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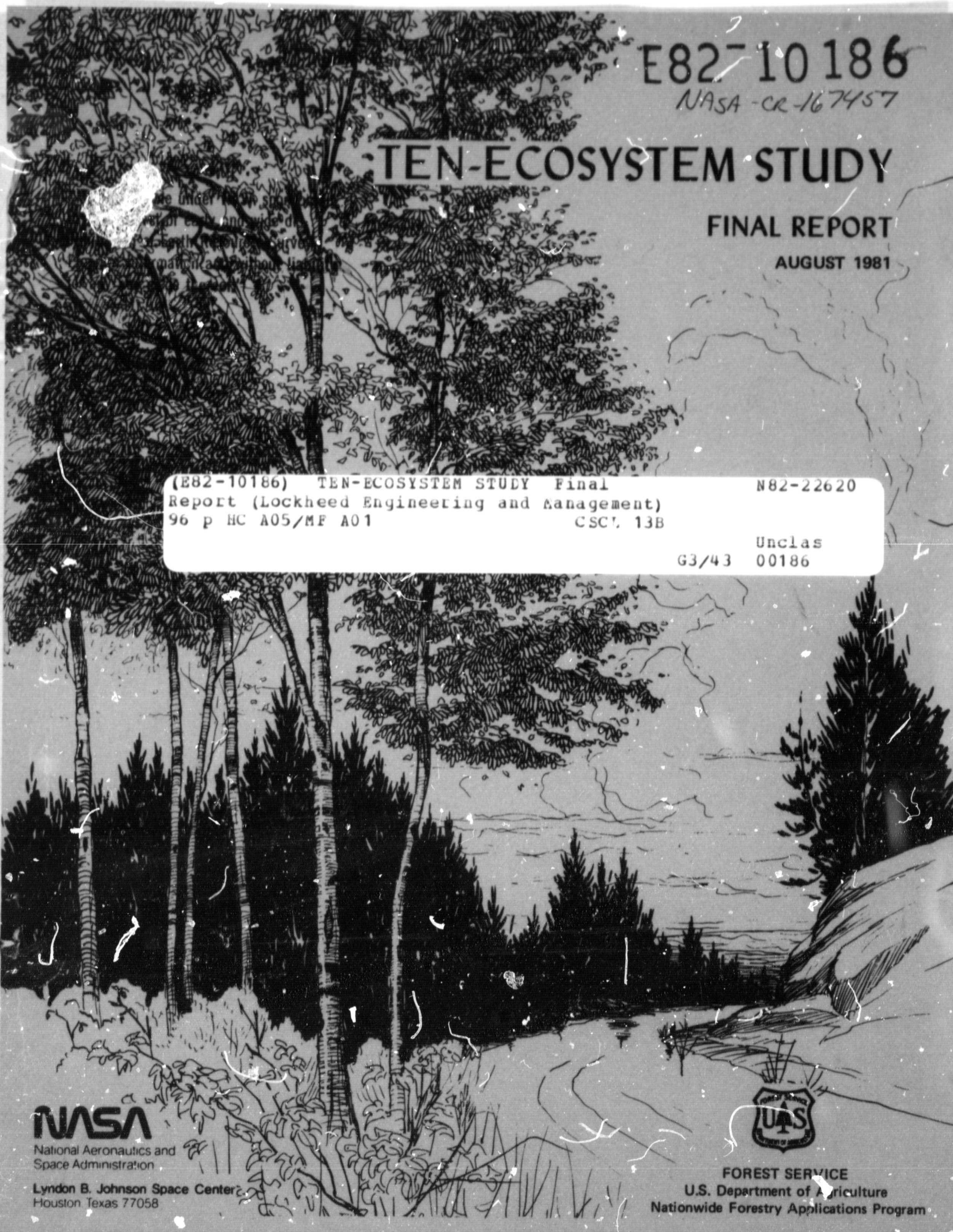
# TEN-ECOSYSTEM STUDY

## FINAL REPORT

AUGUST 1981



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Lyndon B. Johnson Space Center
Houston, Texas 77058

FOREST SERVICE
U.S. Department of Agriculture
Nationwide Forestry Applications Program

TEN-ECOSYSTEM STUDY

Final Report



Prepared under the direction of

A. V. Mazade

LOCKHEED ENGINEERING AND MANAGEMENT SERVICES COMPANY, INC.

Under Contract NAS 9-15800

For

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lyndon B. Johnson Space Center
Houston, Texas 77058

Supporting the

U. S. DEPARTMENT OF AGRICULTURE FOREST SERVICE

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16. Abstract

Remote sensing methodology developed for the Nationwide Forestry Applications Program utilized computer data processing procedures for performing inventories from satellite imagery. In 1976, the U.S. Department of Agriculture Forest Service and the National Aeronautics and Space Administration at the Lyndon B. Johnson Space Center, in a joint effort, created the Ten-Ecosystem Study (TES) to test the processing procedures in an intermediate-sized application study. The results of TES indicate that Landsat multispectral imagery and associated automatic data processing techniques can be used to distinguish softwood, hardwood, grassland, and water and make inventory of these classes with an accuracy of 70 percent or better. The technical problems encountered during the TES and the solutions and insights to these problems are discussed. The TES experience is useful in planning subsequent inventories utilizing remote sensing technology.

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# PREFACE

The Ten Ecosystems Study was a cooperative effort of the National Aeronautics and Space Administration and the U.S. Department of Agriculture Forest Service, Nationwide Forestry Applications Program.

The work which is the subject of this document was performed within the Earth Resources Applications Division, Space and Life Sciences Directorate, at the Lyndon B. Johnson Space Center, National Aeronautics and Space Administration. Under Contract NAS 9-15800, personnel of Lockheed Engineering and Management Services Company, Inc., performed the tasks which contributed to the completion of this research.

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# ACRONYMS

| | |
|---|---|
| ADP | automatic data processing |
| ASE | adjusted standard error |
| ERDA | Energy Research Development Agency |
| ERIPS | Earth Resources Interactive Processing System |
| ERIM | Environmental Research Institute of Michigan |
| GMP | Geographic Mapping Program |
| Image 100 | General Electric Interactive Multispectral Image Analysis System, Model 100 |
| JSC | Lyndon B. Johnson Space Center |
| Landsat | NASA land observatory satellite |
| LEC | Lockheed Electronics Company, Inc.; name changed in 1980 to Lockheed Engineering and Management Services Company, Inc. |
| MSS | multispectral scanner |
| NASA | National Aeronautics and Space Administration |
| NFA | Nationwide Forestry Applications |
| NSCS | National Site Classification System |
| PCC | percentage of correct classification |
| pixel | picture element |
| PSU | primary sampling unit |
| rms | root mean square |
| SCS | Soil Conservation Service |
| SE | standard error |
| SSDA | Sequential Similarity Detection Algorithm |
| SSU | secondary sampling unit |
| TES | Ten-Ecosystem Study |
| TRICPS | Tri-County Pilot Study |
| USDA | U.S. Department of Agriculture |

# 1. PURPOSE OF THE TEN-ECOSYSTEM STUDY

To explore the feasibility of using Landsat multispectral imagery and associated automatic data processing techniques to inventory forest and grassland resources, NASA's Lyndon B. Johnson Space Center and the USDA's Forest Service joined together in 1976 to develop the Ten-Ecosystem Study.[1] By dividing the continental United States into 10 broadly defined ecological communities and examining the similarities and differences among these ecosystems, this study could build on the successes of more localized studies and serve as a prelude to larger scale applications.

The experimental design of the Ten-Ecosystem Study can be seen as having two principal and sequential components. The first, called a type separability study, was to determine at what level of detail forest and grassland features (whether general categories such as softwood and hardwood or more specific groups such as pine and spruce) could be distinguished on the basis of their Landsat spectral responses. A related objective was to determine the season providing the greatest separability. The subsequent principal component, called the simulated inventory study, was to develop a spectral signature for each indicated cover type from the indicated season using only 10 percent of the site and then extend this signature across the site to inventory that type. The classification map resulting from the simulated inventory study was to be evaluated by comparison with interpreted aerial photographs.

To provide comparable results for the 10 diverse ecological situations, the initially chosen procedures (ref. 1) were applied uniformly to all sites, thus precluding the implementation of new analytical procedures that seemed desirable to project personnel. Resource constraints (project was limited to a 17-man-year-equivalent effort) prevented the parallel assessment of such possibly improved techniques. However, the technical problems that arose in the Ten-Ecosystem Study and the insights into their solutions gained by the TES staff afford experience useful in planning subsequent resource inventories utilizing remote sensing technology.

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[1] Definitions:

Landsat — the series of land observatory satellites launched by NASA beginning in 1972, originally named Earth Resources Technology Satellite (ERTS).

Automatic data processing — abbreviated ADP.

NASA — National Aeronautics and Space Administration.

Lyndon B. Johnson Space Center hereinafter called JSC.

USDA — U.S. Department of Agriculture.

Ten-Ecosystem Study — abbreviated TES.

# 2. BACKGROUND ON THE NATIONWIDE FORESTRY APPLICATIONS PROGRAM

The Ten-Ecosystem Study was one aspect of a larger joint effort of the Forest Service and NASA/JSC. This larger effort, established in 1972 as a regional effort called the Forestry Applications Project, was expanded in 1976 to become the Nationwide Forestry Applications (NFA) Program. The program has been given the responsibility of developing the remote sensing methodology, first, to make large area forest and grassland inventories; second, to assess the impact of insect and disease on forest stands; and, third, to monitor the environmental effects of management practices. The NFA Program is responsive to the needs of the Forest Service throughout the country.

The Forest Service receives its direction through Federal legislation, notably through two recent acts of Congress. Enacted in 1974, the Forest and Rangeland Renewable Resources Planning Act required the nationwide assessment of timber and range resources and the planning of long-range programs to meet future needs for these resources. The National Forest Management Act of 1976 in effect amended the previous act and extended the national forestry leadership role of the Forest Service beyond the management of the National Forest System to include natural resources research and cooperative forestry assistance to state and private landowners.[2]

[2]The National Forest System contains 750 000 square kilometers (187 million acres). The forest and rangeland resources of the United States would be several times that area.

Between 1972 and 1975, the Forestry Applications Project conducted a number of localized studies, the largest of which was the 1975 Tri-County Pilot Study (TRICPS). TRICPS (ref. 2) analyzed an area of 6500 square kilometers (1 600 000 acres) using ADP and conventional photointerpretation methods. The feasibility of the techniques used in these studies was supported by the conclusions of other researchers. For example, a study on forest and grassland in southeast Texas reported ADP classification accuracies of 91, 70, and 85 percent for softwood, hardwood, and grassland, respectively (ref. 3).

On the basis of these results, the Forestry Applications Project developed a set of computer data processing procedures for performing inventories from satellite imagery and decided to test these procedures in an intermediate-sized application study. This decision was given impetus by the 1974 Renewable Resources Planning Act.

The Ten-Ecosystem Study in testing a uniform set of remote sensing data analysis procedures over a wide variety of physiographic and ecological conditions has provided a significant benchmark for the Nationwide Forestry Applications Program. This experiment has provided new information on the accuracy and efficiency of the tested procedures.

Based on peer reviews of the Ten-Ecosystem Study in September 1977 and September 1978, research has been undertaken to extend the utility of TES procedures. This research provided for a smooth transition into the Multiresource Inventory Methods Pilot Study. The goal of this large-scale project is to test, evaluate, and transfer significant new remote sensing technology to the Forest Service, in support of renewable resource inventories and the land management planning process mandated by the 1976 National Forest Management Act.

# 3. SITE SELECTION

## 3.1 RATIONALE

This study was intended to cover forest types throughout the United States. The Society of American Foresters described about 150 U.S. forest types, distinguished as to composition and development due to ecological factors (refs. 4 and 5). These ecological factors are primarily temperature and rainfall, modified by soils, slope, and aspect. Vegetation in the contiguous 48 states shows a belted pattern based on these ecological factors, with East-West belts corresponding to latitude in the eastern United States and North-South belts corresponding to elevation in the western United States. Therefore, this study grouped forest types into ecosystems based on this pattern of temperature and rainfall (see fig. 1). Ten ecosystems were generalized from the map of forest types by Shantz and Zon (ref. 6). The number 10 was chosen as providing sufficiently detailed information to the Forest Service and as being manageable within the limited resources of the program.

One site was chosen to represent each of the 10 ecosystems. Selection criteria included the following considerations. The site should include a national forest to enable exchange of information with Forest Service personnel. The site should have 80-percent coverage by NASA photography to ensure a uniform ground-truth base. And, of course, the site needed to have adequate Landsat coverage providing the data to be analyzed. To avoid transition areas, all but one of the sites were located well within the defined boundaries of the ecosystem. The exception was Site V (Kershaw County, South Carolina), where the fall line[3] provided a boundary between two ecosystems. Thus, 9 sites were able to represent 10 ecosystems. The site locations are shown on figure 1.

## 3.2 SITE DESCRIPTIONS

Table I presents a summary description of the nine study sites. The paragraphs that follow provide brief narrative descriptions of the distinguishing characteristics of each site.

[3]A line joining the waterfalls on numerous rivers that marks the point where each river descends from the upland to the lowland and the limit of the navigability of each river.

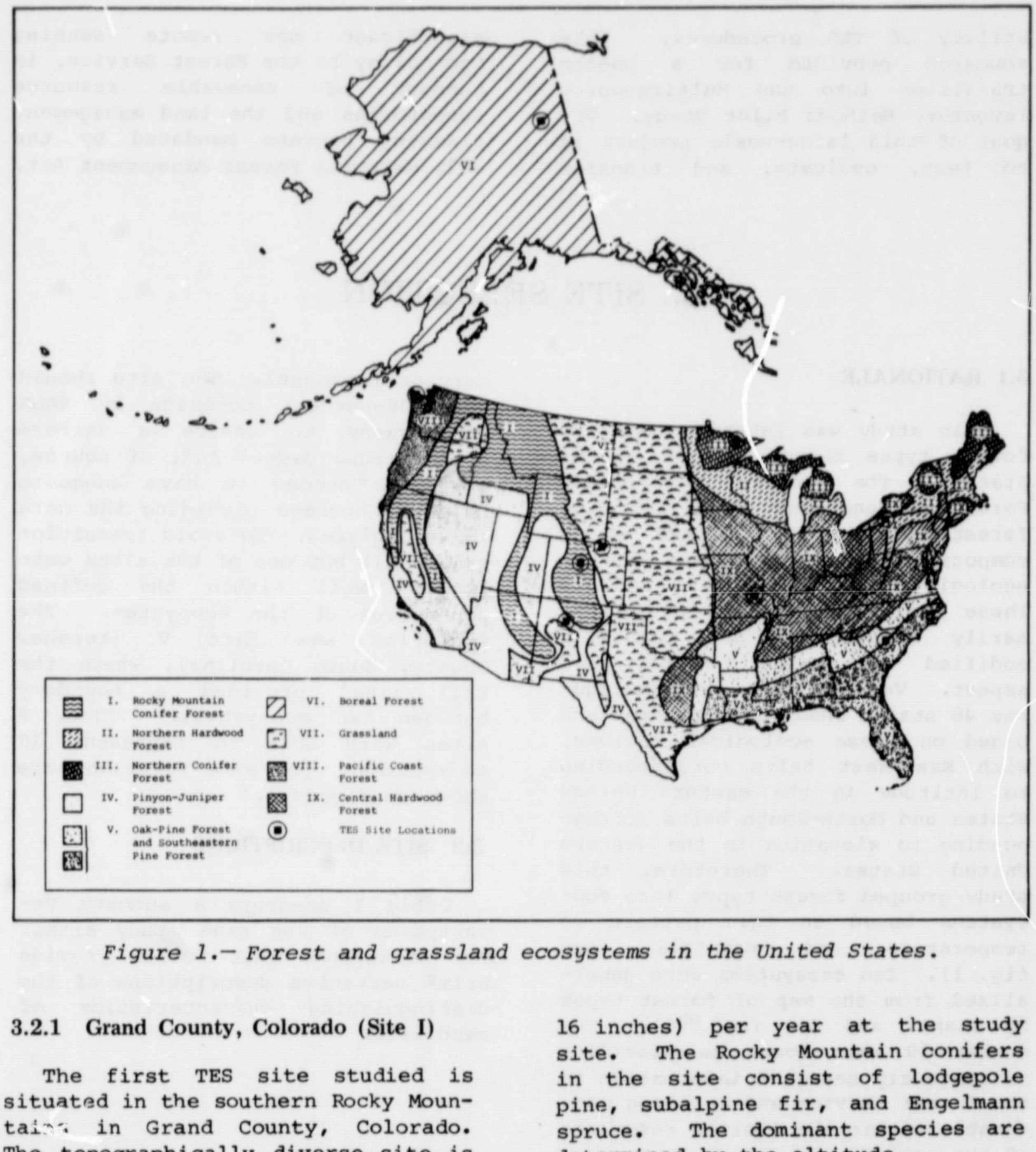


*Figure 1.— Forest and grassland ecosystems in the United States.*

### 3.2.1 Grand County, Colorado (Site I)

The first TES site studied is situated in the southern Rocky Mountains in Grand County, Colorado. The topographically diverse site is of high elevation (to 4000 meters or 13 000 feet), with moderate summer temperatures and very cold winter temperatures. Rainfall averages from 25 to 41 centimeters (10 to 16 inches) per year at the study site. The Rocky Mountain conifers in the site consist of lodgepole pine, subalpine fir, and Engelmann spruce. The dominant species are determined by the altitude.

### 3.2.2 Warren County, Pennsylvania (Site II)

Warren County, Pennsylvania, constitutes the second site. This

TABLE I.— TES STUDY SITES

| Site number | Site location | Ecosystem represented | Center coordinates | | National forest or grasslands | Elevation | | Species |
|---|---|---|---|---|---|---|---|---|
| | | | Latitude, north | Longitude, west | | Meters | Feet | |
| I | Grand County, Colorado | Rocky Mountain Conifer | 39°55' | 105°57' | Arapaho National Forest | 2400 to 4000 | 8000 to 13 000 | Western yellow pine, Douglas fir, larch, and western white pine |
| II | Warren County, Pennsylvania | Northern Hardwood | 41°44' | 79°16' | Allegheny National Forest | 340 to 490 | 1100 to 1600 | Beech, birch, maple, oak, and hickory |
| III | St. Louis County, Minnesota | Northern Conifer | 48°15' | 92°05' | Superior National Forest | 370 to 550 | 1200 to 1800 | Black and white spruce, balsam fir, pine, aspen, and birch |
| IV | Sandoval County, New Mexico | Pinyon-Juniper | 35°45' | 106°37' | Santa Fe National Forest | 2000 to 3440 | 6500 to 11 300 | Pinyon, juniper, single-leaf pine, Douglas fir, scrub oak, and sagebrush |
| V | Kershaw County, South Carolina | Oak-Pine | 34°20' | 80°35' | None | 30 to 180 | 100 to 600 | Oak, hickory, and southern yellow pine |
| | Kershaw County, South Carolina | Southeastern Pine | 34°20' | 80°35' | None | 30 to 180 | 100 to 600 | Southern yellow pine, bottomland oak, tupelo, sweet gum, hickory, and bald cypress |
| VI | Fort Yukon, Alaska | Boreal | 66°41' | 143°25' | Porcupine National Forest (proposed) | 170 to 850 | 550 to 2800 | Black and white spruce, birch, aspen, poplar, and willow brush |
| VII | Weld County, Colorado | Grassland | 40°45' | 104°20' | Pawnee National Grasslands | 1400 to 1840 | 4580 to 6050 | Buffalo grass, blue grama, hairy grama, saltgrass, sagebrush, mesquite, and southwestern broadleaf trees |
| VIII | Grays Harbor County, Washington | Pacific Coast | 47°22' | 123°43' | Olympic National Forest | 0 to 2000 | 0 to 6700 | Douglas fir (coastal form), western red cedar, Sitka spruce, redwood, western hemlock, fir, and red alder |
| IX | Washington County, Missouri | Central Hardwood | 37°57' | 95°59' | Mark Twain National Forest | 210 to 430 | 700 to 1400 | Oak, hickory, pine, elm, ash, maple, and eastern red cedar |

site, chosen as representative of the northern hardwood association, is composed primarily of beech, birch, maple, oak, and hickory. The current forest is a second growth. The original forest was first altered and finally devastated by clearcutting and fire. The region is typified by cool, humid summers, moderate rainfall (110 centimeters or 42 inches per year), cold, wet winters, and significant snowfall (140 centimeters or 54 inches). Warren County is about 460 meters (1500 feet) in elevation, with moderate relief. It has generally well-drained soils.

### 3.2.3 St. Louis County, Minnesota (Site III)

A southern extension of the northern or boreal forest in St. Louis County, Minnesota, is the third site. It has short, hot summers and long, extremely cold winters. Although precipitation is relatively low (64 centimeters or 25 inches per year), poor drainage resulting from the flat topography creates a preponderance of lakes. Although the numerically dominant species are aspen and birch, the forest succession if left undisturbed would favor a climax of spruce and fir. There are scatterings of pine, especially on the drier, sandy soils.

### 3.2.4 Sandoval County, New Mexico (Site IV)

Sandoval County, New Mexico, represents the most xeric site of the TES project. Annual rainfall ranges from 20 to 41 centimeters (8 to 16 inches), increasing with altitude; the summers are dry and hot and the winters dry and cold. The site has much topographic relief, and the vegetation is stratified according to altitude. The lowest parts of the test site are treeless, but the site is generally typified by the pinyon and juniper association at lower elevations and the pine and Douglas fir association at higher elevations.

### 3.2.5 Kershaw County, South Carolina (Site V)

Kershaw County, South Carolina, has the distinction of representing two ecosystems. The Piedmont Plateau region at the foot of the Appalachian Mountains supports an oak-pine community which is stratified by the hilly topography. This region has hot and humid summers, cool and humid winters, and moderate rainfall in summer and winter, with lesser amounts in spring and fall. On the adjacent coastal plain, the lucrative southeastern pine forest (loblolly and shortleaf) grows abundantly. This portion of the site is warmer and wetter than the Piedmont but otherwise rather similar climatologically.

### 3.2.6 Fort Yukon, Alaska (Site VI)

The Fort Yukon, Alaska, site constitutes the northernmost TES site. It exemplifies the subarctic coniferous forest that begins where the tundra ends. This forest is dominated by black and white spruce, with lesser amounts of birch, poplar, and aspen.

The study site is a transition area between two provinces. The larger portion is the Porcupine Plateau and the small portion consists of broad river bottoms resembling the adjoining Yukon Flats. The site is generally flat with permafrost creating marshy conditions. Summers are short and warm, winters very cold, and rainfall limited. Wildfires in the uplands and a changing riverbed in the lowlands have played major roles in the distribution of species.

### 3.2.7 Weld County, Colorado (Site VII)

The only nonforested TES site is located in Weld County, Colorado. It was chosen as a typical high plains grassland association. Dominated by three species (blue grama, buffalo grass, and saltgrass) with scattered shrub sages and no trees, the Weld County site is located on rolling hills at the foot of the Rocky Mountains. Relief is minimal, but the soil is very sandy; drought dominates the community. Summers are hot and dry; winters are cold and dry. Normal rainfall is about 41 centimeters (16 inches) per year.

### 3.2.8 Grays Harbor County, Washington (Site VIII)

The site in Grays Harbor County, Washington, is topographically varied with steep mountains and spectacular panoramas. It is the wettest, most luxuriant TES site. Summers with mild temperatures and moderate rainfall and winters of moderate temperature and heavy rainfall combine to produce the abundant

Pacific Coast conifer forest. This forest is dominated by western hemlock, Douglas fir, and Sitka spruce with lesser amounts of western red cedar and pine, all of which contribute substantial amounts of timber to the American economy. The problems associated with the commercial aspect make this one of the most important of the TES analysis areas.

### 3.2.9 Washington County, Missouri (Site IX)

The final ecosystem is located in Washington County, Missouri, in the northern reaches of the Ozark Mountains. The region is topographically varied. Central hardwoods are the major element and improved grassland is a minor one. Summers are typically hot and humid; winters are cold and humid. Rainfall is moderate, about 100 to 110 centimeters (40 to 45 inches) per year. The forest is composed of oak, hickory, pine, and some maple and eastern red cedar, all mixed in various proportions.

# 4. ANALYSIS PROCEDURES

## 4.1 SEQUENCE OF ACTIVITIES

Data processing in the Ten-Ecosystem Study consisted of the following steps:

1. Preliminary image analysis - to decide which two Landsat images would be most useful for analysis

2. Field survey - to collect ground data on about 70 points in the study site

3. Registration - to register the two chosen images to each other and to a topographic map

4. Type separability study - to develop and test signatures for training fields in 90 percent of the study area, using all available information, and to determine which data set would be most useful in the simulated inventory study

5. Simulated inventory study - to develop and test signatures from training fields in the remaining 10 percent of the study area, using only aerial photographs as ground truth, and to make an inventory of forest types in the whole study area using these signatures

6. Map production - to produce an alphanumeric classification map, using a printer/plotter,[4] and to provide the tapes needed by a subcontractor[5] to prepare a color-coded classification map

## 4.2 EXPLANATION OF PROCEDURES

### 4.2.1 Preliminary Image Analysis

Up to eight frames of Landsat imagery were ordered for each site. Data quality and absence of cloud

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[4]The Gould Printer/Plotter, Model 5000.

[5]Seiscom Delta.

cover were considered in this selection. The frames were chosen to represent the entire year or, failing in that, to represent the spring or summer from year to year.

These Landsat color composite images (1:1 000 000 scale) were visually compared with the associated aerial color-infrared photographs (1:120 000 scale) to determine which two Landsat acquisitions together provided the most forest information.

Two interpreters were used to make this determination. Interpreter A interpreted the aerial photographs covering the site, using stereopairs and a scanning stereoscope. His interpretation of the first quadrant, along with the uninterpreted Landsat image, was given to interpreter B to be used as an interpretation key. Using this key, interpreter B then interpreted the fourth quadrant of the Landsat image. Finally, 100 sample points on this interpreted image were compared with the corresponding points on the interpreted aerial photograph and a percentage of correlation between the two interpretations was calculated.

Of the images from Landsat passes over the same site, the one with the highest correlation was chosen for use. The date with the second highest correlation and with sufficient temporal separation was also chosen.

TABLE II.— PERCENTAGE OF CORRELATION OF EIGHT INTERPRETED LANDSAT IMAGES WITH AERIAL PHOTOGRAPHS*
SITE IX (WASHINGTON COUNTY, MISSOURI)

| Acquisition date | Image identification | Correlation, percent | Remarks |
|---|---|---|---|
| May 24, 1973 | 1305-16121 | 76.03 | |
| August 4, 1973 | 1377-16111 | — | Cloud cover |
| July 30, 1974 | 1737-16025 | 80.16 | |
| September 22, 1974 | 1791-16004 | 76.03 | |
| October 10, 1974 | 1809-16002 | 80.99 | |
| November 15, 1974 | 1845-15591 | 82.64 | |
| March 3, 1975 | 1953-15544 | 78.51 | |
| May 14, 1975 | 5025-15511 | — | Cloud cover |

*Aerial photography acquired in November 1974.

Site IX provides a good example of the results of the process of preliminary image analysis (table II). The Landsat image best correlated with the aerial photographs was that acquired November 15, 1974. The image with the next best correlation was that acquired October 10, 1974; but, since these dates were quite close and since the July 30, 1974, acquisition had almost the same correlation and provided the desired temporal separation, it was chosen as the second image to be used.

#### 4.2.2 Field Survey

The interpreted Landsat imagery was also used in the selection of checkpoints to be visited during the field survey. It was thought that about 70 points could be checked during the 1-week trip. These points were allocated according to the apparent class proportions in the imagery of the site. The locations of these samples were chosen on the basis of accessibility.

An important restriction on the collection of such ground data was that a representative area approximately 10 percent of the site was not to be field checked. During the simulated inventory study, ground truth for this area would be interpreted from the aerial photographs. This procedure simulates future large-scale inventory operations where ground truth by field trip may not be feasible.

Figure 2 is an example of the checklists completed at all field points. The locations of these checkpoints could be changed as field conditions dictated and as Forest Service personnel advised. In fact, an important objective in making this field trip was to coordinate with Forest Service personnel and gather ancillary data from them.

#### 4.2.3 Registration

The registration process consisted of three operations. First, the two selected Landsat images were registered to each other. Then, the Landsat imagery was registered to a topographic map. And finally, the boundary of the county and that of the national forest or grasslands were delineated on the imagery.

Image-to-image registration was performed on the Earth Resources Interactive Processing System (ERIPS). Using channel 2 from each image,[6] the second-ranked image was registered to the first. If the difference between the mean radiance values of the two images was greater than an experimentally determined value, this radiance difference was subtracted from the image with the higher value to make the two more comparable. The operator picked about 60 control points of high contrast on the first image, and the Sequential Similarity Detection Algorithm (SSDA) then located these points on the second image. The operator could delete bad points and enter new ones until the results, as judged by an error vector display, were satisfactory. This operation determined the matching polynomial, which was then applied to all four channels of the second image.

The root mean square (rms) error of the image-to-image registration

---

[6]Channel 2 represents bandwidth 0.6-0.7 μm. The bandwidths represented by the other channels are channel 1: 0.5-0.6 μm; channel 3: 0.7-0.8 μm; and channel 4: 0.8-1.1 μm.

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ECOSYSTEM: Rocky Mountain Conifers
TRAINING FIELD #: 57 5150
DATE: GROUND - 12 Aug P. I. -
CREW: Ward, Tanner

| FACTORS | GROUND DATA | ANCILLARY DATA |
|---|---|---|
| MAJOR SPECIES | Aspen, few lodgepole | |
| CONDITION | Immature (4-8" dbh); sapling | |
| % COVERAGE | 10 % | |
| COVER TYPE # | Aspen | |
| UNDERSTORY SPECIES | Aspen repro, few pine seedlings, cnicle, carex, thistle, fallen pine timber | |
| GRASSLAND: RANGE | – | |
| PASTURE | – | |
| CROPS | – | |
| SOIL: COLOR | Light brownish yellow | |
| TEXTURE | Sandy loam | |
| ROCK TYPE | – | |
| WATER REGIME | moderately moist | |
| ASPECT | SE | |
| SLOPE | 5-10% | |
| ELEVATION | | |
| REMARKS | Aspen on both sides of road. Area has been logged and the pine removed. | |

| | | | |
|---|---|---|---|
| PHOTOGRAPHIC DATA | ROLL # - <br> FRAME #- | PHOTO DATE - <br> FILM & FILTER - | SCALE - |
| COLOR (MUNSEL) | | | |
| TEXTURE | | | |
| % COVERAGE | | | |
| PHOTO POSITION (GRID) | | | |
| REMARKS | | | |

*Figure 2.— Sample checklist completed in the field.*

ranged from 2.4 picture elements (pixels) for Site II to 0.8 pixel for Sites VIII and IX.

Image-to-ground registration was accomplished by registering the first image to a 1:250 000-scale topographic map. First, control points were located on the image, which was displayed on the Image 100.[7] Then, the corresponding points were located on the topo map and their coordinates were digitized.[8] The two sets of control point coordinates underwent a least-squares analysis to determine the coefficients of the matching polynomial. These coefficients were then input to the registration-rotation program to produce a rotation factor, which was used to remove the effect on the Landsat image of the Earth's rotation during the acquisition. Another type of correction was required to complete the image-to-ground registration. A Landsat pixel represents an area that is longer in the north-south direction than in its east-west dimension, but on the Image 100's cathode-ray tube it is displayed in a square array. Thus, the image as displayed is foreshortened. To approximate the true representation, about every third line of data was replicated.

Image-to-ground registration was poorest for Site IV, with a sample rms error of 1.63 pixels and a line rms error of 1.80 pixels, and best for Site IX, which had a sample rms error of 0.104 pixel and a line rms error of 0.757 pixel.

[7]General Electric Interactive Multispectral Image Analysis System, Model 100.

[8]Using the Dell Foster x-y digitizer.

Administrative boundaries were delineated on the registered Landsat images by determining points along these boundaries on the topographic map, using the Dell Foster digitizer, and then approximating the boundary on the image with a series of straight lines between the chosen points, using the Irregular Cursor Program. The results were then stored on the magnetic tape as a separate file.

#### 4.2.4 Type Separability Study

Because the Image 100 screen can display a maximum of 512 pixels by 487 lines, the approximtely 1000- by 1000-pixel image area containing the study site was divided into quadrants, each 485 by 485 pixels. False-color transparencies were made of these quadrants using the production film converter and assigning blue to channel 1, green to channel 2, and red to channel 4.

On these transparencies, the analysts delineated training fields[9] representing the various forest types and other classes of interest. These training fields were chosen from those verified by field survey and thus should have been, like the checkpoints, proportional in number to the extent of the various vegetative classes in the site. As necessary, such ground-verified training

[9]It should be emphasized that these fields were not ordinary crop fields, where relatively pure, field-center pixels and mixed, boundary pixels could be distinguished. Forest areas are generally mixed; therefore, it becomes necessary for the analyst artificially to delineate training fields in an attempt to represent a particular type of growth.

fields were supplemented by training fields verified by photointerpretation, considered almost equally reliable.

The locations of these training fields were entered on three data sets — one set for each of the two selected Landsat acquisitions and a temporal data set composed of channels 2 and 4 from each of those dates.

A signature was then acquired for each class in each quadrant of each data set. Signature acquisition consisted of recording the four radiance values for each pixel in the training fields designated as belonging to that class and then computing the mean vector and covariance matrix for that class. These parameters constitute the signature. The quadrant signatures for the class were then combined into a master signature for that image.

The master signatures for each data set were tested by using them to classify the training field pixels in that data set — the same pixels that had been used to compute these master signatures. The accuracy of this classification was determined by dividing the number of pixels classified into a particular class by the number of pixels in the training fields for that class. Any deviation from 100 percent indicates some overlap between classes. A high percentage (above 80 or 90 percent in this study) indicates that the training fields were consistently chosen by the analyst and that it is possible for this technology to distinguish between the classes.

In the first test of separability, forest, nonforest, and water were divided into Level II classes — softwood, hardwood, grassland, and water. If these categories proved to be separable, then a second test was conducted to determine the separability of the more specific Level III types; e.g., fir, pine, or cedar; oak, maple, or aspen; improved or unimproved.

The acquisition date that produced the highest separability figures was taken to indicate the best season for acquiring data from the site. This data set was also chosen for use in the simulated inventory study.

### 4.2.5 Simulated Inventory Study

The simulated inventory study used the data set found best for separability purposes and produced an inventory at the level of detail indicated by the results of the foregoing study (in every case, Level II). Signature acquisition and testing resembled the procedures used in the separability study except that in this case training fields were chosen from the reserved 10-percent area and verified only by photointerpretation. These signatures were then extended to the whole study site and used to classify it into the Level II categories.

### 4.2.6 Map Production

Before maps were made of the simulated inventory results, the classification tapes went through two processes. The quadrants were carefully joined to form an image of the entire site. The quadrant classification images were also smoothed using the GETMIX/CLEAN program (ref. 7). This program eliminates feature areas smaller than 0.04 square kilometer (10 acres) by assigning these areas the classification of their surroundings. Areas this small are generally not of interest in timber and range management planning, and the removal of the salt-and-pepper effect makes the classified image more comprehensible. Figure 3 shows the effect of GETMIX/CLEAN on one quadrant of the Warren County, Pennsylvania, site.

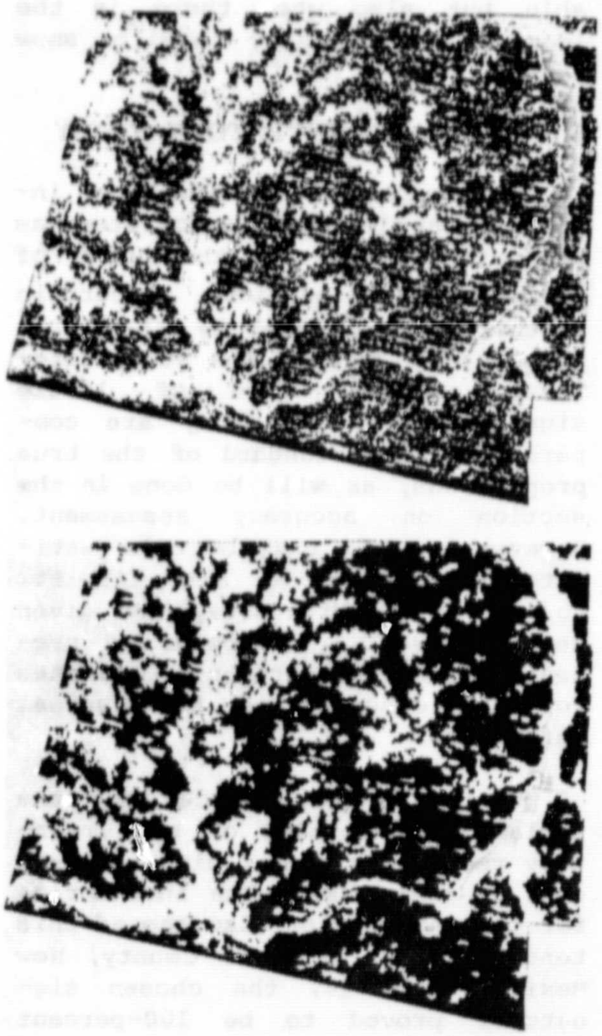

*Figure 3.— Classification of quadrant 2 of Site II (Warren County, Pennsylvania) before and after applying GETMIX/CLEAN. Dark gray = hardwood; light gray = water; white = other.*

The final mapping product for each TES site was a color-coded classification map produced from the simulated inventory results.[10] These maps were produced by a subcontractor.[11] By a direct image process, the classification data are transferred from computer tape to light-sensitive film plates by means of a laser beam. The image is then printed using a three-color lithographic overlay process. The classification map for Site V, Kershaw County, South Carolina, is given here as an example (fig. 4). The classification maps for all the other sites except Sites IV and IX are presented in appendix A (the map for Site IV can be found in section 5.2 and that for Site IX in section 7.1.9).

An interim mapping product, needed for evaluation, was an alphanumeric classification map produced on the printer/plotter. (See section 6.2, figure 6b, for an example of the appearance of such a map.)

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[10]For this product, the classification tapes for the quadrants were joined, but the GETMIX/CLEAN program was not applied.

[11]Seiscom Delta, Inc.
Digital Images Division
P.O. Box 36928
Houston, TX 77036

# 5. RESULTS

## 5.1 TYPE SEPARABILITY STUDY

The results of the type separability study were determinations of the separability of signatures for forest and grassland classes. These determinations were made by an accuracy assessment technique and, as such, will be discussed in section 6.1. Conclusions drawn from the results of the type separability study will be presented here.

The results indicate that separation is attainable at Level II (e.g., softwood from hardwood) but generally not at Level III (e.g., pine from spruce, maple from oak). One case where Level III details did seem separable, as judged by the classification of the training field pixels, was Grays Harbor County, Washington. In the abundant softwood forest of this site, three age categories seemed to be distinguishable — softwood 1 (old growth), softwood 2 (pole stage to sawtimber stage), and softwood 3 (very young, regenerated softwood). (Training field classification accuracies were 90, 85, and 72 percent, respectively.) The old growth was concentrated in the Olympic National Forest; and the young, regenerated trees were concentrated in the privately owned lands.

Another conclusion that was drawn from the results of the type separability study was what portion of the year generally provided the best Landsat data to be used to make forest and grassland inventories. The single-date or temporal data set that produced the highest training field classification accuracies was taken as indicating the best season for separability purposes. The best date for each site is given in table III. The reader should recall that the three acquisitions tested in the separability study were winnowed out of up to eight acquisitions that underwent preliminary image analysis. Thus, the best season conclusion indicates not only when the classes may be most separable but also when there is the least interference by cloud or snow cover.

## 5.2 SIMULATED INVENTORY STUDY

The results of the simulated inventory study were calculated as proportions; that is, the number of pixels classified into a certain category was divided by the total number of pixels in the study site. These estimates are of little significance unless they are compared to some standard of the true proportions, as will be done in the section on accuracy assessment. However, as an example, the estimated proportions for Site III, St. Louis County, Minnesota, are given here (table IV). Appendix B presents the proportion estimates for the other sites for factual reference.

The reader may notice that the unclassified portion of the inventory results is rather high, 37 percent in this case. The inventories for the other sites also showed this tendency. In Sandoval County, New Mexico, Site IV, the chosen signatures proved to be 100-percent

*Figure 4.— Classification map for Site V, Kershaw County, South Carolina.*

NATIONWIDE FORESTRY APPLICATIONS PROGRAM
TEN ECOSYSTEM STUDY

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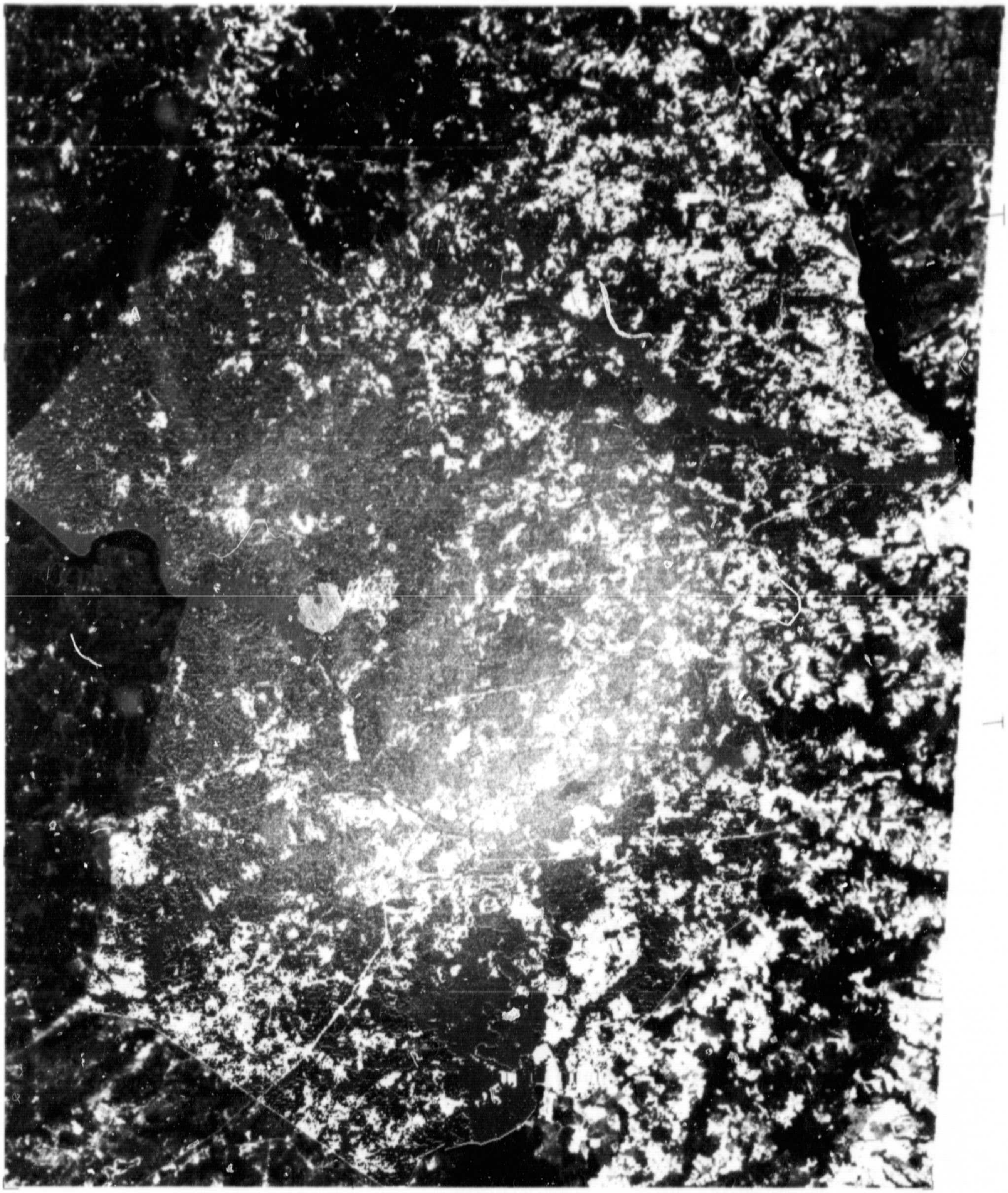
COLOR PHOTOGRAPH

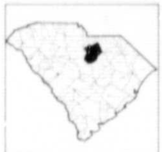
KERSHAW COUNTY, SOUTH CAROLINA




LEGEND

- SOFTWOOD LOBLOLLY, SHORTLEAF, LONGLEAF PINES
- HARDWOOD RED OAK, WHITE OAK, RIVER BIRCH, YELLOW POPLAR
- GRASSLAND
- WATER
- OTHER

CLASSIFICATION FROM LANDSAT 1
1297-15270 MAY 1973
5306-14545 FEBRUARY 1976

SOUTH CAROLINA


Analysis by:
Lockheed Electronics Co., Inc
Forestry Applications Section
April 1978
Contract NAS 9 15200

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COLOR PHOTOGRAPH

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TABLE III.— ACQUISITION DATE OF LANDSAT IMAGERY FOUND BEST FOR SEPARABILITY PURPOSES

| Site number | Site location | Ecosystem represented | Best date |
|---|---|---|---|
| I | Grand County, Colorado | Rocky Mountain Conifer | August 1973 |
| II | Warren County, Pennsylvania | Northern Hardwood | May 1975 |
| III | St. Louis County, Minnesota | Northern Conifer | July 1973 |
| IV | Sandoval County, New Mexico | Pinyon-Juniper | August 1975 |
| V | Kershaw County, South Carolina | Oak-Pine and Southeastern Pine | Temporal (May 1973 and February 1976) |
| VI | Fort Yukon, Alaska | Boreal | Temporal (September 1973 and August 1976) |
| VII | Weld County, Colorado | Grassland | July 1974 |
| VIII | Grays Harbor County, Washington | Pacific Coast | September 1974 |
| IX | Washington County, Missouri | Central Hardwood | July 1974 |

separable; however, 85 percent of the site remained unclassified. TES personnel responded to this situation by reanalyzing Site IV to determine whether the unclassified portion could be categorized. Data from the first study were reanalyzed using an unsupervised clustering algorithm. The results were categorized in an ecologically significant way using the National Site Classification System (NSCS).

The NSCS, developed by Driscoll, Russell, and Meier (ref. 8), structures information on landform, soil, vegetation, and aquatic regime to derive ecological land units and ecological water units. These units can be combined as needed. This classification system thus seems to offer both continuity and flexibility to forestry researchers. In this case, the NSCS allowed TES investigators to rank the spectral

**TABLE IV.- PROPORTION ESTIMATES FOR SITE III, ST. LOUIS COUNTY, MINNESOTA**

[Inventory based on Landsat image acquired in July 1973]

| Class | Proportion estimate |
|---|---|
| Softwood | 0.195 |
| Hardwood | .302 |
| Grassland | .059 |
| Water | .075 |
| Other | .369 |

classes of the site into a natural hierarchy. As there was no registration done for this reanalysis, the accuracy of the unsupervised classification was checked by field observation.

The resultant classes and the percentages of the site they represent are given in table V. If these communities are translated into the original TES categories, the "other" category is reduced to 12 percent, which represents the two categories of bare rock described. Table VI compares the original inventory and the reanalysis. The classification map for this site shows very clearly the topographic statification of the NSCS communities (fig. 5).

## 5.3 COSTS

Because those interested in conducting similar research and those who plan to apply the developed procedures operationally will naturally want to estimate the cost/benefit ratio, the costs of the Ten-Ecosystem Study are presented here as further "results."

In order to provide necessary information to both the research

**TABLE V.— CLASSES DEVELOPED BY REANALYSIS OF SITE IV, SANDOVAL COUNTY, NEW MEXICO**

[Based on an unsupervised clustering and categorized using the NSCS]

| Community | Percentage of site |
|---|---|
| Ponderosa pine and Douglas fir | 17.8 |
| Montane river gallery | 3.9 |
| Pinyon pine | 8.3 |
| Pinyon pine and juniper | 12.2 |
| Grassland and juniper | 9.2 |
| Desert grassland | 19.3 |
| Desert shrub | 16.1 |
| Lowland riverine gallery | 1.3 |
| Dark bare rock | 11.0 |
| Light bare rock | 1.0 |

**TABLE VI.— COMPARISON OF ORIGINAL INVENTORY PROPORTIONS AND REANALYSIS RESULTS FOR SITE IV, SANDOVAL COUNTY, NEW MEXICO**

| Class | Inventory | Reanalysis |
|---|---|---|
| Softwood | 0.087 | 0.402 |
| Hardwood | .004 | .033 |
| Grassland | .061 | .445 |
| Water | .000 | Not applicable |
| Other | .848 | 0.120 |

*Figure 5.— Classification map for Site IV, Sandoval County, New Mexico.*

NATIONWIDE FORESTRY APPLICATIONS PROGRAM
TEN ECOSYSTEM STUDY

SANDOVAL COUNTY, NEW MEXICO

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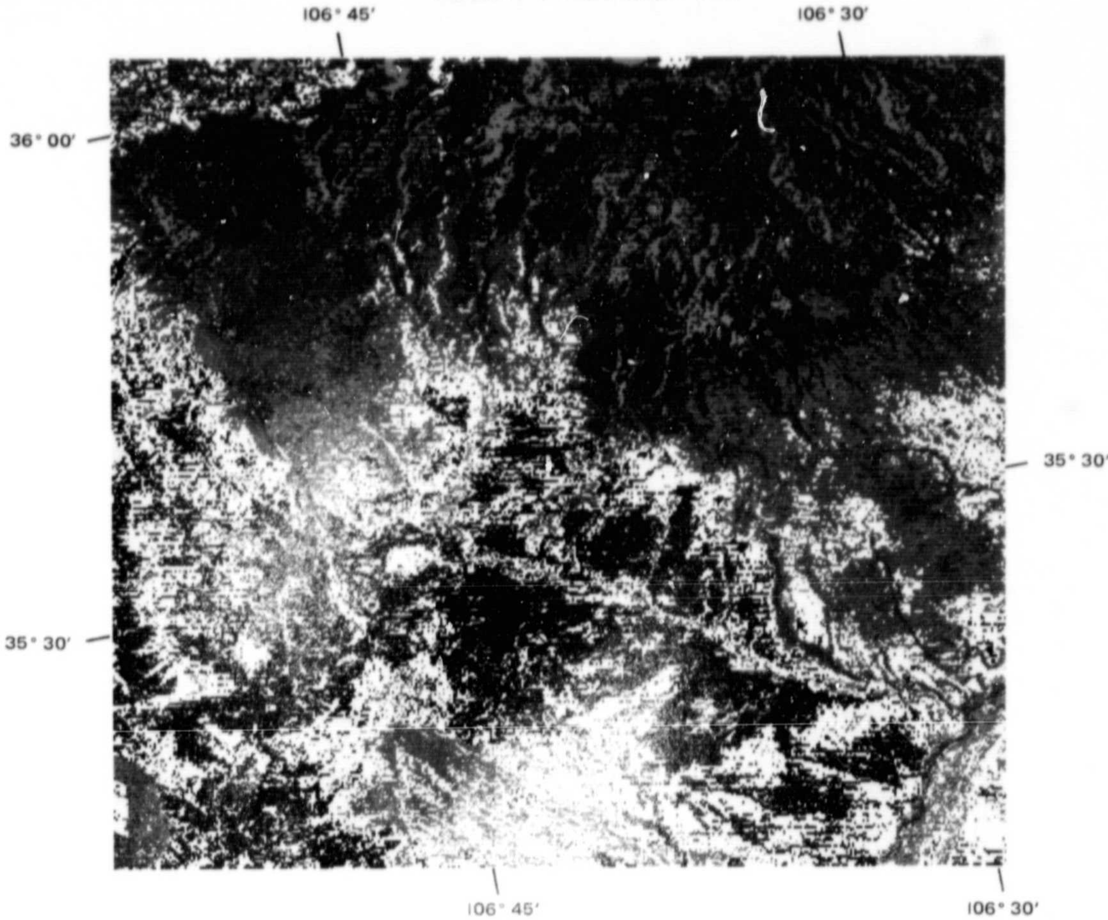
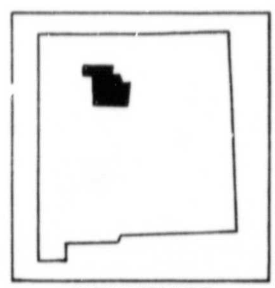



**LEGEND**

- Barren Sand, Pumice, & Rock
- Lowland River Gallery Forest
- Barren Lava or Sandstone
- Grassland – Juniper
- Desert Grassland
- Desert Shrub
- Pinyon and Juniper Woodland
- Pinyon Pine Forest
- Montane River Gallery Forest
- Ponderosa Pine – Douglas Fir Forest

CLASSIFICATION FROM LANDSAT 1
5108 16495 AUGUST 5, 1973

NEW MEXICO

Analysis by:
Lockheed Electronics Co., Inc.
Forestry Applications Section
September 1978
Contract NAS 9-15200

manager and the potential user, TES costs are presented in two formats. Actual research costs are described as incurred for significant work-breakdown units. This allows for an analysis of the projected costs for research having similar technical objectives. Costs that have been subjectively adjusted to an applications environment are also described. The purpose of the latter is to provide a perspective on the situation where the resulting product is the primary concern and where validation processes are used as necessary for quality assurance.

In appendix C are several summary cost tables that support this discussion of project costs.

### 5.3.1 Direct Costs for Research

Research direct costs are accumulated in terms of labor hours, materials, travel, and computer access. The mean direct cost per site is about $60 100.

An analysis of the average costs by function suggests an important consideration for a research manager concerned with estimating and controlling costs. Computer access time must be managed with high efficiency since it may well be the most significant single cost of the project. For TES, approximately 65 percent of the research direct costs are related to computer access charges.

The cost per unit area is calculated by dividing the total cost by the area analyzed. The mean cost is about 20 cents per square hectometer (8 cents per acre), and the range is from 12 to 27 cents per square hectometer (5 to 11 cents per acre).

### 5.3.2 Direct Costs for Applications

An analysis of TES costs in a manner meaningful to application users requires a restructuring of the actual incurred costs to include only those functions that are appropriate to an operational setting. By weighting the actual research costs for these functions, it is possible to estimate applications direct costs.

The estimated average cost per site is about $34 100. The mean costs per function show that an application using TES procedures would have computer costs which, although reduced from the research total, remain the major item.

Applications direct costs show a significant reduction in the cost per unit area. The mean cost of 11 cents per square hectometer (5 cents per acre) for applications is little more than half that for research.

### 5.3.3 Comparison of Costs With Site Features

Variations in costs may often be correlated with some feature of the work process or with some aspect of the materials being processed. If a strong correlation can be established, it is possible to predict the effect of the variables. This, in turn, can be an effective management tool for planning and controlling future costs. Correlations established by linear regression are shown in appendix C.

There is a strong correlation between analyst data processing experience and the cost to process a site. Comparing the average costs for the analysts having the most ADP experience with the average costs for analysts having the least experience suggests that a cost savings can be realized using personnel experienced with ADP.

There is a very weak correlation between site class proportions and the cost to process the site. This weak correlation suggests that the site ecosystem is not a significant force in determining the cost of processing.

### 5.3.4 Total Project Costs

Direct costs for research and applications are only a portion of the actual total project costs. Indirect costs, such as manufacturing overhead, engineering overhead, general and administrative expenses, and profit, often account for more of the final expense than do the directly incurred costs.

Project costs can be divided into components, and a model can be constructed which defines the relationship between the components. For TES, the direct costs are known, and a model can demonstrate how indirect costs are determined on the basis of the direct costs. A sample model for determining total project costs for a fixed-price contract is presented in appendix C. Although it is possible to construct several other types of models which may have equal validity for specific situations, this particular version will serve to demonstrate the total project costs for TES. The rates and computational methods illustrated do not necessarily reflect those used by any one agency or company in particular but are drawn from a number of qualified sources (refs. 9 and 10).

Solving the model, the mean total of direct and indirect costs is $90 627 per site for the research costs of TES and $53 191 for the estimated application costs. Total costs per unit are 29.8 cents per square hectometer (12.0 cents per acre) for research and 17.5 cents per square hectometer (7.1 cents per acre) for estimated applications.

An additional reduction of these costs possibly could be realized through the implementation of efficient processing techniques designed to meet a single set of specific requirements. For example, the contract for a recent project (ref. 11), which employs computer-assisted analysis of Landsat data to identify 18 forest vegetational classes, was awarded at a total cost of about 7.7 cents per square hectometer (3.1 cents per acre).

# 6. ACCURACY ASSESSMENT

## 6.1 TYPE SEPARABILITY STUDY

The purpose of the type separability study was to determine at what level of detail forest and grassland features could be distinguished on the basis of their multispectral scanner response. Training field signatures were acquired for classes at one level of detail, and the separability of these classes was determined by the accuracy of the classification of the pixels from these same training fields. A percentage less than 100 indicates an overlap between classes. This kind of accuracy assessment thus tests how well this sensor detected spectral differences between the designated classes and how consistently the analyst chose training fields characteristic of the classes. The applicability of such signatures remained to be tested in the simulated inventory study.

All the site studies achieved high training field classification accuracies at Level II, but the accuracy figures for Level III classes fell below the requirements. As an example, the accuracy assessment of the type separability study at Site VI, Fort Yukon, Alaska, is presented here (tables VII and VIII). If readers are interested in the exact figures for the other sites, they are referred to the individual final reports.

TABLE VII.— TRAINING FIELD CLASSIFICATION ACCURACIES FOR THE LEVEL II SEPARABILITY STUDY AT SITE VI (FORT YUKON, ALASKA)

| Class | September, percent | August, percent | Temporal, percent |
|---|---|---|---|
| Softwood | 99.0 | 99.5 | 99.9 |
| Hardwood | 98.0 | 95.0 | 99.0 |
| Tundra | 97.0 | 97.0 | 99.0 |
| Water | 99.5 | 99.0 | 99.9 |
| Overall accuracy* | 98.4 | 97.6 | 99.5 |

*Determined by summing all correctly classified pixels and dividing by the total number of pixels.

## 6.2 SIMULATED INVENTORY STUDY

A similar test was made of the signatures developed for the simulated inventory study; and, again, high training field classification accuracies were achieved. However, because the purpose of the simulated inventory study was to determine how successfully signatures acquired from only 10 percent of the area and developed using only photointerpretation could be extended to classify the entire study area, an assessment of the resulting inventory was judged to be more important than the accuracy of the signatures alone.

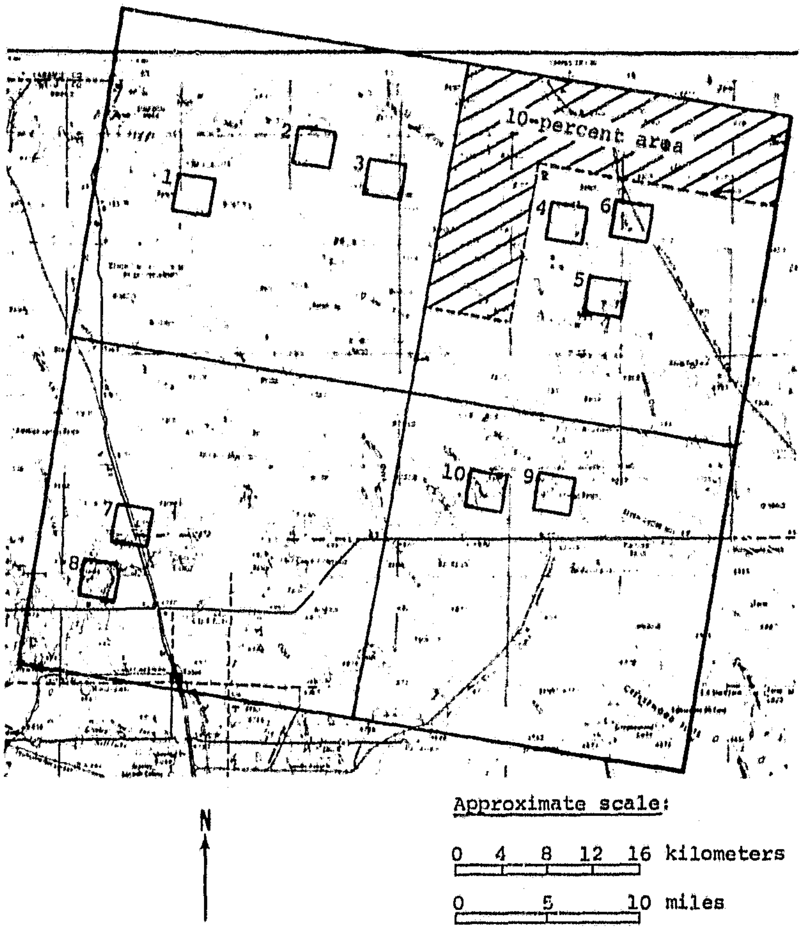
The accuracy of the classification map was assessed by sampling the map and comparing the classification of these samples with the interpretation of the corresponding samples on the aerial photographs of the site. The percentage of correct classification (PCC) was estimated, as was the PCC confidence interval at the 90-percent level.[12]

TABLE VIII.— TRAINING FIELD CLASSIFICATION ACCURACIES FOR THE LEVEL III SEPARABILITY STUDY AT SITE VI (FORT YUKON, ALASKA)

| Class | Temporal, percent |
|---|---|
| Sparse spruce | 92 |
| Dense spruce | 66 |
| Grass tundra | 99.5 |
| Brush tundra | 44 |

[12]The simulated inventory procedures were not amenable to display of pixel-by-pixel classification accuracy in a confusion table or matrix that indicates errors of omission and commission; i.e., how many pixels were classified as B, C, and D when they should have been classified as A (omission) and how many pixels that should have been classified as B, C, or D were classified as A (commission).

A stratified sampling strategy was used (see fig. 6a and b). In some forestry applications, where any one area is likely to be mixed, stratified sampling is more efficient than random sampling. In contrast, random sampling may be preferred in an agricultural situation, where an individual field is fairly pure.[13]




(a) Map of Site VII (Weld County, Colorado) showing the random location of the primary sampling units (PSU's).

□ = PSU

*Figure 6.— Two-stage sampling strategy.*

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[13]By analogy, consider a survey to determine the racial makeup of a city. If the population is well integrated, a limited number of samples can achieve best results if they are grouped to determine the makeup of small areas, which are then averaged to estimate the citywide proportions. Conversely, if the population is segregated, its makeup can more accurately be estimated by distributing the same number of samples at random throughout the city.

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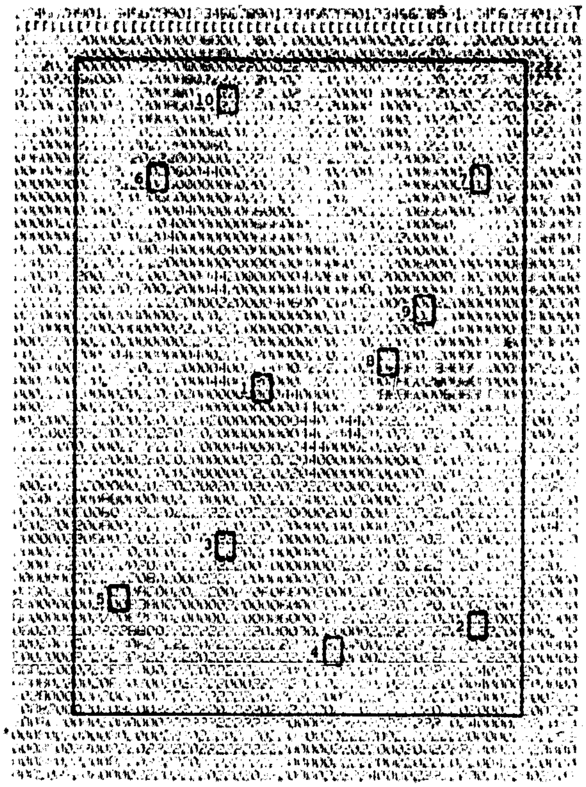

(b) Classification map of PSU 17, quadrant 2, Site VIII (Grays Harbor County, Washington) showing the random location of the secondary sampling units (SSU's).

□ = SSU

*Figure 6.— Concluded.*

To evaluate the accuracy of the TES inventory map, the coordinates of 10 to 25 primary sampling units (PSU's) were randomly generated. If any of these were found to be cloud covered on either the aerial photographs or the Landsat image, they were replaced by the same method.

The aerial photographs were registered with the alphanumeric printout and the 50- by 50-pixel PSU's located on each. Then, again using a random-number generator, 10 secondary sampling units (SSU's), each 2 pixels by 2 pixels, were selected within each PSU on the classification map.

As each PSU on the photograph was alined with the corresponding PSU on the alphanumeric printout,[14] an ad hoc evaluation procedure, developed by Kan (ref. 12), was carried out.

First, the area on the photograph covered by the SSU was interpreted in 10-percent increments (see fig. 7a). The classification of the SSU on the printout was recorded (see fig. 7b). Since the SSU was a 4-pixel area, this classification was necessarily in 25-percent increments. Then the eight surrounding possible locations, each offset from the original SSU location by 1 pixel, were checked to see if their classifications more closely matched the photointerpretation for the SSU (see fig. 7c).

This benefit of the doubt was given in the project evaluation in order to compensate for a possible misregistration of up to 1 pixel and also to compensate for the built-in difference between the 10-percent interpretations of the photograph and the 25-percent classifications of the map.

If the computed difference between the photointerpretation and the classification for the SSU was less than a given threshold, then the SSU was scored as correctly classified. Since there were 10 SSU's per PSU, the number of SSU's scored as right was easily converted to the percentage of correct classification for the PSU (see table IX). These were then averaged to provide the PCC for the site. The PCC was taken to be an indicator of the overall accuracy of the classification map. Statistical formulations

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[14]Using the Bausch & Lomb Zoom Transfer Scope.

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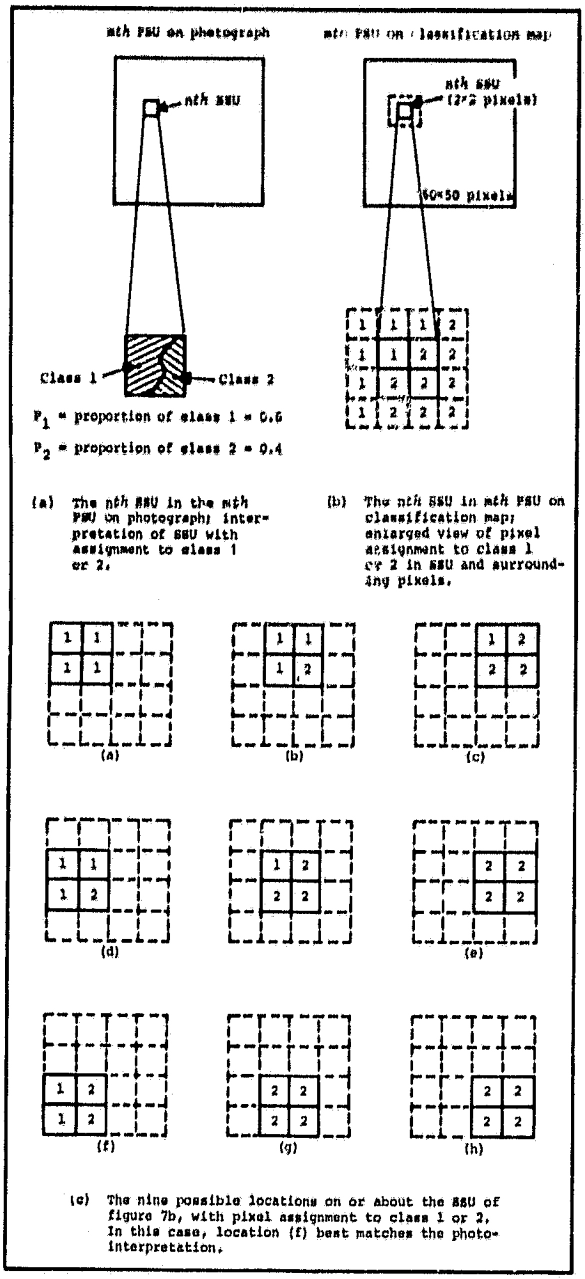


*Figure 7.— TES evaluation procedure.*

TABLE IX.— SUMMARY OF PCC CALCULATIONS FOR SITE IX, WASHINGTON COUNTY, MISSOURI

| PSU number | $PCC_i$ expressed as proportion |
|---|---|
| 1 | 0.80 |
| 2 | .90 |
| 3 | .80 |
| 4 | .90 |
| 5 | .70 |
| 6 | .90 |
| 7 | 1.00 |
| 8 | .80 |
| 9 | 1.00 |
| 10 | .70 |

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

$$= 0.85$$

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

$$s_{PCC} = 0.034$$

$$A = ts_{PCC}$$

$$= 1.833s_{PCC} \text{ at 0.9 confidence level}$$

$$= 0.062$$

Confidence interval of PCC = (PCC − A, PCC + A)
= (0.788, 0.912)

| Inventory PSU's | PCC | Half the confidence interval at 0.9 | PCC ± $A_{0.9}$ |
|---|---|---|---|
| 10 | 85% | ±6.2% | (78.8% – 91.2%) |

Notation

$m$ = number of PSU's in sample scheme

$PCC_i$ = percent correct classification (i = PSU index)

$f$ = finite population constant = (m/N), where
m = number of PSU's in sample scheme and
N = total number of PSU's in entire population

$s^2_{PCC}$ = variance of mean

$s_{PCC}$ = standard deviation

$t$ = constant obtained from statistical tables

(shown in table IX) were applied to determine the confidence interval for the PCC at the 90-percent confidence level. This means that if this evaluation were repeated 100 times, the true PCC could be expected to be contained within the confidence interval in 90 cases. In practice, if the confidence interval exceeded about 7 percent of the PCC, then more PSU's, up to 25, were evaluated. The PCC results are given in table X.

In addition to making this PCC determination, the same averaging scheme was used to determine class proportions from the inventory samples and the photo samples. Assuming the photosampled proportions to be correct, proportion errors and related measures were calculated. These are presented in appendix D, with the results for Site IX, Washington County, Missouri, shown here for explanation (table XI). If the confidence interval around the error contains 0, the estimate may be correct, or at least any bias that exists cannot be said to be significant. A tight confidence interval

TABLE X.— PERCENTAGE OF CORRECT CLASSIFICATION WITH CONFIDENCE INTERVAL

| Site | PCC | Half the confidence interval at the 90-percent level, $\Delta_{0.9}$ | Number of PSU's used* |
|---|---|---|---|
| I | 75.0 | 5.4 | 20 |
| II | 86.6 | 5.8 | 16 |
| III | 76.0 | 5.1 | 20 |
| IV | 93.5 | 3.9 | 20 |
| V | 70.0 | 5.7 | 24 |
| VI | 72.4 | 5.9 | 25 |
| VII | 73.0 | 4.7 | 10 |
| VIII | 71.6 | 6.7 | 25 |
| IX | 85.0 | 6.2 | 10 |

*The number of PSU's is chosen so that $\Delta_{0.9}$ is on the order of 5 percent.

indicates precision (consistency) in making such estimates. The size of the error with respect to the object of the estimate is indicated by the relative error.

In this example, neither the softwood nor the grassland proportion estimate can be said to be significantly biased since both their confidence intervals contain 0. The hardwood proportion estimate from the inventory sample, however, appears to be a significant underestimate of the photosampled proportion. But, because of the abundance of hardwood in this site, its relative error is smaller than that for either of the other two classes.

If such figures are displayed graphically, as was done in this case, they may suggest other information. Figure 8 suggests that the

TABLE XI.— SUMMARY OF CLASS PROPORTION ERRORS FOR SITE IX, WASHINGTON COUNTY, MISSOURI

| Class | Inventory class proportion, $p$ | Photograph class proportion, $\hat{p}$ | Average error, $B$ | Standard deviation of error, $s_B$ |
|---|---|---|---|---|
| Softwood | 0.025 | 0.029 | 0.004 | 0.0099 |
| Hardwood | .803 | .075 | .072 | .028 |
| Grassland | .053 | .061 | .008 | .019 |
| Water* | | | | |
| Other | .120 | .035 | -.085 | .026 |

| Class | Half the confidence interval at the 90-percent level, $\Delta_{0.9}$ | Confidence interval, $B \pm \Delta$ | Percent relative error, RB |
|---|---|---|---|
| Softwood | 0.18 | (-0.014, 0.022) | 13.79 |
| Hardwood | .052 | ( .021, .125) | 8.34 |
| Grassland | .036 | ( -.027, .045) | 14.75 |
| Water* | | | |
| Other | .047 | ( -.132, .038) | -242.86 |

*None in test area.

Notation

$B_i = p_i - \hat{p}_i$ = individual error

$B = \frac{1}{m} \sum_{i=1}^{m} B_i$ = average error

$s_B^2 = \frac{(1 - f)}{m(m - 1)} \sum_{i=1}^{m} (B_i - B)^2$ = variance

$f$ = finite population constant = $\frac{m}{N}$, where
$m$ = number of PSU's in sample scheme and
$N$ = total number of PSU's in entire population

$\Delta_{0.9} = 1.833 s_B$ = half the confidence interval at the 90-percent confidence level

$RB = \frac{B}{p} \times 100$ = relative error

class deficiencies may be the result of migration toward the catchall "other" category.

The sampled inventory proportion estimates were regressed against the photosampled proportions to produce a regression transformation to be applied to the proportion estimates from the whole simulated inventory. The resulting regression equations and the estimates calculated by the

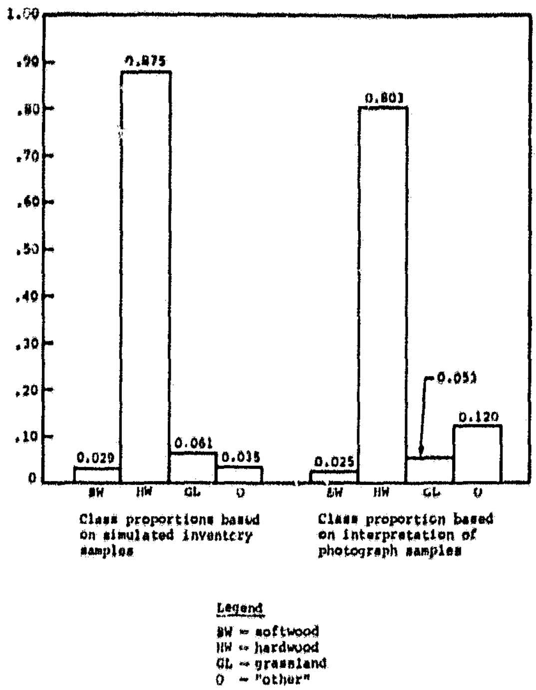


*Figure 8.— Graphic display of class proportion estimates for Site IX, (Washington County, Missouri).*

application of these equations are presented in appendix E. A related calculation, that of the coefficient of determination or $r^2$, can be seen as an accuracy indicator. The coefficient of determination is that portion of the sum of the squared deviations about the mean which is resolved by the regression. If $r^2$ is 1, then the regression equation is able to resolve completely any differences between the estimate and the standard. If it is 0, then there is no linear relationship between estimate and standard and a regression line is useless.

In the example given here (Site III), the coefficient of determination is quite high for softwood, hardwood, and water, thus indicating a good correlation between the sampled inventory proportion estimates for these classes and the corresponding photosampled proportions. The $r^2$ for grassland is quite low and indicates that the inventory estimate for this small proportion of the site is not very reliable (see table XII).

The preceding methods of assessing the accuracy of the simulated inventory classification are all based on internal comparisons. Photointerpretation is held as the standard of ground truth, and such photointerpretation also formed the basis of the signatures used to make the classification. The Ten-Ecosystem Study Investigation Plan (ref. 13) called for comparison with published figures; however, these were not generally available. Still, the scientists for Sites I, II, IV, V, and IX did manage some comparisons using figures from the Forest Service and Soil Conservation

TABLE XII.— REGRESSION ESTIMATES OF PROPORTIONS AND ASSOCIATED PRECISION FOR SITE III, ST. LOUIS COUNTY, MINNESOTA

| Class | Simulated inventory proportion, $p_{inv}$ | Regression equation | Regression estimate, $\tilde{p}$ | Coefficient of determination, $r^2$ |
|---|---|---|---|---|
| Softwood | 0.195 | $\tilde{p} = 1.011\hat{p}_{inv} + 0.0166$ | 0.214 | 0.924 |
| Hardwood | .302 | $\tilde{p} = 1.046\hat{p}_{inv} + 0.0595$ | .375 | .929 |
| Water | .075 | $\tilde{p} = 1.006\hat{p}_{inv} + 0.0147$ | .090 | .974 |
| Grassland | .059 | $\tilde{p} = 0.642\hat{p}_{inv} + 0.0246$ | .062 | .345 |

| Class | Standard error, $s$ | Half the confidence interval at the 90-percent level $\Delta_{0.9}$* | Confidence interval, $\tilde{p} \pm \Delta_{0.9}$ | Percent relative variation, $\frac{\Delta_{0.9}}{\tilde{p}} \times 100$ |
|---|---|---|---|---|
| Softwood | 0.0150 | 0.026 | (0.188, 0.240) | 12.16 |
| Hardwood | .015 | .026 | (.339, .380) | 6.9 |
| Water | .008 | .014 | ( .076, .104) | 15.90 |
| Grassland | .0134 | .023 | ( .039, .085) | 37.18 |

*$\Delta_{0.9} = t_{0.95}(19)s_B = 1.729s_B$.

Service of the USDA. These comparisons are presented in appendix F,[15] with that for Site V given here.

Using the spectral resolution[16] determined according to the established procedures,[17] the relative differences between the proportions estimated by the simulated inventory study and the proportions from the 1967 Forest Service survey (ref. 14) were high. When the spectral resolution used for classification was reduced, the class proportion estimates increased and came closer to the Forest Service figures (see table XIII).

The explanation for this seeming paradox (better classification from lower resolution) may lie in matching the fineness of the resolution to the fineness of the classification desired.[18] The TES inventory attempted to classify an area as pure softwood, for instance, when in reality it was a mixture of softwoods and some hardwoods or even grasses. Furthermore, the inventory attempted to extend signatures developed in one area to classify another area where the feature characteristics might be different. This degree of generalization may account for the better performance using a coarser picture.

In another attempt to assess the accuracy of the simulated inventory classification by comparison to an external standard, the scientists for Sites I, VII, and IX improvised an evaluation by ground-verified test fields. They applied the simulated inventory signatures to classify the pixels of the training fields from the type separability study. All pixels from any one training field were assumed to be of the designated type, which was field checked. The results are shown in table XIV.

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[15]The reader is cautioned that the basis of comparison differs from site to site.

[16]The spectral resolution of a multispectral scanner (MSS) is a function of the number of radiance values in which the data can be expressed. In the case of the Landsat MSS, a datum is recorded as a number from 0 through 127 (0-63 for channel 4). Spectral resolution is not to be confused with spatial resolution, which is a function of the smallest ground area that can be distinguished.

[17]The spectral resolution of the data was to be halved until the variance of the training field signature in any one channel became less than 4.5.

[18]By analogy, it might be easier to distinguish 4 general features in a picture if the specific areas making up these features were colored with 8 crayons rather than 64.

TABLE XIII.— COMPARISON BETWEEN INVENTORY CLASSIFICATION PROPORTIONS AND FOREST SERVICE AND SOIL CONSERVATION SERVICE (SCS) ACREAGE PROPORTIONS FOR SITE V, KERSHAW COUNTY, SOUTH CAROLINA*

| Class | Inventory proportions (radiometric resolution) | | | Forest Service and SCS proportions |
|---|---|---|---|---|
| | 32, 16, 64, 32 | 16, 8, 32, 16 | 8, 4, 16, 8 | |
| Softwood | 0.247 | 0.309 | 0.429 | 0.510 |
| Hardwood | .155 | .254 | .293 | .248 |
| Grassland | .027 | .114 | .162 | .036 |
| Water | .010 | .017 | .017 | .022 |
| Other | .542 | .288 | .079 | .184 |
| Total | .981 | .982 | .980 | 1.000 |

*Total county area equals 2035.54 square kilometers (503 100 acres).

TABLE XIV.— CLASSIFICATION ACCURACY OF SEPARABILITY TRAINING FIELDS USING INVENTORY SIGNATURES

| Class | Total training pixels | Number correctly classified | Percentage correctly classified |
|---|---|---|---|
| Site I | | | |
| Softwood | 1267 | 1053 | 83 |
| Grassland | 548 | 232 | 42 |
| Water | 1064 | 902 | 85 |
| Overall | 2879 | 2187 | 76* |
| Site VII | | | |
| Cultivated | 136 | 13 | 10 |
| Grassland | 892 | 587 | 66 |
| Water | 100 | 34 | 34 |
| Overall | 1128 | 634 | 56* |
| Site IX | | | |
| Softwood | 84 | 61 | 73 |
| Hardwood | 304 | 250 | 82 |
| Grassland | 260 | 170 | 65 |
| Water | 64 | 63 | 98 |
| Overall | 712 | 544 | 76* |

*Determined by dividing the sum of the correctly classified pixels by the total number of pixels.

# 7. TECHNICAL PROBLEMS

Since the purpose of the Ten-Ecosystem Study was to test the applicability of a uniform set of inventory procedures to 10 different ecosystems, it is useful to consider problems that were specific to individual sites, as will be done in section 7.1, and also problems found in the procedures, which will be discussed in section 7.2.

## 7.1 SITE-SPECIFIC PROBLEMS

### 7.1.1. Grand County, Colorado (Site I)

The major problems in analyzing data for Site I were related to its location in the Rocky Mountains.

The Rockies receive measurable amounts of snow from November through May. When snow is on the ground, it is impossible to classify vegetation. Thus, the season for data acquisition is only 5 or 6 months long, and even during this season clouds are frequently a problem.

The high relief causes slope and aspect to be a major factor in controlling growth of some vegetation; more important, it causes variations in illumination. Slope and shadow affected accuracies for Level III classification more than did species variation; however, at Level II, slope and aspect did not measurably affect class accuracies. For more detailed analysis of forest features, some correction must be made for slope and aspect effects (ref. 15).

### 7.1.2 Warren County, Pennsylvania (Site II)

Because of the scarcity of permanent landmarks such as road intersections or stream junctions in the heavily forested Site II, an insufficient number of control points are locatable for good image-to-image registration (see fig. 9). Haze apparent on this image may have contributed to the difficulty in locating landmarks.

### 7.1.3 St. Louis County, Minnesota (Site III)

The registration of Landsat image sets for Site III was difficult because of at least two factors. The relatively low contrast of the radiometric response in the selected Landsat scenes made visual identification of control points imprecise. Permanent cultural features, such as road intersections and dams, which are normally used for control points were difficult to locate on both scenes. Water bodies are plentiful in the area, but they do not make good features for registration because variations in water level cause changes in the size and shape of the water body.

Using the Sequential Similarity Detection Algorithm rather than manual input of two sets of control points is especially helpful in cases like this and the previous site.

### 7.1.4 Sandoval County, New Mexico (Site IV)

Site IV has a great preponderance of rock, bare soil, and dry grass

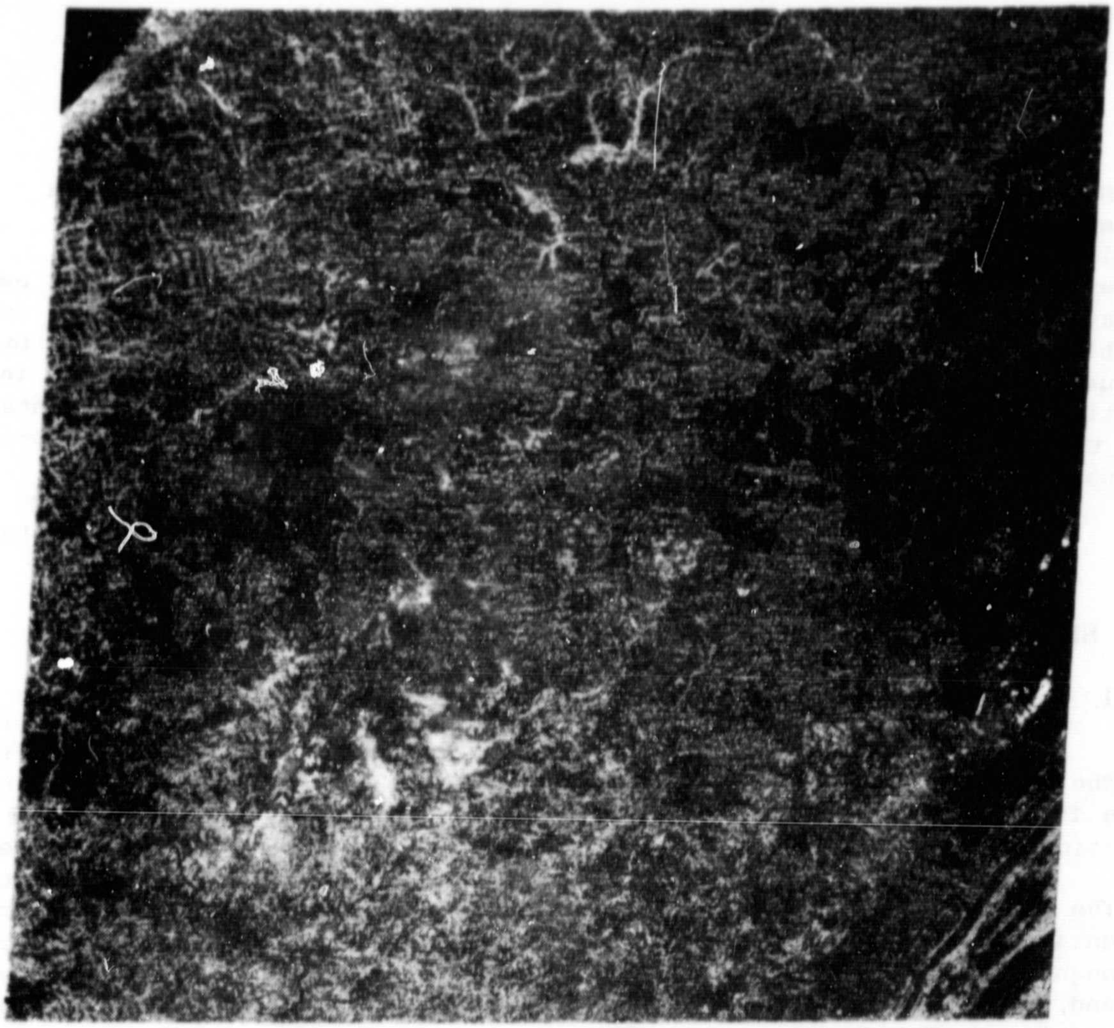


*Figure 9.— Landsat full-frame image including Warren County, Pennsylvania, acquired in September 1972.*

which are typical of semiarid regions. Light-colored rock and soil classified as "other" even though the actual coverage within a pixel may be as much as 50 percent scattered pinyon and juniper (see fig. 10). When the procedure developed for this study is used, a semiarid region with prevalent exposed rock will undoubtedly have a major portion of the scene categorized as "other."

A spectral clustering procedure, such as that used in the reanalysis of this site, offers the possibility of identifying many of the "other" (nonclassified) features in the site.

### 7.1.5 Kershaw County, South Carolina (Site V)

Site V is characterized by small clumps or stringers of hardwood, softwood, and grassland separated by mixtures and transition areas. This situation makes the development of unique class signatures using training fields difficult. Acquiring

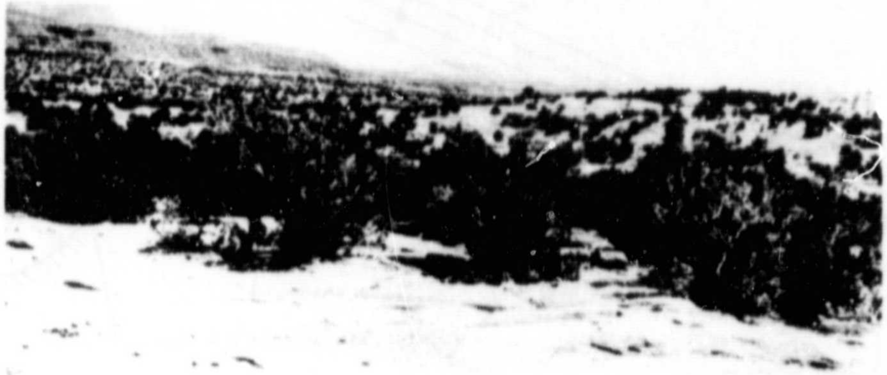


*Figure 10.– Pinyon-juniper with exposed soil and rock – Site IV (Sandoval County, New Mexico).*

cloud-free spring imagery is also a problem since cloud-free days average only 6 to 8 per month from January through May.

### 7.1.6 Fort Yukon, Alaska (Site VI)

Burns have occurred at one time or another over most of Site VI and vegetation appears in all stages of growth and succession. This causes large variations in the spectral qualities of the vegetative classes, making it difficult to select training fields that will produce broadly representative signatures.

### 7.1.7 Weld County, Colorado (Site VII)

The scarcity of prominent features for registration control points is a problem at Site VII. Changes in land management practices between the date of the aerial photographs (1972) and the dates of the Landsat image (1974) created some confusion for the photointerpreters.

### 7.1.8 Grays Harbor County, Washington (Site VIII)

Some very old stands – tall trees that have been naturally thinned – cast enough shadow to alter their spectral signature. These stands and the topographic shadow on the north-facing slopes were frequently classified as water. Clearcutting and subsequent regeneration produce vegetation with atypical spectral signatures which may classify as "other."

### 7.1.9 Washington County, Missouri (Site IX)

Topographic shadow, which altered spectral signatures, was also a problem at Site IX. These shadows include not only true shadows caused by an opaque body but also apparent shadows caused by rays from the low-angle Sun just grazing rather than reflecting from the far side of a hill inclined at a similar angle (see fig. 11). Approximately 20 percent of the western half of the

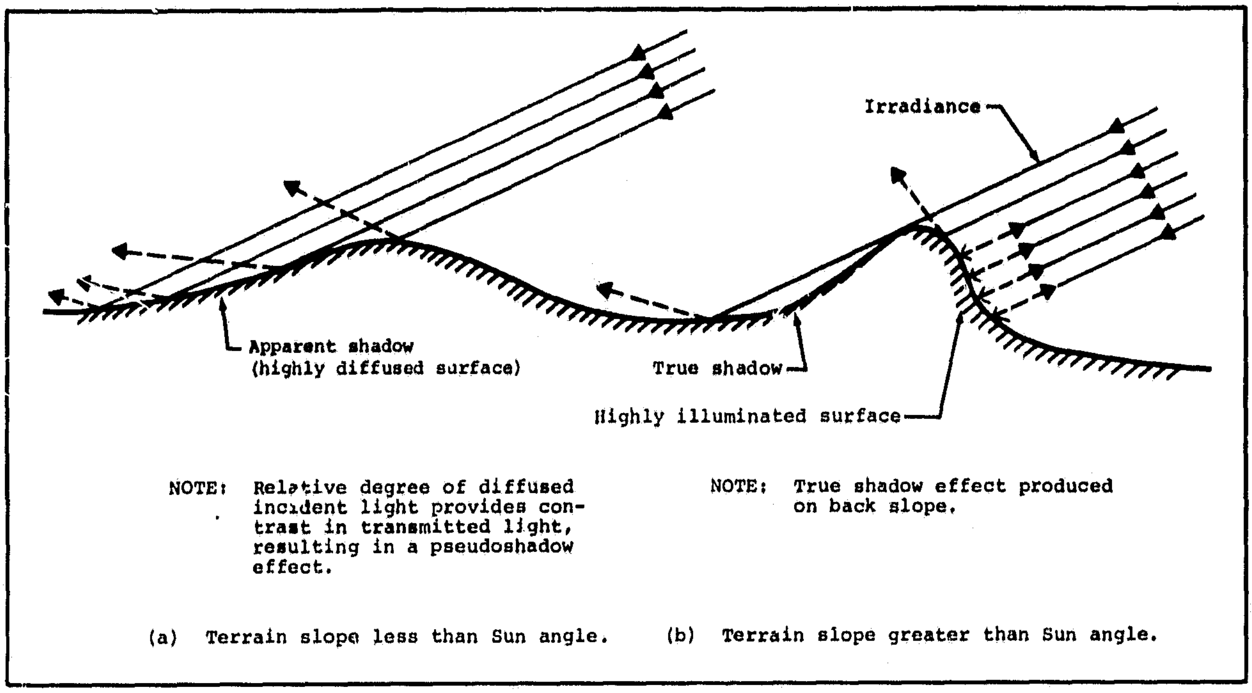



*Figure 11.— True shadow and apparent shadow effects in hilly terrain.*

county was affected by the phenomenon of apparent shadow. This problem and its effect on classification are currently under study.

Mixtures posed a difficulty as the classification map for this site may illustrate (fig. 12). An attempt to develop a separable signature for mixtures of 50 to 80 percent pine and the rest hardwood failed.

The sampling strategy used in the evaluation phase proved to be inadequate. It failed to pick up the small and widely distributed stands of softwood. The sample proportion of softwood was less than 3 percent, whereas the complete inventory and indeed the county statistics showed the softwood proportion to be over 6 percent. Hardwood was overly represented in the sample proportions.

The site-specific problems are summarized in table XV. Problems present at more than one site included an inadequate distribution of registration control points, topographic shadow, highly reflective exposed rock, small homogeneous areas and large mixture areas, and differences in stand age. Problems related to the uniform set of procedures applied to these sites will be discussed in the following section.

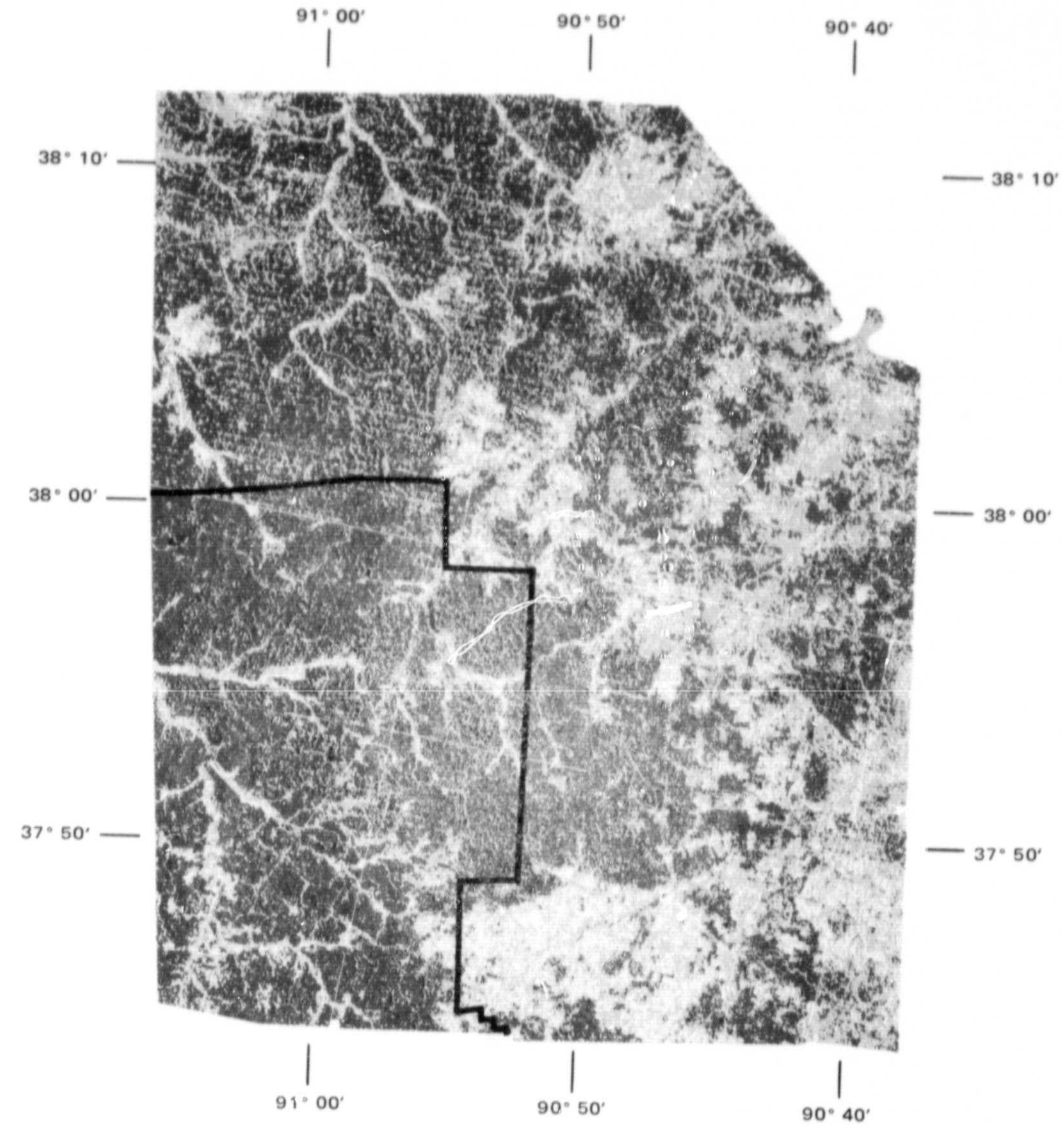
## 7.2 PROCEDURAL PROBLEMS

Some of the site-specific problems just outlined can be traced to more general problems in the TES procedures. These problems fell into two main areas: (1) the inflexibility of the procedures, which prevented an appropriate response to local site characteristics, and (2) the inadequacy of the

*Figure 12.— Classification map for Site IX (Washington County, Missouri).*

NATIONWIDE FORESTRY APPLICATIONS PROGRAM
TEN ECOSYSTEM STUDY

WASHINGTON COUNTY, MISSOURI




LEGEND

- Softwood
- Hardwood
- Grassland
- Water
- Other
- National Forest Boundary

CLASSIFICATION FROM LANDSAT 1
1737 16025 JULY 30, 1974


MISSOURI

Analysis by:
Lockheed Electronics Co., Inc.
Forestry Applications Section
September 26, 1978
Contract NAS 9-15200

TABLE XV.- PROBLEMS SPECIFIC TO EACH SITE

| Problem source | Site | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI | VII | VIII | IX |
| Short snow-free season | X | | | | | | | | |
| Frequent cloud cover or haze | X | X | | | X | | | | |
| Scarcity of cultural or topographic features for registration control points | | X | X | | | | X | | |
| Topographic shadow | X | | | | | | | X | X |
| Highly reflective features or undergrowth | | | | X | | | | | |
| Small homogeneous areas and large mixture areas | | | | | X | | | | X |
| Differences in stand age due to land management and burns | | | | | | X | | X | |

procedures in the integration of mapping and proportion estimation, which led to inefficiencies and errors. Specifically, basic problems occurred in five areas: (1) storage and display of data, (2) registration of data, (3) system parameters used for classification, (4) classification flexibility, and (5) accuracy assessment of results. These problem areas are related to each other; for example, the results of registration affect classification and accuracy. However, in the following discussion, these areas will be treated independently.

### 7.2.1 Storage and Display of Data

The size of the TES study site (about 60 by 60 kilometers or 37 by 37 miles) greatly increased the time required for input and output of data, training signature development, site classification, and production of map displays. Every operation had to be performed four times. The data storage and display of the Image 100 required that the site be divided into quadrants for classification and then recombined for map production. One approach to more efficient operations would be to limit the size of the study site. Another would be to provide increased storage capacity and more flexible display programs. If class proportions alone were desired, a sampling procedure could be developed which did not require the classification or display of all pixels.

### 7.2.2 Registration

The data for each site were registered three times: image to image for the temporal data set, image to ground for map products, and image to photographs for accuracy assessment. The residual registration errors may have led to reduced classification accuracy for the temporal data set and to errors in the accuracy assessment. The root mean square error for the individual registrations ranged from 1 to 2 pixels. Thus, the final error for the accuracy assessment could be 6 pixels or more. The rms error is computed on the basis of the control points used to calculate the transformation. This may not be an adequate measure of the registration error, and an independent set of control points should be used. The reduction in the number of data transformations could reduce processing time and classification error. For example, image-to-ground registration is not required in order to classify the data and assess the accuracy.

### 7.2.3 System Parameters

The Image 100 system required the determination of the radiometric resolution to be used in processing. This usually meant reducing the number of levels from 128 to 64 or 32. The selection of too high a resolution led to underclassification of the site as seen in Site V. A more appropriate criterion than the variance is needed for selection of the resolution to be used for processing. This could include analysis of test field areas. On the other hand, programs that efficiently utilize the full range in radiance could also be used.

### 7.2.4 Classification Flexibility

The selection of training fields and the site classification proved to be lengthy processes, with a varying degree of feature classification accuracy and with large percentages of some sites left unclassified. To a large extent, these problems were due to the use of training fields in complex natural communities. The training fields for a study must be selected both to cover all classes of interest and to cover the variability of a given class. In natural vegetative communities, in the space between "pure" stands, there is considerable mixing. Some of these mixtures are of interest and others are not. An unsupervised classification procedure would allow for a rapid breakdown of the site at the most detailed level, reduce or eliminate the need for training field data, focus field work on anomalous areas, and allow for a more complete classification of the study site with limited ground-verified information.

### 7.2.5 Accuracy Assessment

The TES evaluation procedures were designed to assess the overall accuracy of the classification map and the proportion estimation. These procedures did not allow for a pixel-by-pixel comparison with the ground and the calculation of a confusion matrix for classes. This limitation has led to difficulty in interpreting the results of the study. In addition, the effect of duplicating every third line during the image-to-ground registration is hard to evaluate.

An alternative approach, productive of more conventional statistical results, would be to match classification areas to photographic or ground-truth areas, make a pixel-by-pixel comparison, and develop a confusion matrix. This approach would not require registration of the classification results to the ground and thus would eliminate the line duplication.

# 8. SUMMARY

The results of the Ten-Ecosystem Study indicate that Landsat multispectral imagery and associated automatic data processing techniques can be used to distinguish softwood, hardwood, grassland, and water and to make inventories of these classes with an accuracy of 70 percent or better at an estimated operational cost of 11 cents per square hectometer (5 cents per acre). The potential user would have to decide on the cost/benefit ratio.

The TES experience suggests that both efficiency and accuracy would be enhanced by postponing geometric registration until after classification and its validation. The study indicates that training fields can be accurately selected from aerial photographs. Ground verification could then be reserved for accuracy assessment, where it was universally thought by project scientists to be needed. An alternative approach to the supervised classification system used in TES would be to apply an unsupervised clustering algorithm to the spectral data and then identify the clusters using an ecologically structured hierarchy such as the National Site Classification System.

These findings should be useful in determining what improved remote sensing inventory procedures should be tested by the Multiresource Inventory Methods Pilot Study.

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# APPENDIX A

## Classification Maps for Sites I-III and VI-VIII

[The classification map for Site IV appears on page 19; the map for Site V is on page 15; and that for Site IX on page 35.]

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# APPENDIX A

## CLASSIFICATION MAPS for SITES I-III and VI-VIII

In sequence, classification maps are presented as follows:

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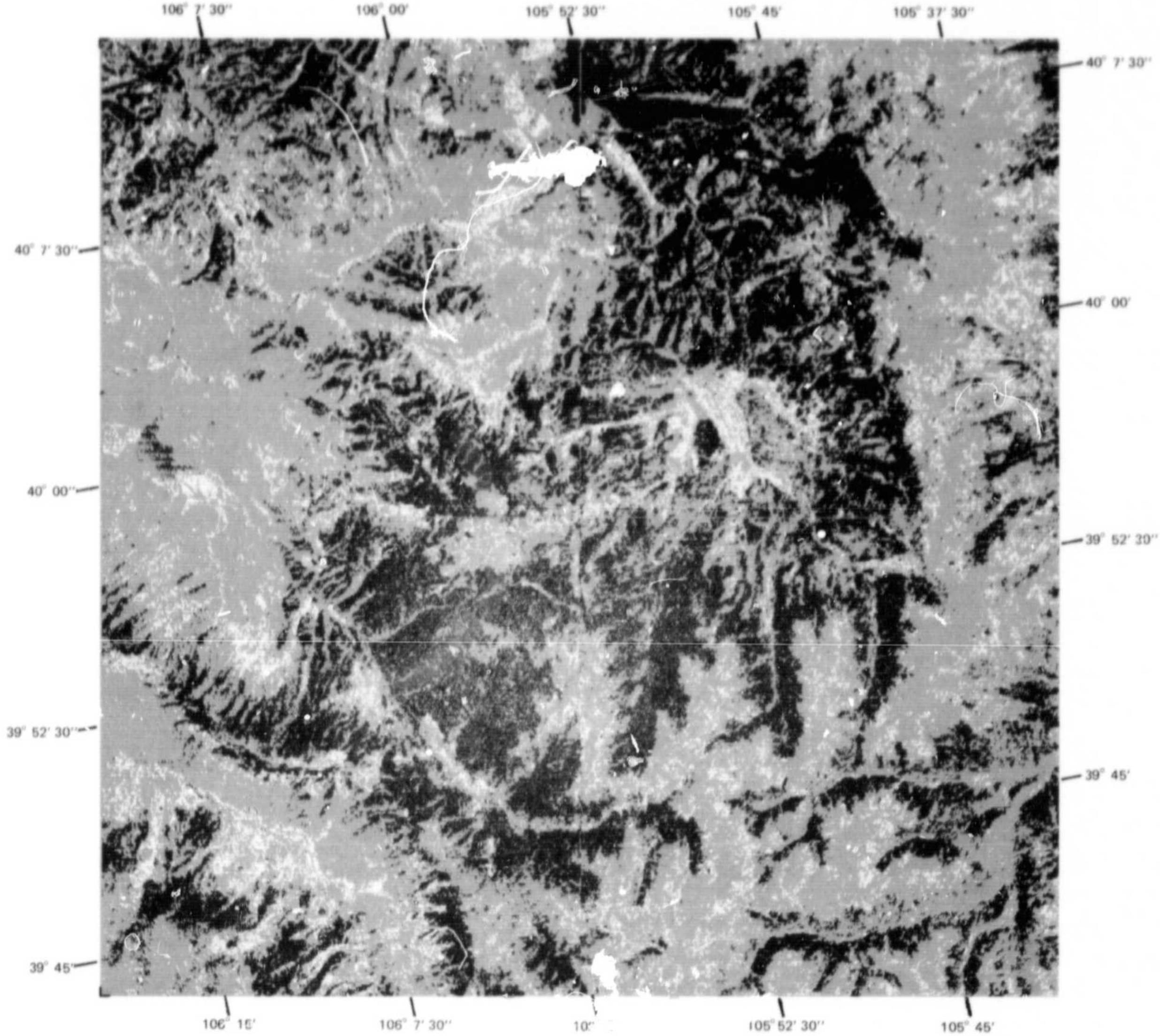
NATIONWIDE FORESTRY APPLICATIONS PROGRAM
TEN ECOSYSTEM STUDY

GRAND COUNTY, COLORADO

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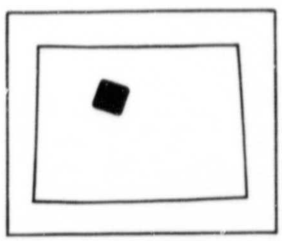
CLASSIFICATION FROM LANDSAT I
1388 17131 AUGUST 1973

**LEGEND**

- Softwood
- Hardwood
- Grassland
- Water
- Other

COLORADO

Analysis by:
Lockheed Electronics Co., Inc.
Forestry Applications Sections
September 1978
Contract NAS 9-15200

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PRODUCED UNDER U.S. PATENTS
NOS. 3.961.306 AND 3.995.312
FOREIGN PATS. PEND.

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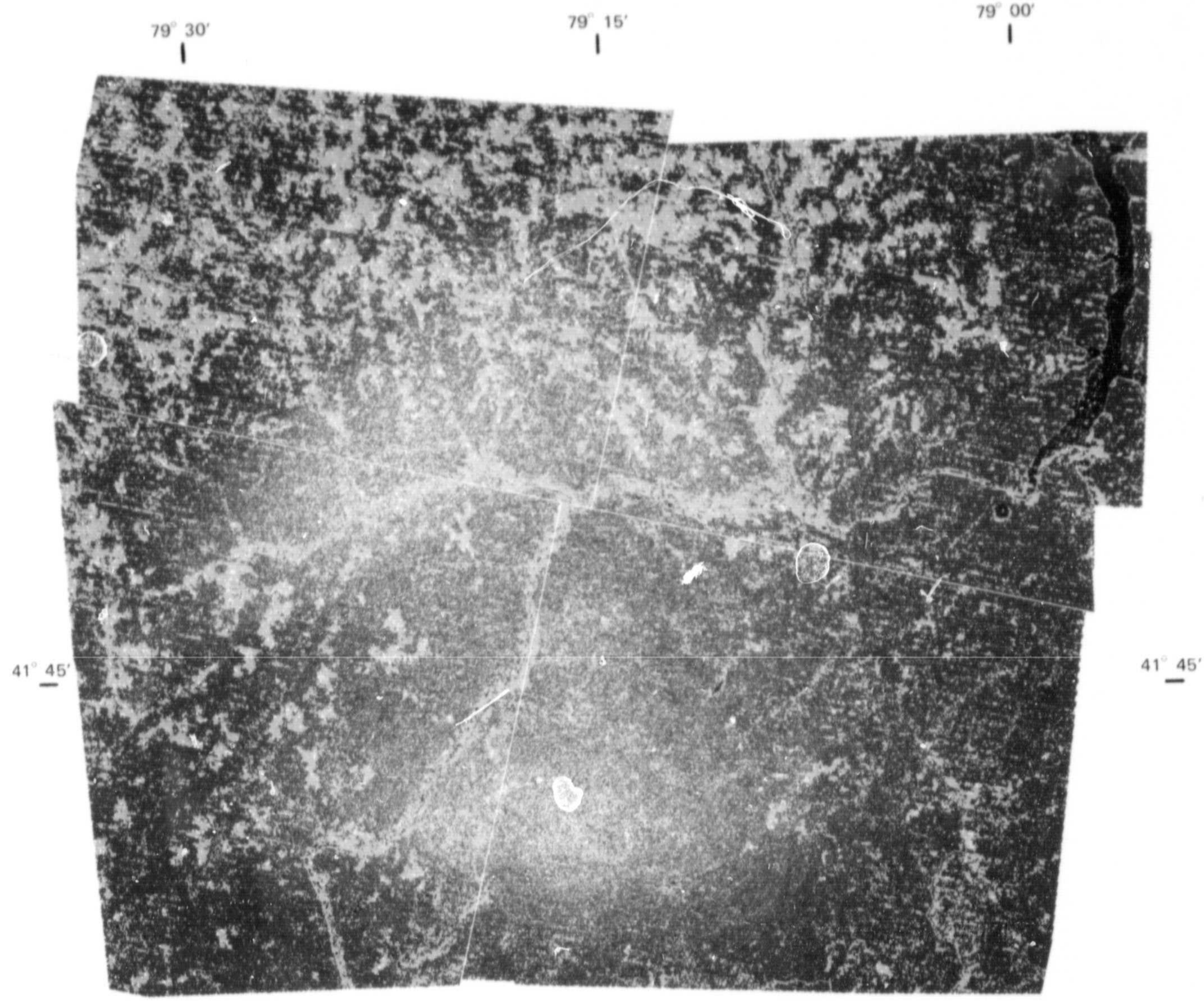
NATIONWIDE FORESTRY APPLICATIONS PROGRAM
TEN ECOSYSTEM STUDY

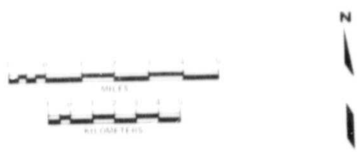
WARREN COUNTY, PENNSYLVANIA

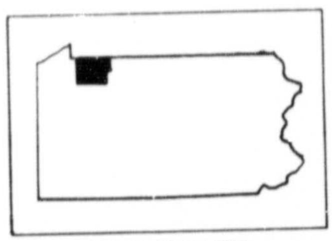



CLASSIFICATION FROM LANDSAT I
5018 15101 MAY 1975

**LEGEND**

- Softwood
- Hardwood
- Grassland
- Water
- Other



PENNSYLVANIA

Analysis by:
Lockheed Electronics Co., Inc.
Forestry Applications Sections
September 1978
Contract NAS 9-15200

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NOS. 3.961.306 AND 3.995.312
FOREIGN PATS. PEND.

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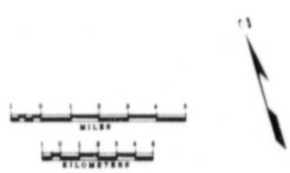
NATIONWIDE FORESTRY APPLICATIONS PROGRAM
TEN ECOSYSTEMS STUDY

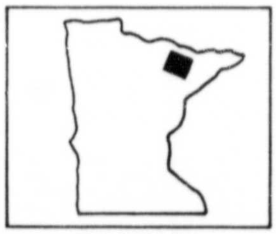
ST. LOUIS COUNTY, MINNESOTA


CLASSIFICATION FROM LANDSAT 1
1345 16313 JULY 1973

**LEGEND**

- Softwood
- Hardwood
- Grassland
- Water
- Other & Clouds
- National Forest Boundary





MINNESOTA

Analysis by:
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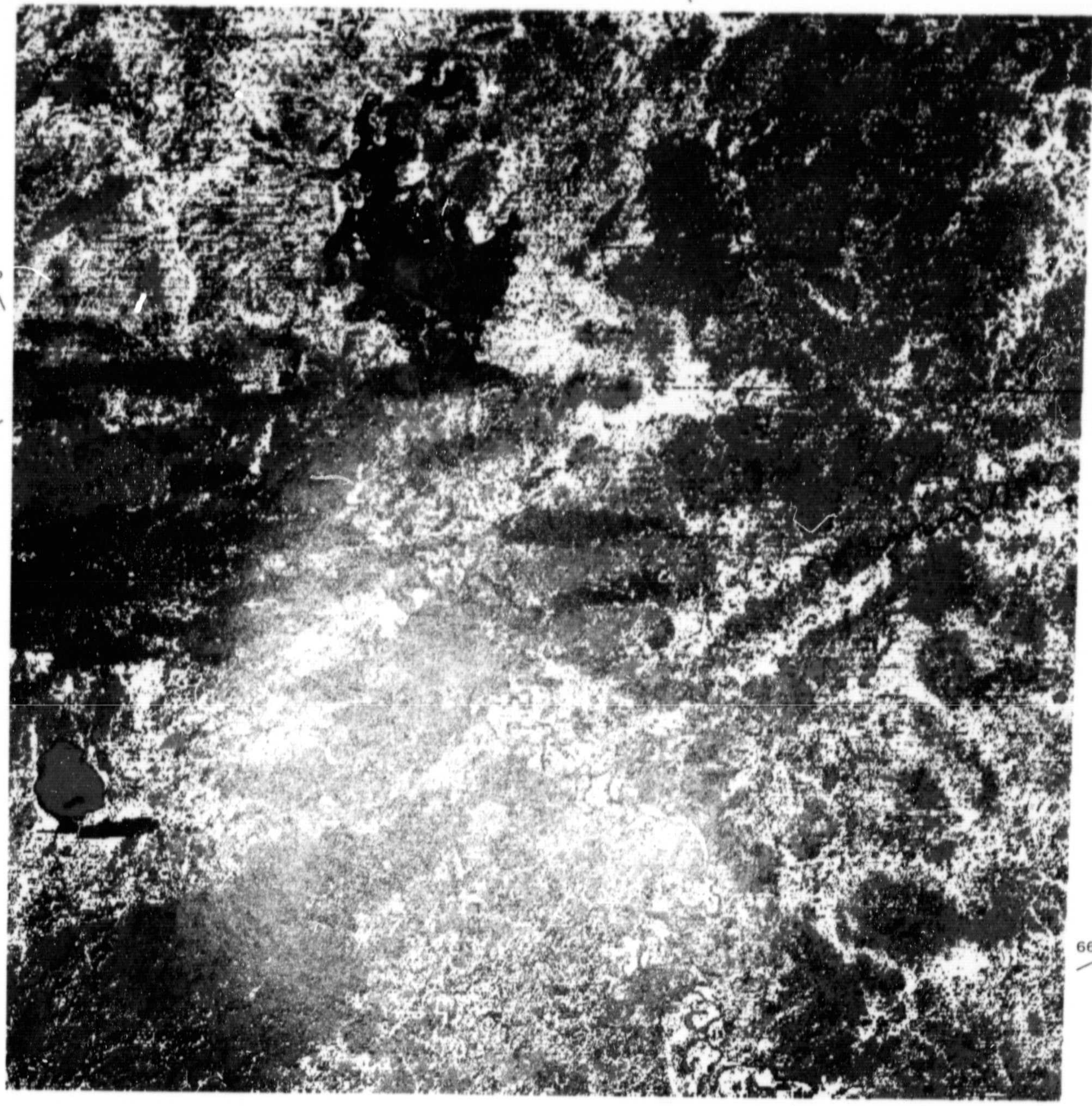
**NATIONWIDE FORESTRY APPLICATIONS PROGRAM**
**TEN ECOSYSTEM STUDY**

FT. YUKON, ALASKA




CLASSIFICATION FROM LANDSAT
1407 - 20371 SEP 73
2583 - 20181 AUG 76

LEGEND

SOFTWOOD
HARDWOOD
TUNDRA
WATER
OTHER

MILES
1 0 1 2 3 4 5

KILOMETERS
1 0 1 2 3 4 5


NOTE: WATER AND CHARRED LAND HAVE SIMILAR SIGNATURES, AND CONFUSION MAY EXIST AS SEEN IN THE OUTLINED AREAS.

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Analysis by:
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Forestry Applications Section
July 1978
Contract NAS 9-15200

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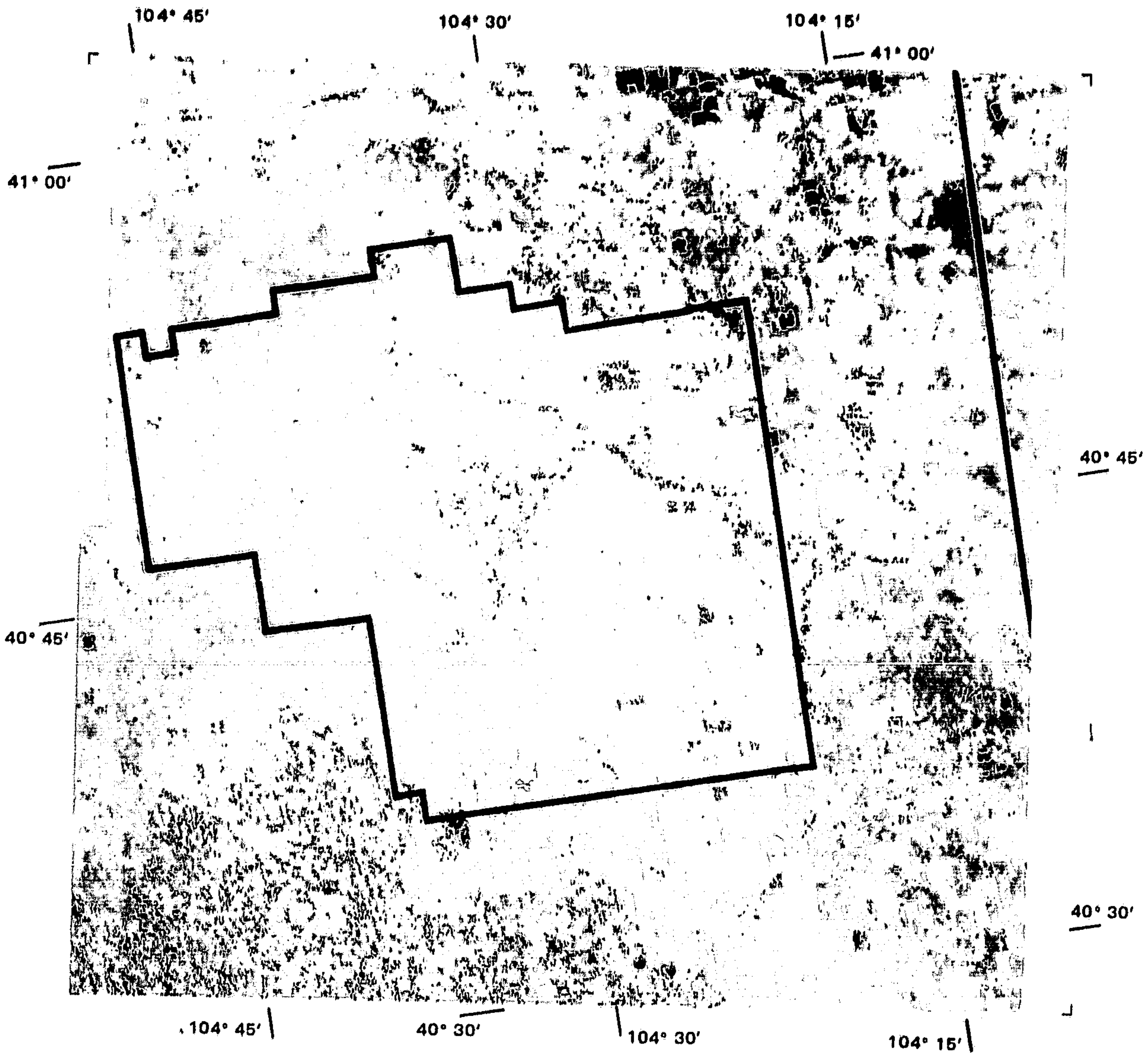
**NATIONWIDE FORESTRY APPLICATIONS PROGRAM**
**TEN ECOSYSTEMS STUDY**

WELD COUNTY, COLORADO




**LEGEND**

Cultivated

Weeds

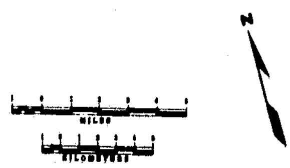
Grassland

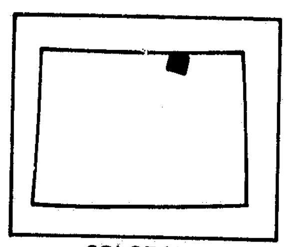
Water

Other & Clouds

National Grassland Boundary

CLASSIFICATION FROM LANDSAT 1
1693 17005 16 JUNE 1974



COLORADO

Analysis by:
Lockheed Electronics Co., Inc,
Forestry Applications Section
September 26, 1978
Contract NAS 9-15200

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COLOR PHOTOGRAPH

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**NATIONWIDE FORESTRY APPLICATIONS PROGRAM**
**TEN ECOSYSTEM STUDY**

GRAYS HARBOR COUNTY, WASHINGTON

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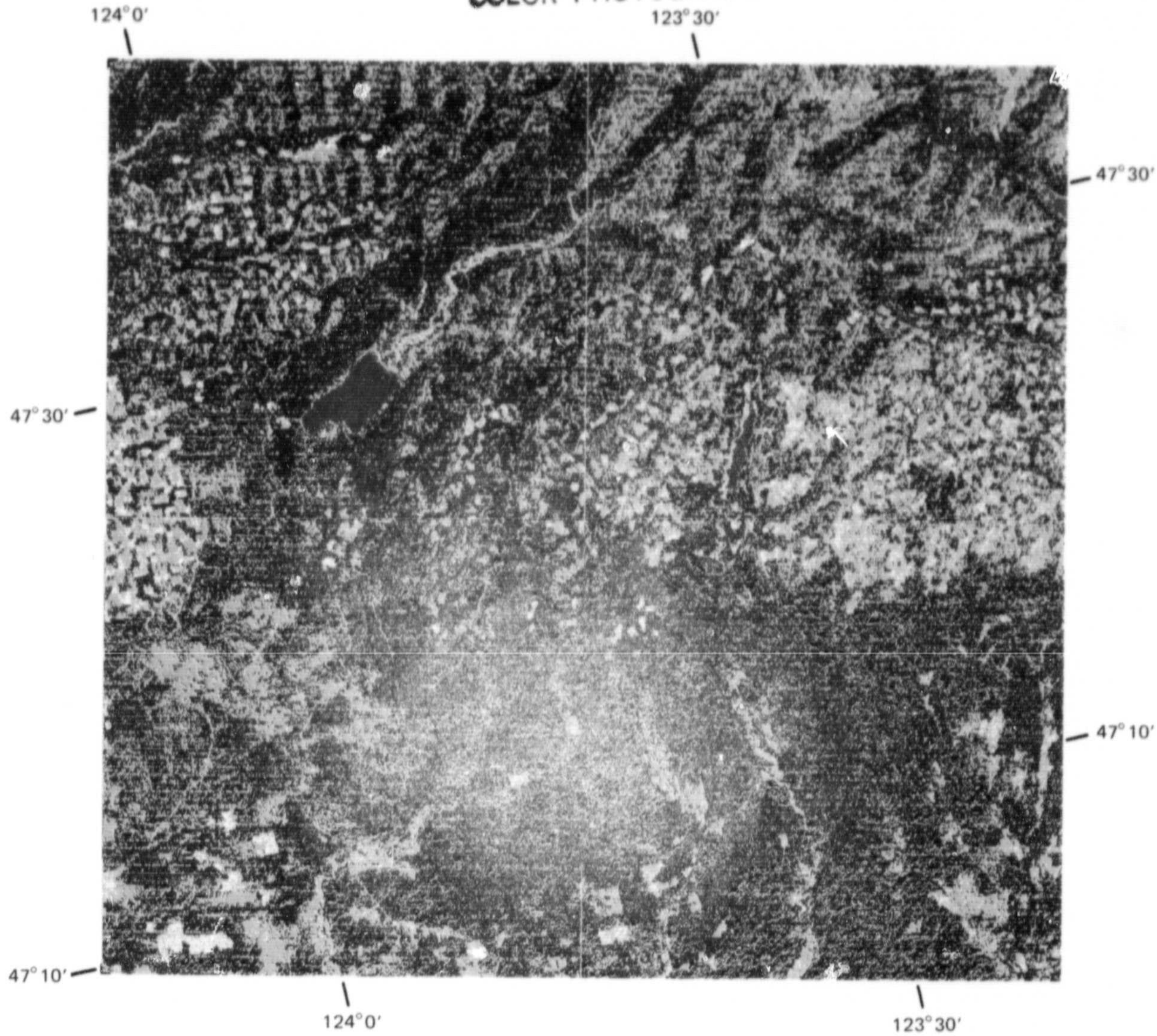



LEGEND

Softwood

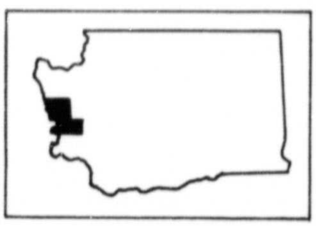
Hardwood

Grassland

Water

Other

CLASSIFICATION FROM LANDSAT 1
1781 18272 September 12, 1974

WASHINGTON

Analysis by:
Lockheed Electronics Co., Inc.
Forestry Applications Section
September 1978
Contract NAS 9-15200

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NOS. 3,961,306 AND 3,995,312
FOREIGN PATS. PEND.

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# APPENDIX B

## Proportion Estimates for Sites I, II, and IV-IX

[The proportion estimates for
Site III appear on page 18.]

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# APPENDIX B

## PROPORTION ESTIMATES for SITES I, II, and IV-IX

TABLE B-I.— PROPORTION ESTIMATES FOR SITE I, GRAND COUNTY, COLORADO

[Inventory based on Landsat image acquired in August 1973]

| Class | Proportion estimate |
|---|---|
| Softwood | 0.277 |
| Hardwood | .000 |
| Grassland | .070 |
| Water | .001 |
| Other | .652 |

TABLE B-II.— PROPORTION ESTIMATES FOR SITE II, WARREN COUNTY, PENNSYLVANIA

[Inventory based on Landsat image acquired in May 1975]

| Class | Proportion estimate |
|---|---|
| Softwood | 0.001 |
| Hardwood | .723 |
| Grassland | .009 |
| Water | .004 |
| Other | .263 |

TABLE B-III.— PROPORTION ESTIMATES FOR SITE IV, SANDOVAL COUNTY, NEW MEXICO

[Inventory based on Landsat image acquired in August 1975]

| Class | Proportion estimate |
|---|---|
| Softwood | 0.087 |
| Hardwood | .004 |
| Grassland | .061 |
| Water | .000 |
| Other | .847 |

TABLE B-IV.— PROPORTION ESTIMATES FOR SITE V, KERSHAW COUNTY, SOUTH CAROLINA

[Inventory based on temporal data set composed of Landsat images acquired in May 1973 and February 1976]

| Class | Proportion estimate |
|---|---|
| Softwood | 0.252 |
| Hardwood | .158 |
| Grassland | .028 |
| Water | .010 |
| Other | .552 |

TABLE B-V.— PROPORTION ESTIMATES FOR SITE VI, FORT YUKON, ALASKA

[Inventory based on temporal data set composed of Landsat images acquired in September 1973 and August 1976]

| Class | Proportion estimate |
|---|---|
| Softwood | 0.278 |
| Hardwood | .124 |
| Tundra | .277 |
| Water | .011 |
| Other | .310 |

TABLE B-VI.— PROPORTION ESTIMATES FOR SITE VII, WELD COUNTY, COLORADO

[Inventory based on Landsat image acquired in July 1974]

| Class | Proportion estimate |
|---|---|
| Cultivated | 0.034 |
| Grassland | .504 |
| Other | .462 |

TABLE B-VII.— PROPORTION ESTIMATES FOR SITE VIII, GRAYS HARBOR COUNTY, WASHINGTON

[Inventory based on Landsat image acquired in September 1974]

| Class | Proportion estimate |
|---|---|
| Softwood | 0.544 |
| Hardwood | .082 |
| Clearcut | .016 |
| Water | .020 |
| Other | .337 |

TABLE B-VIII.— PROPORTION ESTIMATES FOR SITE IX, WASHINGTON COUNTY, MISSOURI

[Inventory based on Landsat image acquired in July 1974]

| Class | Proportion estimate |
|---|---|
| Softwood | 0.068 |
| Hardwood | .445 |
| Grassland | .098 |
| Water | — |
| Other | .388 |

# APPENDIX C
## Detailed Cost Tables for the Ten-Ecosystem Study

## APPENDIX C

## DETAILED COST TABLES for the TEN-ECOSYSTEM STUDY

TABLE C-I.— ESTIMATED DIRECT COSTS FOR RESEARCH

| Site number | Site location | Labor* | Materials† | Travel | Computer access‡ | Total |
|---|---|---|---|---|---|---|
| I | Grand County, Colorado | $20 823 | $1 200 | $1 145 | $36 365 | $59 533 |
| II | Warren County, Pennsylvania | 13 145 | 1 200 | 1 402 | 29 160 | 44 907 |
| III | St. Louis County, Minnesota | 18 854 | 1 200 | 1 487 | 54 315 | 75 856 |
| IV | Sandoval County, New Mexico§ | 21 373 | 1 200 | 1 210 | 41 475 | 65 258 |
| V | Kershaw County, South Carolina | 16 313 | 1 200 | 1 406 | 30 185 | 49 104 |
| VI | Fort Yukon, Alaska | 18 084 | 1 200 | 7 354 | 32 195 | 64 833 |
| VII | Weld County, Colorado | 18 920 | 1 200 | 1 063 | 61 120 | 82 303 |
| VIII | Grays Harbor County, Washington | 18 711 | 1 200 | 1 866 | 31 515 | 53 292 |
| IX | Washington County, Missouri | 13 046 | 1 200 | 887 | 30 750 | 45 883 |
| Mean | | $17 697 | $1 200 | $1 980 | $38 564 | $60 108 |

*Hourly rate inflated to $11 per hour from the Energy Research and Development Agency (ERDA) 1976 estimate of $9.95 for scientific hourly rate in 1976.

†Materials purchased by negotiated subcontract covering all sites, therefore prorated to each site.

‡Calculated at rates of $300 per hour for interactive console, $125 per hour for batch, and $15 per hour for digitizing. Rates estimated by informal government sources.

§For the original study only. A rework of this effort designed to explore applications of the NSCS is not included.

TABLE C-II.— ESTIMATED RESEARCH DIRECT COSTS PER UNIT AREA

| Site | Predominant Level II feature | Approximate cost | Approximate area classified | | Approximate cost per unit area | |
|---|---|---|---|---|---|---|
| | | | $hm^2$* | acre | $hm^2$* | acre |
| I | Softwood | $59 500 | 310 000 | 765 000 | $0.19 | $0.08 |
| II | Hardwood | 44 900 | 381 000 | 941 000 | 0.12 | 0.05 |
| III | Softwood/mixed | 75 900 | 316 000 | 781 000 | 0.24 | 0.10 |
| IV | Softwood (xeric) | 65 300 | 310 000 | 765 000 | 0.21 | 0.09 |
| V | Softwood/mixed | 49 100 | 204 000 | 503 000 | 0.24 | 0.10 |
| VI | Softwood | 64 800 | 314 000 | 776 000 | 0.21 | 0.08 |
| VII | Grassland | 82 300 | 305 000 | 754 000 | 0.27 | 0.11 |
| VIII | Softwood | 53 300 | 304 000 | 751 000 | 0.18 | 0.07 |
| IX | Hardwood | 45 900 | 297 000 | 734 000 | 0.15 | 0.06 |
| Mean | | $60 100 | 304 000 | 752 000 | $0.20 | $0.08 |

*$hm^2$ (hectometer) is equivalent to 1 hectare.

TABLE C-III.— ESTIMATED DIRECT COSTS FOR APPLICATIONS

| Site | Labor | Materials | Travel | Computer access | Total |
|---|---|---|---|---|---|
| I | $13 743 | $1 200 | $1 145 | $18 183 | $32 271 |
| II | 8 676 | 1 200 | 1 402 | 14 580 | 25 858 |
| III | 12 444 | 1 200 | 1 487 | 27 158 | 42 289 |
| IV | 14 106 | 1 200 | 1 210 | 20 738 | 37 254 |
| V | 10 767 | 1 200 | 1 406 | 15 093 | 28 466 |
| VI | 11 935 | 1 200 | 7 354 | 16 098 | 36 587 |
| VII | 12 487 | 1 200 | 1 063 | 30 560 | 45 310 |
| VIII | 12 349 | 1 200 | 1 866 | 15 758 | 31 173 |
| IX | 8 610 | 1 200 | 887 | 15 375 | 26 072 |
| Mean | $11 680 | $1 200 | $1 980 | $19 283 | $34 142 |

TABLE C-IV.— ESTIMATED APPLICATIONS DIRECT COSTS PER UNIT AREA

| Site | Approximate cost | Approximate area classified | | Approximate cost per unit area | |
|---|---|---|---|---|---|
| | | $hm^2$* | acre | $hm^2$* | acre |
| I | $32 300 | 310 000 | 765 000 | $0.10 | $0.04 |
| II | 25 900 | 381 000 | 941 000 | 0.07 | 0.03 |
| III | 42 300 | 316 000 | 781 000 | 0.13 | 0.05 |
| IV | 37 300 | 310 000 | 765 000 | 0.12 | 0.05 |
| V | 28 500 | 204 000 | 503 000 | 0.14 | 0.06 |
| VI | 36 600 | 314 000 | 776 000 | 0.12 | 0.05 |
| VII | 45 300 | 305 000 | 754 000 | 0.15 | 0.06 |
| VIII | 31 200 | 304 000 | 751 000 | 0.10 | 0.04 |
| IX | 26 100 | 297 000 | 734 000 | 0.09 | 0.04 |
| Mean | $34 100 | 304 000 | 752 000 | $0.11 | $0.05 |

*$hm^2$ (hectometer) is equivalent to 1 hectare.

TABLE C-V.— SAMPLE MODEL AND DATA SOURCE TABLE FOR DETERMINING TOTAL PROJECT COSTS

Model:*

$$C = (H \cdot r \cdot s + M + T + V)e \cdot g \cdot p$$

Source table:

| Symbol | Description | Source or rate |
|---|---|---|
| C | Total project cost | |
| H | Hours worked | Individual worklogs |
| r | Average hourly pay rate | \$11.00† |
| s | Manufacturing overhead factor | 1.50‡ |
| M | Cost of materials | Filled purchase requests |
| T | Travel costs | Expense reports |
| V | Other direct costs | Receipts, computer logs |
| e | Engineering overhead factor | 1.10‡ |
| g | General and administrative expense factor | 1.05‡ |
| p | Profit factor | p' + 1.09* |
| | $p' = \dfrac{0.12W + 0.05S + 0.03D + 0.08E + 0.076G}{W + S + D + E + G}$ | |
| W | Wages | $H \cdot r$ |
| S | Manufacturing overhead | $W(s - 1)$ |
| D | Direct costs | $M + T + V$ |
| E | Engineering overhead | $(W \cdot s + D)(e - 1)$ |
| G | General and administrative costs | $(W \cdot s + D)\, e\, (g - 1)$ |

*Trueger, P. M.: Accounting Guide for Defense Contracts, 6th ed. Commerce Clearing House (Chicago), 1971.

†ERDA 1976 estimate, adjusted to 1978 estimate.

‡Estimates derived from various readings.

TABLE C-VI.— RESULTS TABLE FOR TOTAL RESEARCH AND APPLICATIONS FOR THE MEAN OF TES SITES

| Symbol* | Description | Research† | Applications† |
|---|---|---|---|
| W | Wages | $17 697 | $11 680 |
| S | Manufacturing overhead | $8 849 | $5 840 |
| M | Cost of materials | $1 200 | $1 200 |
| T | Travel costs | $1 980 | $1 980 |
| V | Other direct costs | $38 564 | $19 283 |
| E | Engineering overhead | $6 829 | $3 998 |
| G | General and administrative expense | $3 756 | $2 199 |
| P | Profit | $11 752 | $7 019 |
| C | Total project costs | $90 627 | $53 199 |

*Symbol formulas are given in table C-V.
†Calculated using the sample model given in table C-V.

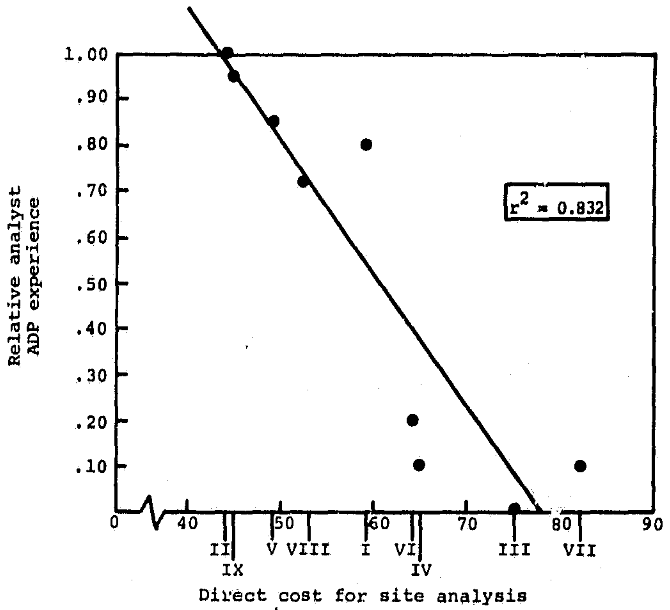


*Figure C-1.- Comparison of direct cost for site analysis with relative analyst ADP experience.*

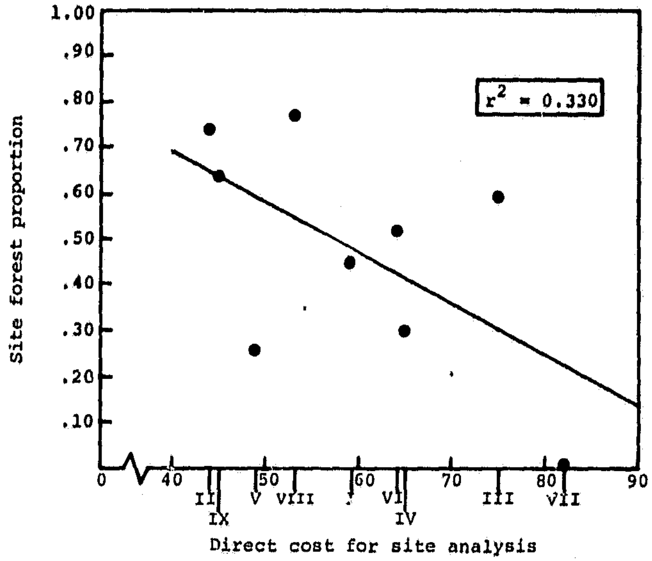


*Figure C-2.- Comparison of direct cost for site analysis with proportion of forest in site.*

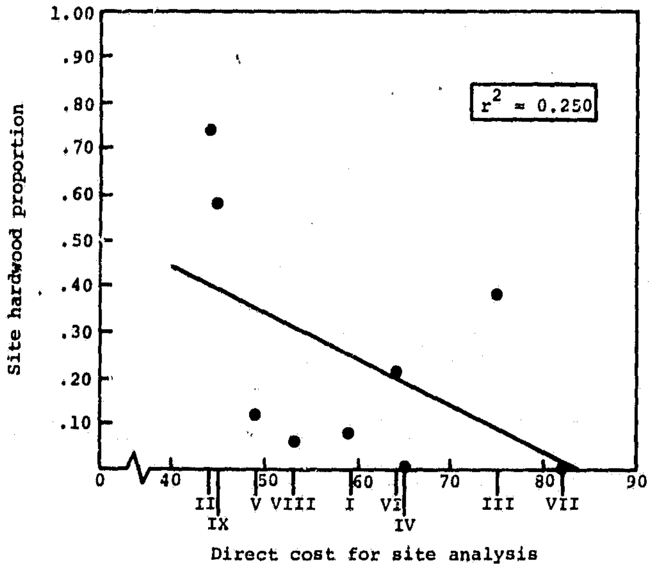


*Figure C-3.- Comparison of direct cost for site analysis with proportion of hardwood in site.*

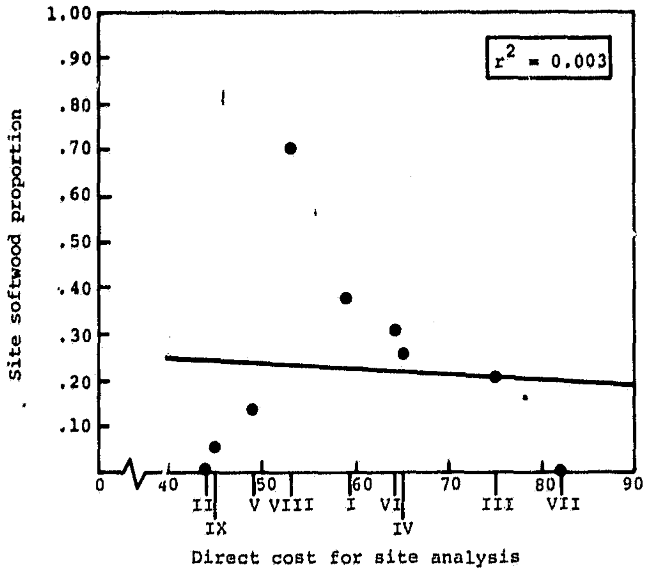


*Figure C-4.- Comparison of direct cost for site analysis with proportion of softwood in site.*

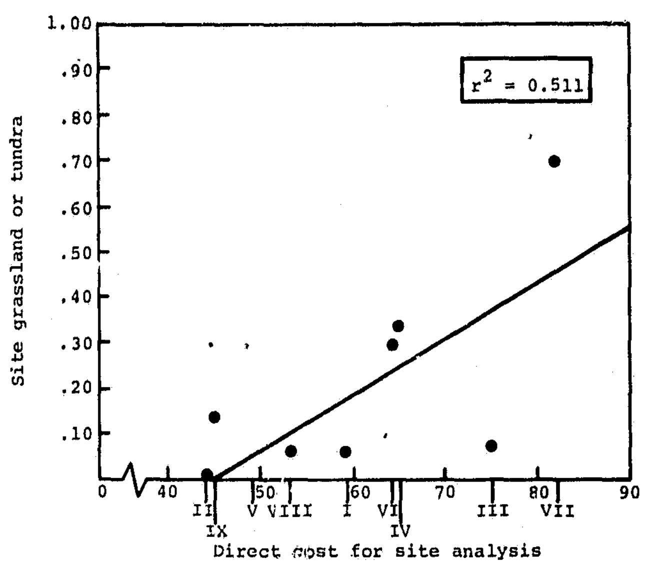


*Figure C-5.- Comparison of direct cost for site analysis with proportion of grassland or tundra in site.*

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# APPENDIX D

## Summary of Class Proportion Errors for Sites I-VIII

[The summary of class proportion errors for Site IX appears on page 27.]

## APPENDIX D

## SUMMARY of CLASS PROPORTION ERRORS for SITES I-VIII

TABLE D-I.— SUMMARY OF CLASS PROPORTION ERRORS FOR SITE I, GRAND COUNTY, COLORADO

| Class | Inventory class proportion, $\hat{p}$ | Photograph class proportion, p | Average error, B | 90-percent confidence interval |
|---|---|---|---|---|
| Hardwood* | | | | |
| Softwood | 0.4275 | 0.531 | 0.1035 | (0.0596, 0.1474) |
| Grassland | .055 | .056 | .001 | (-.0227, .0247) |
| Water | .005 | .0065 | .0015 | (-.0009, .0039) |
| Other | .5125 | .4063 | -.1062 | (-.143, -.069) |

*Extensive hardwood sites did not occur in the area from which signatures were extracted; therefore, this class was not considered for this portion of the evaluation.

TABLE D-II.— SUMMARY OF CLASS PROPORTION ERRORS FOR SITE II, WARREN COUNTY, PENNSYLVANIA

| Class | Inventory class proportion, $\hat{p}$ | Average error, B | 90-percent confidence interval | Significance of error |
|---|---|---|---|---|
| Hardwood | 0.770 | 0.009 | (-0.003, 0.029) | None |
| Softwood | .002 | .013 | ( -.002, .028) | None |
| Grassland | .014 | -.003 | ( -.012, .006) | None |
| Water* | | | | |
| Other | .214 | -.019 | ( -.050, .013 | None |

*None in test area.

TABLE D-III.- SUMMARY OF CLASS PROPORTION ERRORS FOR SITE III, ST. LOUIS COUNTY, MINNESOTA

| Class | Inventory class proportion, $\hat{p}$ | Photograph class proportion, p | Average error, B | Standard deviation of error, $S_B$ |
|---|---|---|---|---|
| Softwood | 0.263 | 0.282 | 0.019 | 0.014 |
| Hardwood | .331 | .406 | .075 | .015 |
| Grassland | .058 | .062 | .004 | .014 |
| Water | .132 | .148 | .016 | .008 |

| Class | Half the confidence interval at the 90-percent level* | Confidence interval, $B \pm \Delta$ | Does interval contain zero? | Percent relative error, RB | Agreed or over/under estimate |
|---|---|---|---|---|---|
| Softwood | 0.024 | (-0.004, 0.044) | Yes | 7.07 | Agreed |
| Hardwood | .025 | ( .050, .100) | No | 19.47 | Under |
| Grassland | .024 | ( -.02, .028) | Yes | 6.47 | Agreed |
| Water | .013 | ( -.003, .029) | Yes | 10.81 | Agreed |

*$\Delta_{0.9} = 1.729 S_B$.

TABLE D-IV.— SUMMARY OF CLASS PROPORTION ERRORS FOR SITE IV, SANDOVAL COUNTY, NEW MEXICO

Inventory 11 PSU's

| Class | Inventory class proportion, $\hat{p}$ | Photograph class proportion, p | Average error, B | 90-percent confidence interval |
|---|---|---|---|---|
| Softwood | 0.132 | 0.164 | 0.032 | (0.001, 0.063) |
| Hardwood | .011 | .011 | -.0004 | (-.031, .031) |
| Grassland | .091 | .096 | .005 | (-.005, .015) |
| Water* | | | | |
| Other | .766 | .729 | -.037 | (-.07, -.004) |

Inventory 20 PSU's

| Class | Inventory class proportion, $\hat{p}$ | Photograph class proportion, p | Average error, B | 90-percent confidence interval |
|---|---|---|---|---|
| Softwood | 0.21 | 0.234 | 0.024 | (-0.001, 0.049) |
| Hardwood | .016 | .018 | .002 | (-.001, .005) |
| Grassland | .05 | .053 | .003 | (-.003, .009) |
| Water* | | | | |
| Other | .724 | .695 | -.029 | (-.054, -.004) |

*None in test area.

TABLE D-V.— SUMMARY OF CLASS PROPORTION ERRORS FOR SITE V, KERSHAW COUNTY, SOUTH CAROLINA

| Class | Inventory class proportion, $\hat{p}$ | Photograph class proportion, p | Average error, B | 90-percent confidence interval |
|---|---|---|---|---|
| Softwood | 0.314 | 0.371 | 0.057 | (0.021, 0.093) |
| Hardwood | .222 | .291 | .069 | ( .036, .108) |
| Grassland | .042 | .039 | -.003 | (-.025, .019) |
| Water | .015 | .018 | .003 | (-.005, .011) |
| Other | .407 | .278 | -.129 | (-.167, .091) |

TABLE D-VI.— SUMMARY OF CLASS PROPORTION ERRORS FOR SITE VI, FORT YUKON, ALASKA

| Class | Inventory class proportion, $\hat{p}$ | Photograph class proportion, p | Average error, B | 90-percent confidence interval |
|---|---|---|---|---|
| Softwood | 0.358 | 0.338 | -0.020 | (-0.052, 0.012) |
| Hardwood | .102 | .142 | .040 | ( .019, .061) |
| Tundra | .268 | .276 | .008 | ( -.021, .037) |
| Water | .005 | .008 | .003 | ( -.002, .008) |
| Other | .267 | .236 | -.031 | ( -.055, -.007) |

TABLE D-VII.- SUMMARY OF CLASS PROPORTION ERRORS FOR SITE VII, WELD COUNTY, COLORADO

| Class | Inventory class proportion, $\hat{p}$ | Photograph class proportion, $p$ | Average error, $B$ | Standard deviation of error, $S_B$ |
|---|---|---|---|---|
| Cultivated | 0.022 | 0.050 | 0.028 | 0.025 |
| Weeds | 0 | .027 | .027 | .028 |
| Grassland | .543 | .441 | -.102 | .050 |
| Water* | | | | |
| Other | .435 | .482 | .047 | .052 |

| Class | Half the confidence interval at the 90-percent level, $\Delta_{0.9}$ | Confidence interval, $B \pm \Delta$ | Percent relative error, RB |
|---|---|---|---|
| Cultivated | 0.047 | (-0.019, 0.075) | 56 |
| Weeds | .035 | ( -.008, .062) | 100 |
| Grassland | .091 | ( -.193, -.011) | 23.1 |
| Water* | | | |
| Other | .096 | ( -.049, .143) | 9.75 |

*There were no significant water bodies in this site.

TABLE D-VIII.— SUMMARY OF CLASS PROPORTION ERRORS FOR SITE VIII, GRAYS HARBOR COUNTY, WASHINGTON

| Class | Inventory class proportion, $\hat{p}$ | Photograph class proportion, p | Average error, B | 90-percent confidence interval |
|---|---|---|---|---|
| Softwood | 0.584 | 0.614 | 0.030 | (-0.018, 0.078) |
| Hardwood | .074 | .103 | .029 | ( -.004, .062) |
| Clearcut | .032 | .070 | .038 | ( .007, .069) |
| Water | .004 | .004 | | ( -.008, .008) |
| Other | .306 | .209 | -0.097 | ( -.137, -.057) |

# APPENDIX E

## Regression Estimates for Sites I, IV, and VI-IX

[The regression estimates for Site III appear on page 28.]

## APPENDIX E

## REGRESSION ESTIMATES for SITES I, IV, and VI-IX

TABLE E-I.— REGRESSION ESTIMATE OF SOFTWOOD ACREAGE FOR SITE I, GRAND COUNTY, COLORADO

| Coefficient of determination, $r^2$ | Regression equation | Standard error, S |
|---|---|---|
| 0.77 | $\tilde{p} = 0.98\hat{p}_{inv} + 0.10$ | 0.031 |

TABLE E-II.— REGRESSION ESTIMATES OF PROPORTIONS AND ASSOCIATED PRECISION FOR SITE IV, SANDOVAL COUNTY, NEW MEXICO

| Class | Simulated inventory proportion, $\hat{p}$ | Photograph proportion, p | Significance of difference $(p - \hat{p})$ | Level of significance |
|---|---|---|---|---|
| Softwood | 0.21 | 0.234 | No difference | 0.01 |
| Grassland | .091 | .096 | No difference | .01 |

| Class | Coefficient of determination, $r^2$ | Regression equation | Standard error* | PSU's |
|---|---|---|---|---|
| Softwood | 0.92 | $\tilde{p} = 1.11\hat{p}_{inv} + 0.0005$ | 2.0 | 20 |
| Grassland | .97 | $\tilde{p} = 0.98\hat{p}_{inv} + 0.01$ | 1.02 | 11 |

*Standard error $= \frac{100\sigma_E}{N}$, where N is the number of PSU's.

TABLE E-III.- REGRESSION ESTIMATES OF PROPORTIONS AND ASSOCIATED PRECISION FOR SITE VI, FORT YUKON, ALASKA

| Class | Simulated inventory proportion, $\hat{p}_{inv}$ | Regression equation | Regression estimate, $\tilde{p}$ | Coefficient of determination, $r^2$ |
|---|---|---|---|---|
| Softwood | 0.2794 | $\tilde{p} = 0.89\hat{p}_{inv} + 0.019$ | 0.2675 | 0.90 |
| Hardwood | .1243 | $\tilde{p} = 0.88\hat{p}_{inv} + 0.052$ | .1612 | .83 |
| Tundra | .2767 | $\tilde{p} = 0.94\hat{p}_{inv} + 0.023$ | .2846 | .83 |
| Water | .0108 | $\tilde{p} = 1.59\hat{p}_{inv} + 0.0004$ | .03283 | .64 |

| Class | Variance of the regression estimate, $s^2$ | Half the confidence interval at the 90-percent level $\Delta_{0.9}$ | Percent relative variation, $\frac{\Delta_{0.9}}{\tilde{p}} \times 100$ |
|---|---|---|---|
| Softwood | 0.00343 | 0.031695 | 11.9 |
| Hardwood | .000148 | .020795 | 12.9 |
| Tundra | .000308 | .030045 | 10.6 |
| Water | .000011 | .005618 | 32.1 |

TABLE E-IV.— REGRESSION ESTIMATES OF PROPORTIONS AND ASSOCIATED PRECISION FOR SITE VII, WELD COUNTY, COLORADO

| Class | Simulated inventory proportion, $\hat{p}_{inv}$ | Regression equation | Regression estimate, $\tilde{p}$ | Coefficient of determination, $r^2$ |
|---|---|---|---|---|
| Cultivated | 0.034 | $\tilde{p} = 2.185\hat{p}_{inv} + 0.0018$ | 0.076 | 0.632 |
| Grassland | .504 | $\tilde{p} = 0.819\hat{p}_{inv} - 0.0045$ | .409 | .727 |
| Other | .460 | $\tilde{p} = 0.7325\hat{p}_{inv} + 0.1634$ | .500 | .628 |

| Class | Variance of the regression estimate, $s^2$ | Half the confidence interval at the 90-percent level $\Delta_{0.9}$ | Percent relative variation, $\frac{\Delta_{0.9}}{\tilde{p}} \times 100$ |
|---|---|---|---|
| Cultivated | 0.000483 | 0.040 | 52.81 |
| Grassland | .002318 | .088 | 21.60 |
| Other | .002329 | .088 | 17.69 |

TABLE E-V.— REGRESSION ESTIMATES OF PROPORTIONS AND ASSOCIATED PRECISION FOR SITE VIII, GRAYS HARBOR COUNTY, WASHINGTON

| Class | Simulated inventory proportion, $\hat{p}_{inv}$ | Regression estimate, $\tilde{p}$ | Coefficient of determination, $r^2$ |
|---|---|---|---|
| Softwood | 0.544 | 0.579063 | 0.64574 |
| Hardwood | .074 | .111653 | .46374 |
| Clearcut | .032 | .057966 | .20448 |
| Water* | .004 | .002032 | .00497 |
| Water† | .020 | .020 | 0 |

| Class | Variance of the regression estimate, $S^2$ | Half the confidence interval at the 90-percent level $\Delta_{0.9}$ | Percent relative variation, $\frac{\Delta_{0.9}}{\tilde{p}} \times 100$ |
|---|---|---|---|
| Softwood | 0.000817 | 0.049 | 8.45 |
| Hardwood | .000410 | .035 | 31.03 |
| Clearcut | .000352 | .032 | 55.41 |
| Water* | .000046 | .012 | 558.9 |
| Water† | .000063 | .014 | 67.76 |

*Unconstrained regression.
†Regression with intercept through origin.

TABLE E-VI.— REGRESSION ESTIMATES OF PROPORTIONS AND ASSOCIATED PRECISION FOR SITE IX, WASHINGTON COUNTY, MISSOURI

| Class | Simulated inventory proportion, $\hat{p}_{inv}$ | Regression equation | Regression estimate, $\tilde{p}$ | Coefficient of determination, $r^2$ |
|---|---|---|---|---|
| Softwood | 0.0681 | $\tilde{p} = 0.725\hat{p}_{inv} + 0.011$ | 0.060 | 0.390 |
| Hardwood | .4451 | $\tilde{p} = 0.330\hat{p}_{inv} + 0.610$ | .757 | .174 |
| Grassland | .0980 | $\tilde{p} = 0.417\hat{p}_{inv} + 0.039$ | .080 | .278 |

| Class | Variance of the regression estimate, $s^2$ | Half the confidence interval at the 90-percent level $\Delta_{0.9}$ | Percent relative variation, $\frac{\Delta_{0.9}}{\tilde{p}} \times 100$ |
|---|---|---|---|
| Softwood | 0.000261 | 0.030 | 49.4 |
| Hardwood | .007809 | .162 | 21.4 |
| Grassland | .000326 | .030 | 41.4 |

# APPENDIX F

## Comparisons of Ten-Ecosystem Study Results With Published Figures for Sites I, II, IV, and IX

[A comparison for Site V is presented on page 30.]

## APPENDIX F

### COMPARISONS OF TEN-ECOSYSTEM STUDY RESULTS WITH PUBLISHED FIGURES FOR SITES I, II, IV, AND IX

TABLE F-I.— SOFTWOOD AREA ESTIMATES AND COMPARISON FOR SITE I, GRAND COUNTY, COLORADO

| Softwood area estimates | Fraser Township | |
|---|---|---|
| | Square kilometers | Acres |
| Forest Service stand map* | 67.48 | 16 678 |
| Photointerpretation† | 70.04 | 17 310 |
| ADP pixel count‡ | 67.77 | 16 751 |
| Corrected (regression) estimate | 60.50 | 14 952 |
| Adjusted standard error of regression estimate§ | 2.33 | 576 |
| Confidence interval of regression estimate (0.9 level)∇ | (56.47, 64.53) | (13957, 15949) |
| Total area inside unit | 95.52 | 23 607 |

*Forest Service stand map over township was measured by a planimeter; stand map was more than 5 years old.

†Area measured by planimeter using interpreted overlays of 1:120 000-scale color-infrared photographs (not corrected geometrically); photographs were taken in September 1972.

‡ADP of August 1973 Landsat data, using signatures developed in the separability study.

§Precise standard error depends on how different the area to be corrected is from the average area used in the regression analysis. Adjusted standard error (ASE) relates to standard error (SE) by the equation

$$(ASE)^2 = (SE)^2[1 + n(P_o - P)^2/\Sigma(P - \bar{P})^2]$$

where n = number of data points in regression

$P_o$ = the area to be corrected

P = area (data value) of regression data

$\bar{P}$ = average of P

∇Confidence interval = t(ASE), where the value of t is taken from a statistical table.

TABLE F-II.— HARDWOOD AREA ESTIMATES AND COMPARISON FOR SITE II, WARREN COUNTY, PENNSYLVANIA

| Condition | May estimates | | September inventory estimate | Forest Service survey figures* |
|---|---|---|---|---|
| | Separability | Inventory | | |
| Hardwood proportion | 0.773 | 0.77 | 0.488 | 0.794 |
| Area, square kilometers (acres) | 1821.88 (450 196) | 1814.80 (448 447) | 1150.16 (284 211) | 1870.46 (462 200) |
| Differs from Forest Service survey area, percent | -2.60 | -2.98 | -51.20 | 0 |

*Ferguson, R. H.: The Timber Resources of Pennsylvania. Northeastern Forest Experiment Station, USDA Forest Service (Upper Darby, Pa.), 1968.

TABLE F-III.— COMPARISON BETWEEN ADP CLASSIFICATION AND MEASURED FEATURES FOR TOWNSHIP 17 NORTH, RANGE 2 EAST, SITE IV, SANDOVAL COUNTY, NEW MEXICO

| Class | ADP classification | | | Measured features | | $\Delta$* |
|---|---|---|---|---|---|---|
| | Pixels | Square kilometers (acres) | Percent total area | Square kilometers (acres) | Percent total area | |
| Softwood | 335 | 1.10 (272) | 1.16 | 1.49 (368) | 1.60 | 0.44 |
| Hardwood | 2 | .008 (2) | 0 | .29 (72) | .31 | .31 |
| Grassland | 444 | 1.46 (361) | 1.54 | 1.60 (395) | 1.72 | .18 |
| Water† | | | | | | |
| Other | 27 996 | 92.11 (22 761) | 97.30 | 89.89 (22 212) | 96.37 | .93 |
| Total‡ | 28 777 | 94.67 (23 395) | 100 | 93.27 (23 048) | 100 | |

*$\Delta$ = measured features - ADP classification.
†None in test area.
‡The difference in the total area is 1.52 percent.

TABLE F-IV.— SIMULATED INVENTORY VERSUS WASHINGTON COUNTY STATISTICS

[Class proportions based on pixel count]

| Data source | Level II class | | | Other | Total area, including water |
|---|---|---|---|---|---|
| | Softwood | Hardwood | Grassland | | |
| Simulated inventory: | | | | | |
| Proportion | 0.0681 | 0.4451 | 0.0980 | 0.3888 | 1.00 |
| Square kilometers | 136.06 | 889.83 | 195.87 | 777.20 | 1998.58 |
| Acres | 33 620 | 219 800 | 48 400 | 192 050 | 493 860 |
| County statistics:* | | | | | |
| Proportion | 0.0622 | 0.6743 | 0.1399 | 0.1236 | 1.00 |
| Square kilometers | 122.62 | 1330.20 | 275.96 | 239.57 | 1972.60 |
| Acres | 30 300 | 328 700 | 68 190 | 59 200 | 487 440 |
| Proportion error | 0.0059 | -0.2292 | -0.0419 | 0.2652 | 0.013 |

*County statistics obtained from Essex, Burton L.; and Spencer, John C., Jr.: Timber Resource of Missouri's Eastern Ozarks, 1972. North Central Forest Experiment Station, USDA Forest Service (St. Paul, Minn.), 1974.