem generally is identified by large areas of spruce-fir climax forest, concentrated areas of even-aged jack pine (figure 2-2) regeneration in disturbed areas (e.g., burns), white spruce (figure 2-3), and upland black spruce on drier soil. Lowland black spruce and tamarack grow in poorly drained bog areas and lake margins, whereas aspen and birch are found in large regenerated areas (figure 2-4).

The majority of forest production is for pulpwood, most of which comes from aspen. Aspen and birch are the most widespread types of trees in the area. Although the dominant species in numbers are aspen and birch (figure 2-3), the forest succession would

Figure 2-2.— Jack pine in St. Louis County.

Figure 2-3.– Spruce Regeneration (foreground) and birch-aspen and white spruce intermixed (background).

Figure 2-4.- Birch with spruce understory.

favor a climax of white spruce, black spruce, and balsam fir if left undisturbed; hence, the ecosystem is classified as northern conifer. Jack pine, red pine, and white pine are scattered throughout the site with occasional pure stands of jack pine (figure 2-2) on the drier, sandy soils. Jack pine is well adapted to this type of soil and escapes the competition of the more tolerant species.

Although aspen is the most widespread forest type in the area, it is also found in association with other types such as pine, spruce, balsam fir, and birch. The best and most likely sites are the medium-moisture sites with average nutrient availability.

Black spruce is found in pure stands in the swampy or organic peat accumulations. Other tree species found in lesser concentrations throughout the test site are tamarack, yellow birch, big-tooth aspen, and balsam poplar. Although tamarack is potentially a species of local community significance, the history of the tamarack's susceptibility to insect attack has, over time, restricted the extent of occurrence so much that only one pure stand was located within the test site boundary.[1]

2.3 IMAGE EVALUATION RESULTS

2.3.1 AIRCRAFT FRAMES

The photointerpretation accuracy of the frames taken from aircraft was not determined until after the field trip; it was then determined by comparing the classification of the field sample points with the classifications delineated from the aircraft

[1]Personal communication from Dr. Phil Weber, USDA, Forest Service.

frames. Of the 75 field points sampled, 63 were in agreement with the photointerpretation. The photointerpretation accuracy was therefore calculated to be 85 percent.

2.3.2 LANDSAT FRAMES

The statistical comparison between the photographic interpretation and the Landsat interpretation required the construction of a gridded overlay for each interpretation type. These overlays were constructed by selecting an easily recognized feature near each corner of the photograph; then, corresponding features were marked on the Landsat frames. By connecting these four points a rectangle was constructed which enclosed the same areas. With the use of a 10-point divider, each rectangle was divided into 81 small rectangles and 100 intersecting points. By placing one thus constructed grid over the aircraft photointerpretation overlay and the other constructed grid over the figure generated from the Landsat frame, 100 corresponding points on each interpretation became available for comparison. The Landsat accuracies were determined, and the two frames with the highest probability of correct classification (PCC) were selected for the site study.

2.3.2.1 Results Obtained

Four Landsat frames were examined: (1) 1255-16322, April 1973; (2) 1345-16313, July 1973; (3) 1795-16203, September 1974; and (4) 5029-16110, May 1975.

The PCC values ranged from 33.88 to 44.63 percent. The major cause of the lower-than-expected results was the difficulty in determining the difference between softwood, hardwood, and the mixture of these two. However, there were also errors resulting from feature size changes that occurred during the time period between the Landsat acquisition and the aircraft data acquisition.

For example, some points on the photograph which fell in such an obvious classification as water were off just enough to appear to be on land when viewed with the Zoom Transfer Scope. Apparently, the water body had changed its size or shape during that time. The May 1975 Landsat data were not selected because of a cloud haze that covered both the upper and lower sections.

As an extra measure for decision, four interpreters from the Nationwide Forestry Applications Program (NFAP) group were assigned the task of reviewing the four Landsat frames. Each interpreter selected the same two frames as being the best representative frames to study. These selections were in agreement with the higher PCC calculations.

2.3.2.2 Frames Selected

The two frames selected for the St. Louis County, Minnesota, study site and their interpretation accuracies were: 1345-16313, July 1973 ($PCC_{Level\ II}$ = 44.63 percent) and 1795-16203, September 1974 ($PCC_{Level\ II}$ = 41.32 percent).

2.3.3 FIELD TRIP

A trip to the study area was conducted during the period of October 17 through 22, 1976, to compare ground truth with interpretations obtained from aerial photography and to aid in selecting representative training fields to be used in automatic processing of the Landsat data.

The study area was divided into two parts and the personnel into two teams. One team was dispatched to the northern half of the site and the other to the southern half. Each team had a preselected set of sample points or features to investigate. At each point, notes were recorded to describe the distinguishing characteristics of the sample point. Photographs were taken at each point, and the roll number and exposure were recorded. About 37 points were visited by each team to provide a total of 74 points that were visited in the field.

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3. PREPROCESSING AND PROCESSING

3.1 PREPROCESSING

The preprocessing activity involved (1) image-to-image registration of two data sets, (2) registering the data to ground control points, (3) superimposing administrative boundaries on the registered data, (4) filming the registered data, and (5) selecting training fields on the film transparencies.

3.1.1 IMAGE-TO-IMAGE REGISTRATION

The July data set was chosen as the base image, and the September data set was registered to it. On the Earth Resources Interactive Processing System (ERIPS), 11 control points were selected on each image. Evaluation of the positional accuracy of the control points showed that the residual error of certain control points was higher than the allowable 1.5-pixel requirement (ref. 4), and these points were placed on reserve. However, it was not possible to retain 8 to 10 control points and meet the 1.0-pixel root-mean-square (rms) error and the 1.5-pixel residual error requirements. On five different occasions, control points were picked and the final control points (nine total) had an rms error of 2.0 and the largest residual error of 2.2 pixels.

The high number of errors indicated that the data sets were not well registered. This indicated that the temporal set would probably produce poor results.

3.1.2 IMAGE-TO-GROUND REGISTRATION

Thirty-two control points were selected initially. A least-squares analysis was run; control points with a sample or line error greater than 2.4 pixels were eliminated. Based on 11 final control points, an rms sample error of 0.968 pixels and an rms error of 1.24 pixels were obtained. The coefficients generated by the least-squares analysis were input to the registration program.

A rotation factor of 0.061788760 was computed. As explained in the Technical Analysis Procedures (ref. 4), the value of the Gx = Landsat pixel/image pixel was set at 1. Since the Landsat pixel is rectangular, the Gx and Gy values cannot both be 1. The Gy value (Gy = 485/355) calculated by the registration rotation program was 1.366; consequently, 355 Landsat lines were read into 485 image lines. Approximately every third line was duplicated. The same rotation factor and Gy ratio were used for the September data set. Using the Jacobi formula, the pixel size was computed as 0.336 square hectometers (0.831 acre) per pixel.

3.1.3 ADMINISTRATIVE BOUNDARIES

After the images were rotated, new control points were selected to superimpose the national forest boundaries on the image. Four control points were chosen on each quadrant. These control points and the digitized forest boundaries were input to the registration-rotation program (ref. 4). This program created a file containing the boundaries which could be superimposed on the image. Using a version of the Irregular Cursor program (ref. 4), the boundaries were read into refresh memory. A mask was prepared, thereby excluding any area outside of the forest boundaries; this mask was stored in channel 5 for future use.

The September data bands 4, 5, 6, and 7 were read onto channels 1, 2, 3, and 4 of the Interactive Multispectral Image Analysis System, Model 100 (Image 100). Additionally, the boundaries generated for the July data were read into channel 5 of the machine. The resulting five-channel image was then written to tape. Since the total Image 100 screen area can accommodate only a 485- by 485-pixel area, the total study site was divided into four segments of that size.

3.1.4 TRAINING FIELD SELECTION

Training fields were selected based on the field checks and photo-interpreted aerial photography. The fields were delineated on the color transparencies of the registered Landsat data filmed on the Passive Microwave Imaging System/Data Analysis Station (PMIS/DAS).

For the type separability study, the chosen training fields were distributed over all four quadrants of data except for a portion reserved for the simulated inventory. That reserved portion was part of quadrant 4 and contained about 10 percent of the study area. The training fields for the simulated inventory were selected in this 10-percent area entirely from aerial photography without supplemental ground checks. The allocation of training fields for each category is presented in the following table. The sizes of training fields in both cases ranged from approximately 4.05 to 12.14 square hectometers (10 to 30 acres). Table 3-1 shows how training fields were allocated for both the separability study and the simulated inventory.

TABLE 3-1.— TRAINING FIELD ALLOCATION

Item	Softwood	Hardwood	Grassland	Water
Timber type separability	23	23	13	15
Simulated inventory	4	3	3	3

3.2 PROCESSING

A separability study and a simulated inventory study were the two primary stages of the processing phase. The separability study included (1) determining cell resolution size, (2) obtaining a composite signature for each class, (3) determining the training field accuracies, and (4) determining the best date based on overall separability study accuracies.

The simulated inventory included (1) developing a feature signature from 10 percent of the study areas, (2) classifying the entire site, and (3) producing acreage estimates and classification theme prints. The primary hardware used in this study was the Image 100 processing system.

3.2.1 SEPARABILITY STUDY

3.2.1.1 Dynamic Range

The dynamic range for this site was set at 128, 128, 128, and 64 for bands 4 through 7, respectively. However, the variance on these training fields was larger than the standards prescribed in the TES procedures (ref. 4). The cell size of 32 was tried, and the variance value was within the acceptable limits.

3.2.1.2 Composite Signature Acquisition

The signatures from all training fields were composed to obtain the composite signature. A distinct signature for each feature was obtained so that the same pixel was not classified into more than one class.

3.2.1.3 Maximum Likelihood

The July and September softwood signature represented pine, fir, and spruce. The hardwood signature represented aspen, birch, and maple. Since softwood and hardwood signatures overlapped to some extent, a maximum likelihood decision program was run to resolve the overlap. This program allowed a weighting factor to influence the disputed pixel assignment. The *a priori* inputs were 25 for softwood, 41 for hardwood, 7 for grassland, and 7 for water. These numbers were derived from a historical tabulation of the class acreages for the county. Not too surprisingly, hardwood received all the disputed pixels (ref. 4).

3.2.1.4 Training Field Accuracies

Level II training field accuracies for a class were obtained by dividing the number of correctly classified pixels for that class by the total number of pixels for that class. This procedure was followed for each class. The overall accuracy was obtained by summing all correctly classified pixels, classes 1 through 4, and dividing by the total number of pixels. Overall, the July data appeared to be the best date. The accuracy percentages are shown in table 3-2.

TABLE 3-2.— SEPARABILITY TRAINING FIELD ACCURACY PERCENTAGES

Date	Class 1, softwood	Class 2, hardwood	Class 3, grassland	Class 4, water	Overall
July	99.73	94.60	100.0	100.0	98.58
September	99.46	98.93	63.75	100.0	90.54

The procedures require that a Level III separability study be made if the training field accuracy percentages are 90 or better. Since both hardwood and softwood were above 90 percent, a Level III separability test was made for those two categories. (There was not enough grassland in the study to warrant such a test, nor was the water category separable into more than one type.)

As a result of the study, softwood was subdivided into pine and spruce, and hardwood was subdivided into aspen and birch. The results of the Level III classification are shown in table 3-3.

TABLE 3-3.— SEPARABILITY CLASSIFICATION ACCURACY FOR LEVEL III

Softwood, %		Hardwood, %	
Pine	Spruce	Aspen	Birch
55	46	42	54

3.2.2 SIMULATED INVENTORY

The purpose of the simulated inventory was to investigate how accurately the study site can be classified using signatures from training fields selected from a limited area (10 percent of the site in one conterminous block) using supplemental aerial photography but no ground truth. The July data were used for the simulated inventory because the overall accuracy was 98.58 percent (table 3-2). Signatures were developed from these fields, and the entire study site was classified.

The training field accuracies were calculated as follows:

Softwood.	73 percent
Hardwood.	88 percent
Grassland	39 percent
Water	90 percent

This provided an overall accuracy of 73 percent for the simulated inventory. Acreages were determined and are shown in tables 3-4 and 3-5. Since grassland comprises a very small part of the whole site, it happened to be even smaller, percentage wise, when selected from the 10-percent area. The grassland training field was small and probably infringed (pixel wise) into adjacent categories, which made the accuracy percentage smaller than it had been for the Level II separability study. The same analysis applies to the water category, although the percentages did not drop as much as those for grassland.

TABLE 3-4.– CLASSIFICATION BREAKDOWN FOR SIMULATED INVENTORY WITHIN USDA, FOREST SERVICE BOUNDARIES

[Includes Little Sioux Unit of Boundary Waters Canoe Area and private lands within the USDA, Forest Service boundaries]

Class	Quadrant 1			Quadrant 2			Quadrant 3			Quadrant 4			Total study area (Forest Service lands)		
	Pixels*	Acres	Square hectometers	Pixels*	Acres	Square hectometers	Pixels*	Acres	Square hectometers	Pixels*	Acres	Square hectometers	Pixels*	Acres	Square hectometers
Softwood	29 775	24 743	10 014	64 227	53 373	21 600	13 483	11 204	4 534	1 744	1 449	586	109 229	90 769	36 734
Hardwood	12 746	35 522	14 376	43 356	36 029	14 581	32 359	26 890	10 882	3 099	2 575	1 042	121 560	101 016	40 881
Grassland	7 811	6 491	2 627	11 316	9 404	3 806	61 369	50 998	20 639	294	244	99	80 790	67 137	27 171
Water	9 479	7 877	3 188	16 882	14 029	5 678	2 631	2 186	885	2 633	2 188	886	31 625	26 280	10 637
Other	54 765	45 510	18 418	83 929	69 745	28 226	30 776	25 575	10 350	3 924	3 261	1 320	173 394	144 091	58 314
Total	144 576	120 143	48 623	219 710	182 580	73 891	140 618	116 853	47 290	11 694	9 717	3 933	516 598	429 293	173 737

*One pixel equals 0 336 square hectometers (0 831 acre)

TABLE 3-5.— CLASSIFICATION BREAKDOWN FOR SIMULATED INVENTORY

[Little Sioux Unit, Boundary Waters Canoe Area only]

Class	Quadrant 1			Quadrant 2			Total area		
	Pixels*	Acres	Square hectometers	Pixels*	Acres	Square hectometers	Pixels*	Acres	Square hectometers
Softwood	3 628	3 015	1 220	36 689	30 489	12 339	40 317	33 503	13 559
Hardwood	4 725	3 926	1 589	19 242	15 990	6 471	23 967	19 917	8 060
Grassland	348	289	117	4 700	3 906	1 581	5 048	4 195	1 698
Water	4 658	3 871	1 567	7 164	5 953	2 409	11 822	9 824	3 976
Other	6 502	5 403	2 187	39 771	33 050	13 375	46 273	38 453	15 562
Total	19 861	16 504	6 679	107 566	89 387	36 174	127 427	105 892	42 853

*One pixel equals 0.336 square hectometers (0.831 acre).

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4. POSTPROCESSING AND EVALUATION

4.1 POSTPROCESSING

The purpose of the postprocessing activity was to generate classification products in the form of film transparencies, photographic prints, and gray-scale prints for use in the evaluation process and in producing final map products (refs. 1, 4). Figure 4-1 is a reduced reproduction of the classification map of this study site.

After classifying the St. Louis County study site Landsat data into four categories (hardwood, softwood, grassland, and water) plus "other," computer-compatible tapes of these five classifications were made. ("Other" means all features other than the categories listed; i.e., the pixels remaining after prescribed features are classified.) The study site was divided into four segments, each being 485 by 485 pixels in size, with each pixel representing 0.336 square hectometers (0.831 acre) on the ground; therefore, total area determinations could be made for each category.

Gray-scale prints of the five classifications for each quadrant were produced; i.e., 20 gray-scale prints were produced from the Gould printer. The four quadrants were carefully joined to produce a composite (970 by 970 pixels) of the study area for each class. These four quadrant composites were registered to each other for the purpose of making film negatives of each classification category. In addition, composite DAS transparencies were used to produce photographically enlarged classification maps at scales of 1:126 000 and 1:63 360.

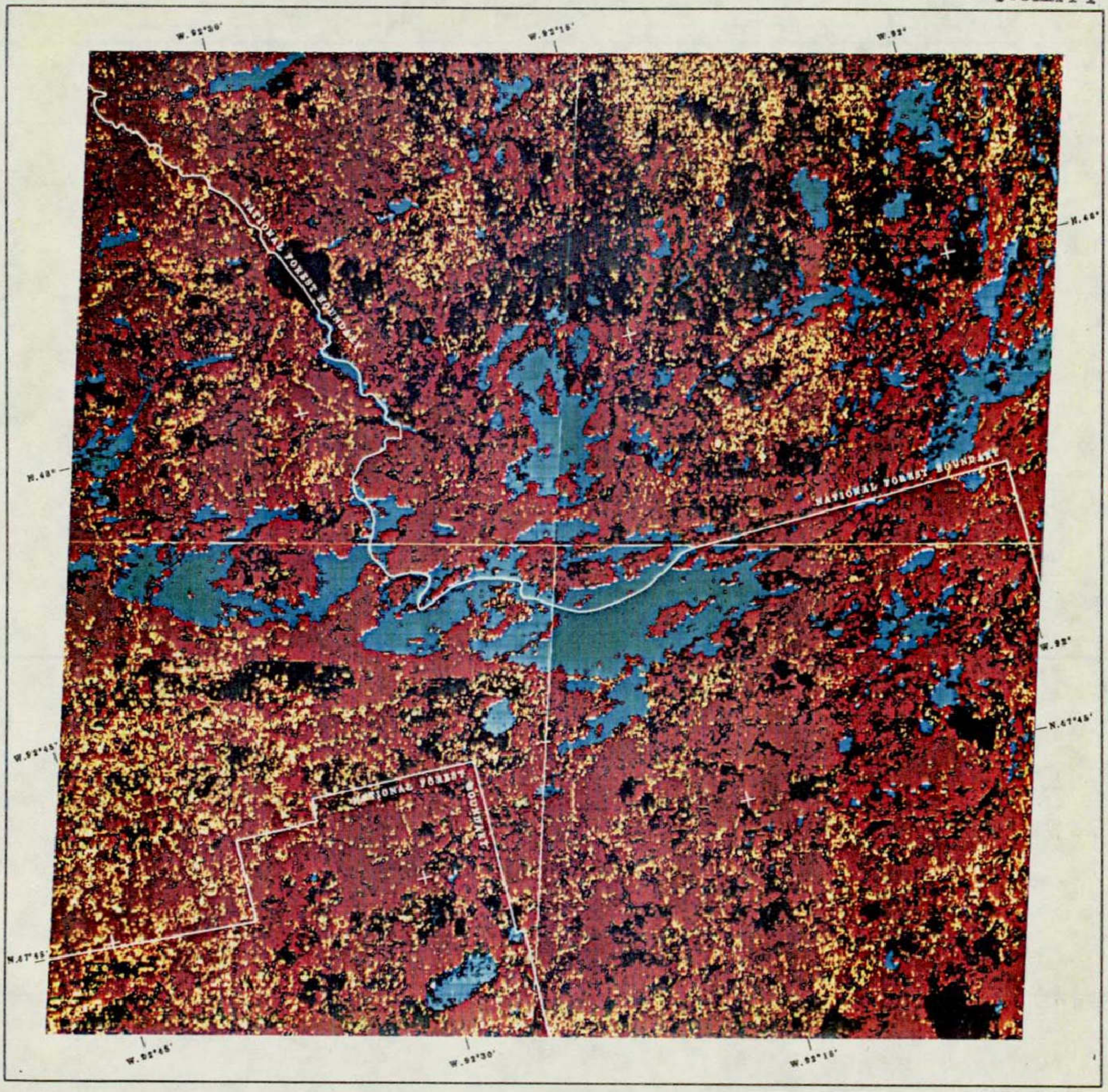
Alphanumeric printouts covering the entire area were produced for the purpose of evaluating the results. Each alphanumeric

NATIONWIDE FORESTRY APPLICATIONS PROGRAM

TEN ECOSYSTEMS STUDY

ST.LOUIS COUNTY, MINNESOTA

A PORTION OF THE SUPERIOR NATIONAL FOREST



LEGEND

GREEN - PINE
BLUE - WATER
RED - HARDWOOD
YELLOW - GRASSLAND
BLACK - OTHER & CLOUDS
——— - NATIONAL FOREST BOUNDRY

PREPARED BY:

SFB. CARTOGRAPHIC TECHNOLOGY LABORATORY
EARTH OBSERVATIONS DIVISION
S & LSD, JSC-NASA
HOUSTON, TEXAS APRIL 1978

Figure 4-1.

KEY MAP

character represents one classified pixel. The evaluation process was performed using these printouts. The description of the process follows.

4.2 EVALUATION

This portion of the task was to determine the PCC, the range (confidence interval) within which the PCC will occur at a specified confidence level, the proportion error for each class, and the final acreage estimate of the class proportion using regression estimates.

Twenty primary sampling units (PSU's) were chosen randomly. The PSU's were plotted on both the enlarged PMIS/DAS-produced Landsat transparency and the appropriate aerial photograph, using electronic scaling equipment (Dell Foster RSS-4DP/S-4). Both the Landsat scene and the photograph had to be free of cloud cover and/or cloud shadow where the PSU was selected. When clouds did occur, the PSU was discarded and another PSU was selected randomly. These PSU's were used for comparing the manually interpreted aerial photograph (ground truth) with the ADP classification. To do this, 10 secondary sampling units (SSU's) were also selected randomly within each PSU. These SSU's are actually the portion of the PSU that is used in making the comparison. Since the PSU's are scaled and delineated on both the Landsat frame and the aerial photograph, the SSU's are also a part of both. For evaluation purposes, the Landsat SSU's were machine classified and identified by an alphanumeric printout, but the aerial photograph SSU's were manually classified from the aerial photography using the Zoom Transfer Scope. The SSU consists of a 2- by 2-pixel area and, in order to compensate for a possible 1-pixel location error in any direction, nine SSU classifications were read for each SSU, each of these being offset from the primary SSU location by one pixel (ref. 4). Assuming that there is an error of no more than one pixel in location, one of the nine classification SSU's should correspond to the photointerpreted SSU.

The SSU accuracies were determined (by comparing each photointerpreted SSU with the machine SSU) and then combined to develop the PCC and class proportions for the entire site.

4.2.1 PROBABILITY OF CORRECT CLASSIFICATION

Twenty PSU's, each containing 10 SSU's for a total of 200 SSU's, were processed and tested against the interpreted aerial photographs. (The photographs served as ground truth.) The PCC for each PSU was determined by dividing the number of correctly classified SSU's by 10 (since 10 is the total number of SSU's tested). From this calculation, a final site PCC was determined by averaging the 20 PSU's. The confidence interval was then determined by calculating Δ, where Δ is one-half of the 90-percent confidence interval. The lower limit of the confidence interval is determined by subtracting Δ from the PCC; the upper limit by adding Δ to the PCC. (See table 4-1 for a summary of PCC and confidence interval calculations.)

The results obtained after calculating the 20 PSU's were found to meet the criterion set forth in the Technical Analysis Procedures (ref. 4); these results were the following:

PCC. . . . . 76 percent
Confidence interval. . . . . . 71 to 81 percent
Confidence level . . . . 90 percent

This means that the average PCC, using data of the type used in this study and in the same general area, can be expected to fall between 71 and 81 percent, 90 percent of the time.

TABLE 4-1.- SUMMARY OF PCC AND CONFIDENCE INTERVAL CALCULATIONS

[Calculations, ref. 4]

Quadrant	PSU no.	PCC_i
1	1 23 29 35	0.70 .90 .70 .80
2	2 4 5 21 22 36	0.60 .80 .90 .70 .90 .70
3	1 26 28 30 34	0.70 .50 .70 .70 .50
4	2 4 5 24 32	0.80 .90 1.00 .90 .80

$$PCC = \frac{1}{m} \sum_{i=1}^{m} PCC_i$$

$$= 0.76$$

$$S_{PCC}^2 = (1 - f)\frac{1}{m(m - 1)} \sum_{i=1}^{m} (PCC_i - PCC)^2$$

$$= 0.029$$

$$\Delta = tS_{PCC} \quad (t = 1.729)$$

$$= 1.729S_{PCC} \text{ at 0.9 confidence level}$$

$$= 0.051$$

Confidence interval of PCC

$$= (PCC - \Delta, PCC + \Delta)$$

$$= (0.71, 0.81)$$

NOTE: Total number of PSU's = m = 20. The PSU numbers listed here are those used in the calculations and do not include those PSU's randomly selected but not used because of cloud cover, hazy photographic rendition, etc. Thirty-five PSU's were randomly selected originally, but 15 were eliminated from use.

4.2.2 CLASS PROPORTION

Photointerpretation class proportions, p, were determined by evaluating the PSU's on the photographs; and the estimated simulated inventory proportion, $\hat{p}$, was determined from the computer classification. The average error of the estimate, B, was determined by the following formula (ref. 4):

$$B = \frac{1}{m} \sum (p_i - \hat{p}_i)$$

where

m = number of PSU's (20)

i = PSU index

p_i = class proportion (from photographs) for the *ith* PSU

$\hat{p}_i$ = estimated class proportion (from computer alphanumeric printout) for the *ith* PSU

The confidence interval for B was determined in the same manner as for the PCC (ref. 4); that is,

$$S_B^2 = (1 - f)\frac{1}{m(m - 1)} \sum_{i=1}^{m} (p_i - \hat{p})^2$$

$$\Delta.9 = t.95(19)S_B \text{ at the 0.9 confidence level}$$

The 90-percent confidence interval of the error is $(B - \Delta, B + \Delta)$.

Table 4-2 presents the proportion of each class found from evaluating the PSU's on the photographs, p, and the simulated inventory classification proportion, $\hat{p}$. Table 4-3 presents a summary of the proportion of each class found from evaluating the PSU's on the photographs and the inventory alphanumeric map. Table 4-4 shows the regression estimates, p_o, for the wall-to-wall proportion classification.

TABLE 4-2.— SUMMARY OF INVENTORY ADP CLASS PROPORTION ERRORS COMPARED TO PHOTOINTERPRETATION CLASS PROPORTION ESTIMATE

Class	Simulated inventory estimate, $\hat{p}$	Photointerpretation estimate, p	Average error, B $(p-\hat{p})$	Standard deviation error, S_B	One-half confidence interval, $\Delta_{.9}$, for error (a)	Confidence interval (B±Δ)	Does interval contain zero?	Relative error, % (100B/p)	ADP agreed, over/under estimate
Softwood	0.263	0.282	0.020	0.014	0.024	(-0.004, 0.044)	Yes	7.07	Agreed
Hardwood	.331	.406	075	.015	.025	(050, 100)	No	19.47	Over
Grassland	.058	062	.004	.014	.024	(- 02, .028)	Yes	6.47	Agreed
Water	.132	.148	.016	.008	.013	(-.003, .029)	Yes	10.81	Agreed

[a] $\Delta_{.9} = 1.729 S_B$.

TABLE 4-3.— SUMMARY TABLE SHOWING PROPORTION OF EACH CLASS

[Computed by evaluating PSU's on the photographs, p_i, and on the alphanumeric map, $\hat{p}_i$]

Landsat quadrant	PSU No.	Softwood		Hardwood		Grassland		Water		Other	
		p_i	$\hat{p}_i$	p_i	$\hat{p}_i$	p_i	$\hat{p}_i$	p_i	$\hat{p}_i$	p_i	$\hat{p}_i$
1	1	0.05	0.025	0.72	0.6	0.07	0.225	0.03	0	0.13	0.15
	23	.41	0.4	.08	.05	.02	.075	.03	.025	.46	.45
	29	.22	0.15	.31	.225	.03	.1	0	0	.44	.525
	25	.2	0.225	.58	.4	.09	.125	0	0	.13	.25
2	2	0.44	0.475	0.11	0.075	0	0	0	0	0.45	0.45
	4	.15	0.225	.64	.525	.04	0.025	.10	.10	.07	.125
	5	.65	.575	.11	.05	.04	0.075	.20	.20	0	.1
	21	.51	.425	.42	.375	.07	0	0	0	0	.2
	22	.73	.75	.02	0	0	0	.25	.2	0	.05
	36	.55	.475	.21	.125	.04	0	.15	.15	.05	.25
3	1	0.04	0.075	0.65	0.475	0.22	0.125	0	0	0.09	0.325
	26	.02	.125	.6	.4	.07	.125	.3	.175	.01	.175
	28	.16	.2	.58	.45	.1	0	.15	.175	.01	.175
	30	0	0	.7	.65	.29	.175	0	0	.01	.175
	34	.19	.1	.59	.55	0	0	.22	.125	0	0.225
4	2	0.28	0.125	0.52	0.55	0.03	0.05	0.12	0.1	0.05	0.175
	4	.12	.075	.23	.225	.04	.025	.51	.5	.1	.175
	5	0	0	.05	.05	0	0	.9	.9	.05	.05
	24	.3	.225	.7	.7	0	0	0	0	0	.075
	32	.62	.6	.3	.15	.08	.025	0	0	0	.225

TABLE 4-4.– REGRESSION ESTIMATE OF TOTAL SITE PROPORTIONS

Class	Inventory estimate, $\hat{p}_o$	Regression equation	Regression estimate, p_o	Coefficient of determination, r^2	Standard error, S	One-half confidence interval, Δ.9 (a)	Confidence interval (p_o±Δ.9)	Relative variation, % (100Δ/p_o)
Softwood (183 863 pixels)	0.195	p_o=1.011$\hat{p}_o$ +0 0166	0.214	0.924	0.0150	0.026	(0.188, 0.240)	±12.16
Hardwood (266 502 pixels)	302	p_o=1.046$\hat{p}_o$ +0 0595	375	.929	.015	.026	(.339, .380)	±6.9
Water (68 802 pixels)	.075	p_o=1.006$\hat{p}_o$ +0.0147	.090	.974	.008	.014	(.076, .104)	±15.90
Grassland	.059	p_o=0.642$\hat{p}_o$ +0 0246	.062	.345	.0134	.023	(.039, .085)	±37.18

[a]$\Delta.9 = t.95(19)S_B = 1.729$.

Analysis of the four tables indicates that for softwood the class proportion, $\hat{p}$, of 0.263 is not significantly lower than the true class proportion, p, of 0.283 because the confidence interval contains zero. For hardwood, $\hat{p} = 0.331$ is significantly lower than $p = 0.406$ and the interval 0.050 to 0.100 does not contain zero. From the grassland proportion error analysis, the error between the ADP results and the photointerpreted estimate seems to be insignificantly different from zero, also. However, since grassland occupies only approximately 1 percent of the entire site, the analysis is not very reliable, as is also evident from the regression analysis of p versus $\hat{p}$, which shows a low coefficient of determination, r^2. (See the following explanation and table 4-4.) Water has an average error, B, of (-0.003, 0.029), which does contain zero. This indicates that the average error, B, is not significant and since B is positive, the classifier tends to agree on the areas of water.

To improve precision and compensate for classifier biases (underestimate or overestimate), a linear regression analysis, $p = a\hat{p} + b$, was performed on each class. (See table 4-4.) If the coefficient of determination, r^2, is good, the inventory classification proportion over the entire site, $\hat{p}_o$, can be used to obtain an adjusted proportion estimate on the site. That is, the value $p = a\hat{p} + b$ would be a more precise estimate over the site than the estimate given by averaging the sampled proportions (ground truth) calculated from the PSU's.

The coefficient of determination, r^2, is a measure of the correlation between p and $\hat{p}$ and gives the percentage reduction of the sum squared deviations about the mean due to the regression. If all points in question lay on a straight line, r^2 would equal 1. Therefore, the closer r^2 is to 1, the more highly correlated are p and $\hat{p}$.

The standard error for the regression for softwood was calculated to be 0.015; for hardwood, 0.015; and for water, 0.008. These standard errors correspond to the 90-percent confidence relative variations of ±12.16, ±6.9, and ±15.9 percent, respectively.

5. ANALYSIS OF RESULTS

A 10-percent area located in the southeast quadrant of the study site was designed for selecting training fields for the simulated inventory. The training fields were selected by manual photo-interpretation methods using the aerial color infrared, 1:120 000-scale photography. The purpose of the simulated inventory was to determine how well ADP methods can be utilized in extending a prespecified amount of ground truth to an area approximately 10 times larger. In addition, map products were to be made of the classification results obtained. (See figure 4-1.)

By selecting training fields in this 10-percent area [36 000 square hectometers (89 000 acres)] using the photointerpretation method, the ground-truth signatures were extended to see how well ADP techniques and Landsat data can classify the total area [360 000 square hectometers (890 000 acres)]

From the evaluation calculations, as outlined in the TES procedures (ref. 4), it was found that the overall site classification had a PCC of 0.76 with a 90-percent confidence interval of 0.71 to 0.81. This means that, using the techniques employed in this study for this ecosystem, the PCC will be between 71 and 81 percent, 90 percent of the time (see table 4-1). It was also determined by the evaluation results that the technique is good for making areal estimates for softwood, hardwood, and water classes. This is evidenced by the proportion error of adjusted estimate values of 0.15 for softwood and hardwood and 0.008 for water. Since grassland comprises approximately 1 percent of the entire site, the analysis of grassland is probably unreliable. This unreliability is evidenced by the p versus $\hat{p}$ regression analysis, which shows a low coefficient of determination, $r^2 = 0.345$.

This unreliable estimate for grassland is probably also caused by a mixture of some grasses with brush, understory, and other ground cover vegetation; e.g., Labrador-tea.

When the computer estimate, $\hat{p}$ (see table 4-2), is larger than the photointerpretation estimate, p, and the confidence interval does not contain zero, the computer has overestimated. When the computer estimate, $\hat{p}$, is smaller than the photointerpretation estimate, p, and the confidence interval does not contain zero, the computer has underestimated. In either case, if the confidence interval contains zero, the computer agrees with the photointerpretation estimate.

Table 4.2 shows that the computer agreed on grassland, because the confidence interval of -0.02 to 0.028 contains zero. The computer also agreed on softwood and water, but overestimated hardwood for the July data inventory.

In section 3.1.1, the image-to-image registration process and the resulting rms error were discussed. Analysis of the error indicates that it was caused by the difficulty in locating the same control points on both data sets. Reliably and uniformly distributed control points such as road intersections and stream junctions were difficult to find in this heavily wooded site.

In addition, the satellite images appeared to be at slightly different scales. Although it is theoretically possible to register any two data sets, the performed registration using from 2 to 20 control points produced rms and residual errors which did not meet the previously specified standards. Hence, temporal analysis was not carried out in the processing activities.

6. CONCLUSIONS AND RECOMMENDATIONS

This section presents the conclusions and recommendations derived from the results of machine processing the data from Site III, St. Louis County, Minnesota. The primary machine or hardware used in this study was the Image 100 processing system.

The overall study involved 10 different forest and range ecosystems; this one pertains only to the Northern Conifer Ecosystem. The overall study had three primary objectives and three secondary objectives as listed below.

The primary objectives of the TES were to

- Investigate the feasibility of state-of-the-art ADP remote sensing technology to inventory forest, grassland, and inland water areas by administrative boundaries in the 10 ecosystems of the United States
- Identify problems and recommend specific solutions for individual sites or ecosystems
- Recommend the definition and requirements of an integrated ADP system to support a nationwide forest and grassland applications system verification test (ASVT)

Secondary objectives of the TES included

- Determining type mapping accuracies at different levels of hierarchy in the ecosystems
- Establishing the season or seasons that offer the greatest potential for type mapping in each ecosystem
- Providing the USDA, Forest Service with project findings, and conducting evaluation workshops

6.1 CONCLUSIONS

It was found that the Image 100 system can separate softwood, hardwood, grassland, and water using Landsat data, with an overall training field PCC of 98.58 percent when training fields scattered throughout the study area are used. This implies that the current state of the art of ADP remote sensing analysis is probably adequate for separating forest and inland water areas at a Level II hierarchy in this ecosystem. The results also indicate that a Level III hierarchy of classification in this ecosystem will not be reliable, although that conclusion could be the result of registration difficulties.

The simulated inventory results indicate that signatures derived from only 10 percent of this study site can be extended, but with a loss of classification accuracy on the order of 19 to 29 percent.

Because of an insufficient network of roads and other static landmarks in the study area, problems were encountered in the registration of these Landsat data sets. In other areas of the ecosystem, this problem may not exist. Although water bodies are plentiful in the area, they do not make good features for registration because of the variations in water levels. When water levels change, the shape and size of the water body change also. Water bodies were used as control points and this limited the accuracy of the registration, which in turn may have had a negative effect on both the PCC and the proportion estimates.

Because the separability training field accuracies for water were 100 percent for both July and September, and the simulated inventory water training field accuracy was 90 percent, the assumption is made that water bodies can be mapped with a high degree of reliability. Evidence indicates that the quality of the training fields depends on the accuracy of the ground truth. Conversely, the better the ground truth, the better the training fields. From this it can also be said that a much better statistical evaluation of the Landsat capability would result if the field investigations, aircraft data acquisition, and Landsat data were acquired simultaneously.

6.2 RECOMMENDATIONS

This report documents a demonstration of the type and level of classification possible using digital Landsat data and automatic processing tools for the Northern Conifer Ecosystem. The usefulness of this system and the Landsat data depends on the classification detail and the accuracy level required by the USDA, Forest Service for nationwide forest resources planning.

It is recommended that the classification results in this specific site be investigated to see if they can be useful to area or regional resources data bases for planning, modeling, or management updates of existing inventory systems.

7. REFERENCES

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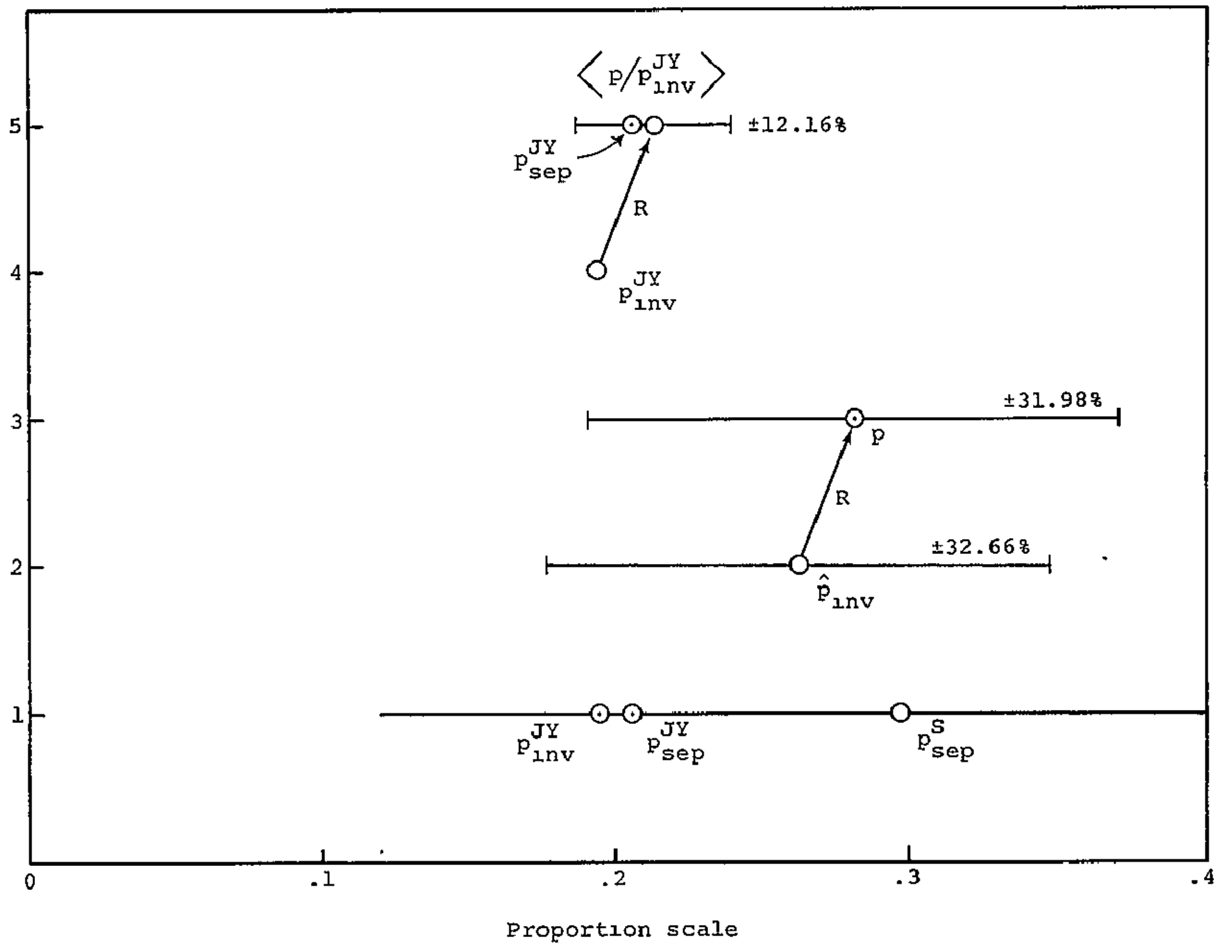
APPENDIX

ADDITIONAL STATISTICAL DATA

TABLE A-1.— PROPORTIONAL ESTIMATES FOR SITE III, ST. LOUIS COUNTY, MINNESOTA

Type estimate	Level II		Level I			
	Softwood	Hardwood	Forest	Grassland	Water	Other
July 1973 separability	0.206	0.387	0.593	0.067	0.085	0.255
September 1974 separability	.297	.496	.793	.026	.100	.081
July 1973 inventory	.195	.302	.497	.059	.075	.369
July 1973 inventory sample ($\hat{p}$)	.263	.331	.594	.058	.132	
August 1976 photointerpretation sample (p)	.282	.406	.688	.062	.148	
Regression estimate	.214	.375	.589	.062	.090	
Inventory on Boundary Waters Canoe Area	.316	.188	.504	.040	.093	.363
Boundary Waters Canoe Area inventory regression estimate	.336	.256	.592			
Forest Service estimates on Boundary Waters Canoe Area (% total area)	.43	.40	.83			(.170)



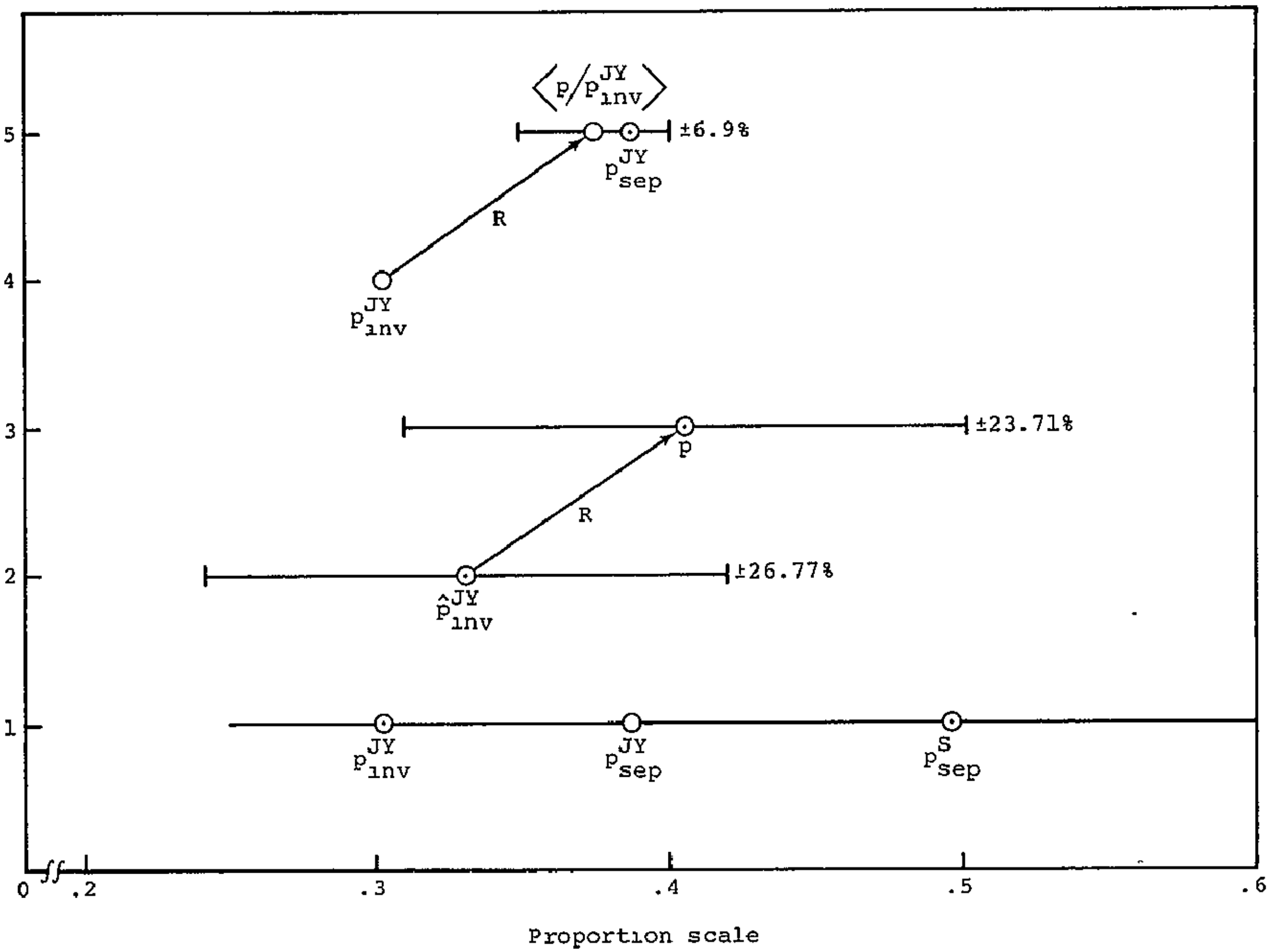
LEGEND:

inv — inventory
JY — July
p — photointerpretation class proportion
$\hat{p}$ — simulated inventory class proportion
R — regression estimate
S — September
sep — separability

LINE NUMBER:

1 — ADP separability and inventory estimates (wall to wall)
2 — Simulated inventory estimate from 20 PSU/s
3 — Photointerpretation estimate from 20 PSU/s
4 — Simulated inventory
5 — Regression estimate

Figure A-1.— Proportion estimates of softwood, St. Louis County, Minnesota.



LEGEND:

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$\hat{p}$ — simulated inventory class proportion
R — regression estimate
S — September
sep — separability

LINE NUMBER:

1 — ADP separability and inventory estimates (wall to wall)
2 — Simulated inventory estimate from 20 PSU/s
3 — Photointerpretation estimate from 20 PSU/s
4 — Simulated inventory
5 — Regression estimate

Figure A-2.— Proportion estimates for hardwood, St. Louis County, Minnesota.