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# PACIFIC SOUTHWEST Forest and Range Experiment Station



**EVALUATION OF ERTS-1 DATA FOR  
FOREST AND RANGELAND SURVEYS**

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Technical Coordinator  
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Cover: An enlarged portion (X 10) of an Earth Resources Technology Satellite (ERTS) color composite, MSS bands 4, 5, and 7 (green, red, and near infrared, respectively), obtained June 22, 1973 over part of the Black Hills, South Dakota. Snow is covering the ground but is not in the treetops. Scale is approximately 1:375,000.

## FOREWORD

When the Earth Resources Technology Satellite (ERTS-1) was launched in 1972, new and exciting applications of satellite imagery in resource management were expected. Although many of these exciting possibilities have materialized or show promise, this report shows that satellite imagery has limitations as well as positive aspects.

The report describes experimental uses of ERTS-1 imagery for inventorying forests and rangelands and for detecting areas of forest disturbance or stress—either because of adverse natural phenomena or activities of man. It suggests the levels of success a resource manager might expect if he uses ERTS-1 data for any of a number of inventory objectives.

The work was done under Contract S-70251-G (May 1, 1972 to October 9, 1974) between the Goddard Space Flight Center of the U.S. National Aeronautics and Space Administration, and the U.S. Department of Agriculture.

NASA provided funds and the Forest Service provided resource scientists from the Pacific Southwest Forest and Range Experiment Station, through its Remote Sensing Research Work Unit at Berkeley, California, and the Rocky Mountain Forest and Range Experiment Station, through its Range Inventory and Evaluation Research Work Unit at Fort Collins, Colorado.

Robert C. Heller was principal investigator, and Robert C. Aldrich, Richard S. Driscoll, and Frederick P. Weber were coinvestigators during the 29-month study. This Research Paper is based on the final report submitted to NASA in fulfillment of the contract.

Various portions of the ERTS-1 data products were processed and analyzed at the Pacific Southwest Station; Colorado State University, Fort Collins; and the Purdue University Laboratory for Applications of Remote Sensing.

Although this Research Paper points out limitations in the use of satellite imagery in its present stage of development, the overall success of ERTS-1 was such that a second satellite—LANDSAT-2—was launched in 1975. Data currently being beamed from LANDSAT-2 will be even more useful in developing better ways to inventory and manage forests and related natural resources.

**ROBERT W. HARRIS**, *Director*

Pacific Southwest Forest and Range Experiment Station

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Trade names and commercial enterprises or products are mentioned in this report solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied.

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## GLOSSARY

- Band:** For ERTS, one of four wavelength bands of the electromagnetic spectrum sensed by the multispectral scanner (MSS). Band 4 = 0.5 to 0.6  $\mu\text{m}$ , band 5 = 0.6 to 0.7  $\mu\text{m}$ , band 6 = 0.7 to 0.8  $\mu\text{m}$ , band 7 = 0.8 to 1.1  $\mu\text{m}$ .
- Bulk Data:** (Also called System-Corrected data.) ERTS data as reconstructed by NASA in a form which has only fair positional accuracy but excellent scene radiance and excellent registration. Available in 70-mm or 9.5-inch positive or negative transparencies and prints, color composites, or computer-compatible tapes. One scene covers 100 by 100 nautical miles. (See Precision Data.)
- Color Composite:** A false-color reconstruction of ERTS data in photographic form, created from two or more bands for one scene. The colors assigned to the three bands used by the NASA Goddard Space Flight Center were: band 4, blue; band 5, green; band 7, red. Color composites made at PSW combined only bands 5 and 7, as band 4 was felt to cause a hazy appearance and to supply little additional information.
- Computer-Compatible Tape (CCT):** A reconstruction of ERTS data in magnetic tape form suitable for computer analysis. Available in 7- or 9-track, 556 and 800 BPI respectively. Only 7-track tapes were used in this study.
- Digital Element:** (Also called Pixel.) A single picture element of digital image data recorded on an ERTS computer-compatible tape. The land area represented by a digital element is considered to be approximately 56 m horizontal and 79 m vertical.
- ERTS:** Earth Resources Technology Satellite
- LARS:** Laboratory for Applications of Remote Sensing
- Multispectral Scanner (MSS):** For ERTS, an electronic-optical line scanning device with an oscillating mirror continuously scanning perpendicular to the satellite path. Radiance detectors collect reflected energy in four spectral bands simultaneously. Radiance information is transmitted by telemetry to ground stations, where it is reconstructed for use.
- Pixel:** See Digital Element.
- Precision Data:** (Also called Scene-Corrected Data.) ERTS data as reconstructed by NASA in a form which has good positional accuracy at the expense of registered radiance. Available as 9.5-inch black-and-white individual band transparencies, 9.5-inch color composites, or computer-compatible tapes. One scene covers area 100 by 100 nautical miles. (See Bulk Data.)
- PSW:** Pacific Southwest Forest and Range Experiment Station
- Radiance:** The brightness of an object as seen from a remote observation point. In physics, it is a measure of the power radiating from a unit area of a source through a unit solid angle. Typical units of radiance are watts/meter<sup>2</sup>-steradian.
- Remote Sensing Unit (RSU):** A single digital element which has been geometrically corrected, registered, and combined; the basic unit on which all statistical and spectral signature analyses are performed. (Term used and defined by R. Hoffer.)
- Scene:** Term used for ERTS imagery (in photographic or tape form) covering an area approximately 100 nautical miles square. Scenes are identified by number and date.
- Scene-Corrected Data:** See Precision Data.
- Spectral Signature Analysis:** Analysis of the relative radiance from objects in several visible and infrared wavelength bands. Objects are often discriminated and classified by their spectral patterns or signatures.
- System-Corrected Data:** See Bulk Data.



## SUMMARY

Heller, Robert C., *technical coordinator*

1975. Evaluation of ERTS-1 data for forest and rangeland surveys.

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*Retrieval Terms:* Earth Resources Technology Satellite; multi-spectral imagery; photointerpretation; remote sensors; forest stress; forest inventory; range inventory; plant communities; land classification; Atlanta, GA. (Test Site); Black Hills, SD (Test Site); Manitou, CO. (Test Site).

The potential value to forestry of the Earth Resources Technology Satellite ERTS-1 was explored in a 29-month study. Applicability of the low-resolution satellite data to resource management was studied in tests of classification of land use and forest and range vegetation, identification of disturbances of forest patterns, and detection of effects of stress on forest vegetation. Sites previously used for remote sensing studies were chosen near Atlanta, Georgia; Manitou, Colorado; and the Black Hills, South Dakota.

ERTS data were supplied by NASA in reconstructed form for analysis by photointerpretive and computer-assisted techniques. Slightly different instrumentation and methods were used at the different sites, and conditions and problems encountered also varied, but in general the approach was similar.

At all three sites, ERTS-1 data were found useful for broad classification. Land-use classes, such as Forest or Nonforest, and range vegetation classes at the Region level were distinguished with acceptable accuracy as checked against ground truth. Forest disturbances could be successfully detected on ERTS color composites when compared with 6-year-old aerial photography. Further breakdowns of cover types could not be made with acceptable accuracy, however, except for certain classes. The results varied considerably among the sites. Forest stress from insect infestation could not be detected. In another, more limited study, however, large stands of dying eucalyptus trees were distinguishable on combined imagery for two dates.

Additional conclusions drawn from the studies:

1. Classification can be done most effectively by computer, but photointerpretation produces equally accurate results. Choice would depend on availability of trained people and equipment.

2. Managers of large ownerships (more than 4000 ha or 10,000 acres) would benefit by using ERTS enlargements for planning. Color composites are preferable and scales of 1:125,000 to 1:250,000 are most

useful. For black-and-white enlargements, the best band is MSS-5. (Such enlargements, to scales of 1:125,000, can be effectively used for high-altitude aerial navigation, especially in remote areas, where existing maps are inadequate.)

Summaries of the individual studies composing this report follow. Further investigation is needed to clarify and extend the information gathered.

**Forest Inventory**—Eight land-use classes, at two levels, and nine disturbance classes were defined. Because seasonal coverage allows closer discrimination between uses, ERTS scenes for fall, spring, and early summer were chosen. Photographic techniques allowing control of image quality of color composites were developed at PSW Station, Berkeley. Geometric quality was tested to determine methods for locating sample points; positional errors averaged more than 200 m. Ground truth was established from high-altitude NASA aircraft underflights and from ground checks.

After preliminary training, photointerpreters viewed simultaneously two sets of imagery representing different seasons or time periods. Results were summarized by number and percent of correct identifications. Computer-assisted analysis covered three test blocks within the site. Techniques involving computer programs to convert the raw ERTS digital tape output to a final color-coded map product were developed at PSW, Berkeley; and at LARS, Purdue University. Accuracy evaluations used area classified in each land-use class and a point-by-point check to compare LARS and PSW results with ground truth.

On 1:1,000,000-scale color composites, interpreters consistently distinguished Forest and Nonforest classes with 96 percent accuracy, regardless of combination of seasons used. Interpreters could not classify Level II cover-type classes to acceptable accuracies. Pine was identified with 60 to 65 percent accuracy, and Hardwood, 50 percent; other classes ranged from 7 to 85 percent.

Computer-assisted analysis by both LARS and PSW systems distinguished Forest from Nonforest 94 to 96 percent of the time. Performance on Pine and Hardwood cover types was better than that of the interpreters; on other land-use types, performance was similar—only fair. On point-by-point check, the LARS system was found about 20 percent more accurate than the PSW system. The best average—achieved on only one block—was 74 percent, not good enough for land-use classification. Attempts to use seasonal data to improve computer classification were not successful.

In general, tests in Atlanta showed ERTS-1 data provide a good Level I forest classifier and can be useful for detection of U.S. Forest Survey inventory plot changes or disturbances where there is much human activity.

**Range Inventory**—Classification of range plant communities at the Manitou site was based on the ECOCLASS system. Identification at two levels—three Region and eight Series classes—was attempted. Three ERTS scenes were used—August 1972 and 1973 and June 1973. Ground truth included photos from two NASA underflights (June and September 1972) as well as Forest Service CIR photos. In addition to visual interpretation of photos, analysis by microdensitometer was tested. Computer-assisted analysis was done by LARS and Colorado State University.

Photointerpreters classified Conifer and Grassland on June-to-September ERTS imagery and high-flight aerial photos with 95 to 99 percent accuracy. Deciduous forest—mostly aspen—was difficult to separate from Conifers; accuracy was only 63 percent on ERTS and 65 percent on aerial photos when averaged for all three dates. August was best for Region level classification on ERTS imagery; then the Deciduous class was correctly distinguished 92 percent of the time. Interpreters achieved no acceptable results in classifying to the Series level. Most errors on both satellite and aircraft imagery were made on north-facing slopes. Grassland classes were more accurately separated at this level than Forest classes. One experienced range ecologist had significantly more correct calls than the others—from 83 to 100 percent. Shortgrass and Wet Meadow classes were identified correctly from 88 to 99 percent of the time; Mountain Bunchgrass only 50 percent, except by the experienced interpreter. Stereo aircraft photos were better for discrimination of Grassland classes than was non-stereo satellite imagery.

Analysis by microdensitometer showed highly significant differences between all vegetation combinations at two dates (July and August). Thus it appears possible to do automatic scanning of an ERTS color

composite and relate density levels to Region level vegetation classes. At the Series level, there was much overlapping of densities except for Aspen and Wet Meadow classes.

Computer-assisted analysis on training samples by LARS was more successful (90 percent or better at both levels) than total performance on entire units (70 percent at Region level, 48 percent at Series level). Effects of slope, aspect, and shadows were pronounced. Improvements in computer signature analysis are needed to make computer-produced maps usable. For one Series class, Ponderosa Pine, adjusting spectral response to a midslope response level improved computer performance. Further tests are needed.

**Forest Stress**—For the Black Hills study, general methods were similar to those used for forest inventory tests. Classification was attempted at Levels II and III, with Dead Ponderosa Pine and two categories of crown closure in Level III. Cloud-free ERTS imagery was difficult to secure; scenes for August and September 1972 covering two blocks on the site, with three sub-blocks for intensive study, were used. Ground truth data were available from earlier studies.

Attempts to study radiance sensing by ERTS by means of transmission of ground data to the satellite encountered operational difficulties, but some useful spectral data were gathered: (1) A 51-percent increase in scene radiance occurs on satellite imagery in MSS band 4—a result of atmospheric scattering; (2) the atmosphere affects MSS band 5 less than band 4; (3) bands 6 and 7 have reduced radiance, primarily because of absorption by the intervening atmosphere.

Photointerpretation was 100 percent correct for Conifer, Wet Pasture, Bare Soil, and Water. Most errors were in Dry Pastures and Hardwood. Errors in separating dense stands of Pine from open stands were excessive (50 percent). No Dead Pine was detected, regardless of size, season, or processing technique. Best results in classifying seven cover types were achieved by specialists familiar with the site.

Computer-assisted techniques did not improve results in identifying Dead Pine. The 3 percent of land area identified by PSW as Dead Pine did not coincide with ground truth. Both LARS and PSW systems were reasonably successful in classifying cover types at Level II; accuracy was just acceptable at Level III. The PSW performance was better for distinguishing density of Ponderosa Pine by area; point-by-point checks showed similar accuracy for both systems.

Large stands of eucalyptus killed by freezing weather could be delineated on a combination of imagery for two dates. This technique may be useful in developing countries where access is difficult.

The use of remote sensing techniques has long been accepted in forestry. At an early stage of development, aerial photography was recognized as a valuable tool in land resource management, and advantage has been taken of improvements in techniques. The launching of the ERTS-1—Earth Resources Technology Satellite—in June 1972 introduced a new element. The assessment of its potential value to forestry became an urgent need.

For application to forestry, ERTS-1 data must be in a usable form. The satellite's multispectral scanners (MSS) transmit photometric data received from the earth's surface; the data must be reconstructed for visual interpretation. The NASA Goddard Space Flight Center (GSFC) converts the raw data into photographic form as black-and-white or color transparencies. Also, GSFC provides magnetic tapes capable of producing, through computer-assisted analysis techniques, graphic representations of the earth as viewed by the satellite. Both the transparencies and tapes are low in resolution of detail, compared with conventional aerial photography.

The study reported here was designed to explore the applicability of this low-resolution satellite data, supported by conventional aerial photography and ground data, to forest and range management. Specifically, the study dealt with the applicability of ERTS data to certain ongoing Forest Service programs:

1. Inventory of forest and rangelands, including (a) classification of land use, (b) classification of forest and range vegetation, and (c) identification of disturbances of forest patterns by both natural causes and human activity.
2. The detection of effects of various stresses (insects, disease, temperature, moisture, etc.) on forest vegetation.

## Objectives

The original objectives of the study, as outlined in the NASA contract proposal, were these:

1. To test the hypothesis that ERTS multispectral imagery will permit identification of forest, rangeland, nonforest, water resources, and forest stress.

2. To determine the gains to be made in using satellite imagery as a first level of information when coupled with aircraft underflights and ground examination in a multistage and multiseasonal sampling system for quantification of the forest-related resources.

3. To compare the utility and cost effectiveness of various data and interpretation modes—such as single-channel versus multispectral-channel data, and human versus automated interpretation—to separate and identify forest and rangeland resources.

The contract objectives were somewhat modified during the course of the study. An experiment based on data from a new remote sensing system presents problems that are difficult to forecast even in carefully thought-out study plans. Many difficulties did not become evident until the interpreters actually received and began working with ERTS photography, and the programmers began to analyze the computer-compatible tapes (CCT's). As a result, procedures were changed and new techniques were developed. It was not feasible to carry out some of the objectives of the original contract proposal. Lack of appropriate underflight imagery on the Atlanta test site and lack of seasonal ERTS imagery prevented our analyzing the multistage-multiseasonal part of the proposal. Part of the range inventory site was used, however, to investigate the use of several stages of small- and large-scale aerial photos coupled with ground samples for multistage inventories.

Also, because most of the successful procedures and techniques in handling the data were developed only after many trials, we felt it would be unrealistic to show development costs in making technique comparisons (computer-assisted analysis versus visual or microdensitometric photointerpretation, etc.). Therefore, no iso-cost and iso-error curves were developed.

## Study Areas

To test applications of ERTS-1 data, three widely separated representative areas (*fig. 1*) were chosen. These had already been the sites of remote sensing studies, and the investigators had gained much experience and firsthand knowledge of ground conditions there. The sites selected were near Atlanta, Georgia;



Figure 1—The study areas indicated on this map were used for different phases of the ERTS-1 data evaluation: Atlanta, Georgia—forest inventory; Manitou, Colorado—rangeland inventory; Black Hills, South Dakota—forest stress from mountain pine beetle; Berkeley, California—forest stress from cold temperatures.

near Manitou, Colorado; and in the Black Hills, near Lead, South Dakota. In many phases of the work, the investigators in each area proceeded independently of the others; however, the three studies were similar in general approach.

The forest inventory site just west of Atlanta, Georgia, was selected as a representative area in Southeastern United States where a high level of forest management is taking place and where rapid changes to forest land are occurring. Forests here occupy about 60 percent of the land area, but they are broken up into small units by agricultural fields, pastures, and water bodies. Most of the forest ownerships are small (less than 200 hectares or 500 acres) which results in a checkerboard pattern on aerial imagery. Such an area, with many field and forest borders, presented a challenge to the investigator to properly classify forest land use.

Rangelands such as the Manitou, Colorado, site are important national resources and need to be inventoried, protected, and managed. They are becoming more valuable as our food and fiber supplies diminish. An orderly system of classifying vegetation according to its relation to other plants and animals and its

potential for vegetative development (ECOCCLASS) has been devised by Forest Service ecologists<sup>1</sup> and this hierarchical system was used to determine the level at which ERTS-1 data can accurately assess range vegetation types.

On the third site, in the Black Hills of South Dakota, a severe outbreak of mountain pine beetle (*Dendroctonus ponderosae* Hopk.) has killed several hundred thousand ponderosa pine trees (*Pinus ponderosa* Laws.) over the past 10 years. Early detection of the dying pines, which discolor to a yellow and yellow-red hue, would assist forest managers in assessing the severity of the outbreak and in planning control and salvage operations—particularly if the assessment could be done accurately and quickly from satellites. Experience from analysis of aircraft photos showed that color infrared film taken at a scale of 1:32,000 could be used to detect all but the smallest target infestations of 1 to 2 trees (3 to 6 m or

<sup>1</sup> Pfister, Robert D. and John C. Corliss, task force co-chairmen. 1973. ECOCCLASS—a method for classifying ecosystems. Report on file at Forestry Sciences Laboratory, Intermountain Forest and Range Experiment Station, Missoula, Montana.

10 to 20 ft in size) with better than 90 percent accuracy. This part of the experiment tested the null hypothesis that ERTS-1 data could not detect insect infestations of any size. The coinvestigator at this site also established a biophysical station which transmitted ground sensing data (including ERTS-matched spectral radiance) to ERTS via three data collection platforms (DCP's) and thence back to the Goddard Space Flight Center where the data were encoded on punchcards for analysis.

A limited study of temperature stress effects was made in Berkeley, California, when the Remote Sensing staff was asked to investigate mortality of eucalyptus trees from low temperatures during the winter of 1972.

## ***Materials and Techniques***

The ERTS-1 materials used in this study for photographic interpretation were received from the Goddard Space Flight Center as black-and-white transparencies and as *color composites*—false color transparencies made from the black-and-white materials. The multispectral scanner collects reflectance data in four wavelength *bands* representing four portions of the electromagnetic spectrum. The color composites are a combination of the data from two or more of the bands, each band being assigned a color. The transparencies, and also the tapes used in the computer-assisted analysis, are identified as *scenes*, each covering 100 by 100 nautical miles. Transparencies and tapes are available as *bulk* or *precision* data. (For further explanation and specifications for the italicized terms, see the Glossary.)

The ERTS-1 transparencies were combined and enhanced at the laboratory of the Remote Sensing Research Work Unit of the Pacific Southwest Forest and Range Experiment Station. The methods developed there for producing color composite inter-negatives are described in Appendix 1.

The computer-compatible tapes were analyzed by various methods described in the body of this report and in Appendix 2. Essentially, these techniques consisted of conversion of the ERTS data into a visual composite of *digital elements* (also called *pixels*), each representing a land area of specified dimensions. The result was a map produced on a line plotter equipped with color pens, or by photographing a cathode-ray tube display.

Slightly different photointerpretation instruments and techniques were used at each of the three test sites. For example, all three coinvestigators used Bausch and Lomb Zoom 70 microscopes to examine and classify cover types on color composites. However, a Variscan rear-projection viewer was also used to advantage with the Black Hills imagery. An overhead projector was used at all sites for comparisons of color composites with previously drawn cover-type maps. At the Atlanta site, comparisons of the bulk color composites at three time periods were made with an Old Delft scanning stereoscope, while disturbance detection was best accomplished on a Zoom Transfer Scope. Similarly, at the Atlanta and Manitou sites many replicated training and test sets were randomly selected for each of the land-use and vegetative classes. In the Black Hills, the nine cover-type classes had to be purposively selected because there was insufficient cloud-free imagery during the growing season, so that the necessary replicates were not available.

During the studies described here, covering a period of over two years, large quantities of data were gathered and many techniques were developed and modified in the light of experience. For this report, much detail was necessarily omitted. Both data and techniques require further analysis. The report is by no means definitive, but is intended primarily as an aid to those who will be attempting to use data from earth resources satellites in forestry applications in the future.

# FOREST INVENTORY

## Land-Use Classification and Forest Disturbance Monitoring

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Wallace J. Greentree

The primary aim of the forest inventory test of ERTS data was to determine the accuracy with which forest land could be classified. Although we recognized that forest land managers require detailed in-place information on volume, stand condition, and growth, the prelaunch specifications for ERTS data resolution did not encourage use of the output for these purposes. We reasoned that we could classify land use accurately enough, however, and we might be able to obtain forest area statistics for small political units such as counties. This test would also indicate the true capabilities of ERTS-type data and allow us to develop techniques and acquire skills for handling these unusual kinds of data.

The forest disturbance phase of the inventory was included because at various times a resource manager or a resource inventory analyst needs to know where and how much forest land has been disturbed—either by natural causes or by human influences. Logically, ERTS would be a proper and beneficial tool for monitoring these changes if the ground resolution were good enough, although the ERTS 18-day cycle is more frequent than would normally be required for the purpose.

### Study Area

The site near Atlanta, Georgia (fig. 2) is the one used for the Apollo 9 inventory study in 1969 (Langley and others 1969) and for the high-altitude aircraft studies sponsored by NASA's Earth Resources Survey Program between 1970 and 1972 (Aldrich and Greentree 1971, 1972). The area is typical of a large part of the Southern United States in its "checkerboard" land-use pattern, complex enough to test any remote sensing system. Principal land uses in the area are forest, grassland (pasture), and urban. Agriculture is not a major use of land on this site but some scattered grain and soybean crops are grown. The major forest types in the area are loblolly pine, oak-pine, oak-hickory, and oak-gum-cypress. Commercial forest occupies approximately 60 percent of the land area and is found primarily in small farm woodlots. Changes between forest and nonforest categories occur quite rapidly, influenced by the pulp and paper industry and the expansion of metropolitan Atlanta.

### Classification System

For government agencies concerned with land use, the U. S. Geological Survey Circular 671, *A Land-use Classification System for Use with Remote-Sensor Data* (Anderson and others 1971) has become the accepted reference for definitions of generalized land-use classes at two levels of precision. Using Circular 671 as a basis, we developed our own hierarchy for the piedmont area of Georgia (table 1), for use in evaluating remote sensing at three levels. Levels I and II of our hierarchy designate eight classes of resource data obtainable from ERTS. Level III designates more restricted classifications definable from high-altitude aircraft photography or from some higher resolution satellite imagery. Knowledge of the location of these classes is helpful in distinguishing variations over time in the ERTS imagery, and in clarifying the reasons for differences in interpretation at Levels I and II by both human and machine classification systems.

The eight land-use classes recognized on ERTS data for this study are defined according to Munsell Color notations (Munsell 1920-60), converted to ISCC-NBS color designations (ISCC-NBS 1955). The definitions take into account the temporal variation discernible on the simulated color infrared (CIR) composites for the three ERTS scenes used in this study.

In the forest disturbance tests, we were concerned with identifying shifts in use between forest and non-forest classes, as well as timber harvesting, and natural disturbances such as fire, insect damage, disease, or flooding. Disturbance classes we hoped to identify were established as follows:

*No disturbance*—Areas showing no detectable changes in the forest cover.

*Harvesting*—Forest areas where timber has been removed, usually resulting in a rather severe disturbance. Area shows numerous interlacing woods roads, skidways, and either complete or almost complete removal of the merchantable trees.

*Silvicultural treatments*—Forest areas, such as pine plantations or natural hardwood stands, given a cultural treatment to improve vigor or growth. Although high-grading is a poor practice and not considered a silvicultural treatment in the normal sense, it would

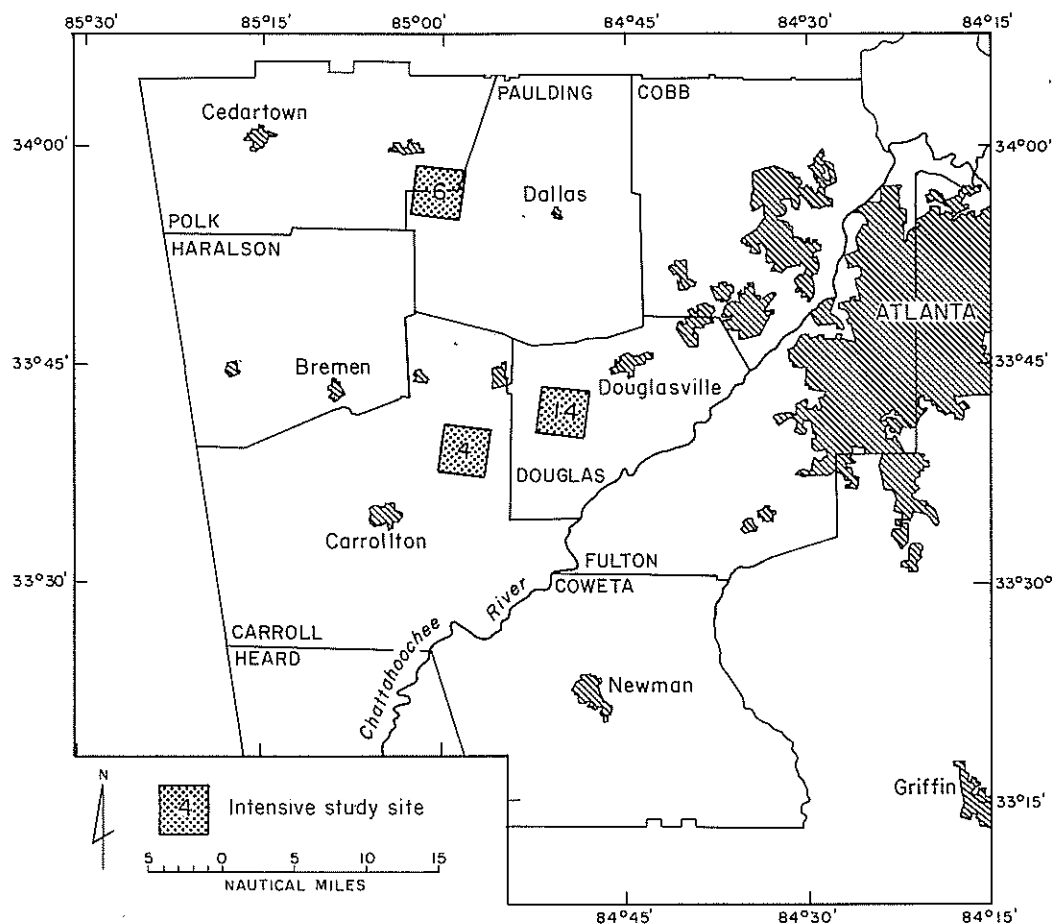


Figure 2—The Atlanta site, used for evaluating ERTS-1 data in forest inventory, includes nine counties. The three intensive study sites were used for computer-assisted mapping.

appear the same as partial removal or intermediate selective cutting.

**Land clearing**—Usually areas where timber removal or harvesting has been followed by site preparation, including slash and stump removal, with eventual replanting with tree seedlings. This category may also include tree removal, site preparation, and conversion to nonforest land uses. Land that has been cleared but not converted usually shows windrows of slash and tree trunks; usually this land is still considered commercial forest.

**Insects and disease**—Areas showing evidence of damage by these agents. Under endemic conditions, attacks may mean the mortality of a single tree. Under epidemic conditions it may mean mortality of hundreds of trees in a single spot. Faded tree crowns or openings in the stands are indicative of tree mortality.

**Wildfire**—Areas showing evidence of fire. Crown fires as well as ground fires are included. Prescribed

burns, which are restricted to the ground, may appear exactly like wildfires. The actual “going” fires may be detected, but usually the noninfrared-reflective burned vegetation and humus material show as blackened areas on remote sensing imagery.

**Flooding**—Areas where man-caused or natural floods have inundated forest land and caused tree damage or death. Permanently flooded areas must be removed from the forest area base. The extent of these areas is obvious on infrared imagery. Intermittently flooded forest may be permanently damaged or may survive after the water recedes.

**Regeneration**—Areas that indicate an increase in the forest area base because nonforest land has been converted to forest land, either naturally or artificially. Areas of regeneration may be apparent in early years by evidence of fire breaks built by the landowner to protect his investment from wildfire. Indications of tree growth will appear in 3 to 5 years after planting.

Table 1—A land classification hierarchy for remote sensing and ground information sources compatible with current nationwide Forest Survey objectives; colors discernible on simulated color infrared ERTS composites.

| Classification                 | Color definitions (based on Munsell 1920-60, ISCC-NBS 1975)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|--------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| I FOREST LAND                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| II Conifer                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| III Pine                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Pine-Hardwood                  | Density of conifer stands and number of hardwoods mixed in stand influence color value and chroma. Dense stands are darker with less chroma. In the fall, before advanced hardwood coloration and leaf fall, conifer stands appear dark purplish red. Separation between Conifer and Hardwood classes is less distinct in fall than in winter or early spring. Where hardwoods and conifers are mixed in stands, hardwood color predominates, and stand is usually classified as Hardwood. In spring before hardwoods are foliated, conifers appear moderate to dark purplish red.                                               |
| II Deciduous Hardwood          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| III Upland Hardwood            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Bottomland Hardwood            | Stands appear moderate grayish purplish red in fall and pale purple to moderate purplish red in spring. In fall, upland hardwoods cannot be distinguished from bottomland hardwoods. In spring, before foliation, upland hardwoods appear pale purple to light grayish purplish red. Bottomland hardwoods are generally a moderate purplish red.                                                                                                                                                                                                                                                                                 |
| I NONFOREST LAND               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| II Grassland                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| III Undisturbed Grass          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Disturbed Grass                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Dead Grass (Annual)            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| New Improved Grass             | Grassland appears deep pink in both fall and spring; sometimes mistaken for immature cropland in spring.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| II Cropland                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| III Immature Grain             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Immature Row Crop              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Mature Crop                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Harvested Crop                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Orchard                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Farmsteads                     | Mature crops in fall appear bluish gray to grayish blue. In spring, immature crops appear deep pink and may be mistaken for grassland.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| II Bare Soil                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| III Plowed Fields              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Erosion                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Urban (site preparations)      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Rock Outcrop                   | In fall and spring bare soil appears cream colored. There is no distinction between plowed agricultural fields and sites prepared for new commercial developments. Generally in spring most areas of bare soil are newly plowed fields either recently or soon to be planted.                                                                                                                                                                                                                                                                                                                                                    |
| II Wild Vegetation             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| III Idle Land                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Abandoned Land                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Transitional                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Kudzu                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Marshland                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Alder Swamp                    | In fall, areas range from grayish purple of idle land to grayish purplish red of abandoned land to deep pink of wild Kudzu vine. Marsh and alder swamps are a moderate purple because of wet background. In spring, idle land becomes light grayish red to dark pink because of influx of new infrared reflectant vegetation. Abandoned-transitional land (reverting to forest), on the other hand, is grayish purplish red and marsh and alder swamps are grayish violet. Deciduous Kudzu vine, purplish gray in the spring, easily separates itself from all other vegetation when fall and spring images are viewed together. |
| II Urban                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| III Transportation & Utilities |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Home Developments              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Commercial Developments        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Recreation                     | Areas are light blue in the fall and very pale blue in the spring. Unfortunately, because of low resolution of ERTS data, secondary roads, minor roads, and most utility lines are not resolved.                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| I WATER                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| II Water                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| III Clear Lakes & Ponds        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Turbid Lakes & Ponds           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Rivers & Streams               | Water is darkish greenish blue in fall and light greenish blue in spring. Farm ponds of less than 1 acre can be seen on ERTS images if there is sufficient contrast with background.                                                                                                                                                                                                                                                                                                                                                                                                                                             |

*Other*—Land suspected of being disturbed, but yet not fitting into any of the above categories. This includes, for example, land being worked for turpentine. On remotely sensed imagery, such land would appear similar to silvicultural cuttings but with little or no removal, and only slight disturbance of the ground cover.

## **ERTS Data**

Collection of forest resource data by ERTS at regular intervals is useful for forest inventory because it almost guarantees cloud-free coverage more than once each year over the same area. During the first 12 months of operation, for example, ERTS passed over Atlanta 21 times. Weather was particularly bad that year, yet 3 passes out of the 21 were completely free of clouds and fulfilled study requirements: scenes 1084-15440, October 15, 1972; 1264-15445, April 13, 1973; and 1336-15441, June 24, 1973.

Three stages of phenological development are represented by the three scenes: (1) fall before the leaf fall, (2) spring before new leaf development, and (3) early summer after complete leaf development. Seasonal coverage such as this is valuable because it makes possible closer discrimination between land uses.

Two methods of data analysis were used in the Atlanta study. The first, conventional photointerpretation, made use of the ERTS false-color photo composites on transparency film, which we tested for image quality and geometric quality, as described below. The second, computer classification, used spectral data in digital form on the computer-compatible tapes (CCT's), by means of two systems, one developed by LARS, Purdue, and the other developed at PSW, Berkeley. Computer techniques were used only in the land-use classification portion of the study. For this, all four spectral bands of the October 1972 and April 1973 scenes were used.

### **Image Quality**

False-color photo composites of the ERTS bulk data used in this part of the evaluation were produced at the PSW facilities in Berkeley. Originally we intended to use false-color composites produced by the Goddard Space Flight Center (see Introduction) in the photo analysis. We soon found, however, that without some degree of control over the image enhancements as well as the photo processing, we could not make valid comparisons between seasons. This was evidenced by extreme variation in the film densi-

ty as well as other characteristics that led to many incorrect interpretations made on Goddard color composites. To overcome this problem, we combined and enhanced the ERTS images and produced our own color composites, using an International Imaging Systems (I<sup>2</sup>S)<sup>2</sup> additive color viewer and a specially designed copying system (Appendix 1). This system enabled us to scale the ERTS scenes to match 1:1,000,000 map overlays, a capability that proved a distinct advantage later on during interpretation. Another advantage was the lower contrast values of the Berkeley composites. Although they were less pleasing to the eye than the Goddard products, they were more effective for extracting information.

### **Geometric Quality**

The value of ERTS data for forest inventory is affected by the positional accuracy of points within the image, particularly when timber stands, sample plots, or other specific areas of interest are to be located precisely. For example, location of a perfectly square 4-hectare (10-acre) stand of timber requires a positional accuracy of at least  $\pm 120$  m (390 feet). Relocation of a circular 0.4-hectare (1-acre) permanent sample plot requires a positional accuracy of only  $\pm 30$  m (100 feet). Location of a 100-meter-square sample, randomly selected and identified on an overlay, as called for in the original experimental design for this study, required a positional accuracy of  $\pm 50$  meters (164 feet).

To check the geometric fidelity of both precision and bulk color composites, we made a test using over 90 random control points. These points were located within a rectangle formed by 30-minute geographic plane coordinate intersections—longitude 84°00'W, 84°30'W, and latitude 33°00'N, 33°30'N. The points were transferred from 1:120,000 scale CIR transparencies (dated October 2, 1972) to a copy of the original 1:250,000 Atlanta map sheet using a Zoom Transfer Scope (See Photointerpretation Procedures, below.) An overlay of the point locations made on stable base material was copied photographically to a 1:1,000,000 scale. From this negative, a transparent template was printed and attached to the color-composite ERTS image, also at a 1:1,000,000 scale. The template included 15-minute plane coordinate intersections, 50,000-m UTM grid intersections, and major natural and cultural features. The template was then matched to a bulk color-composite image

<sup>2</sup> International Imaging Systems is now known as Stanford Technology Corporation.

(1102-15442, bands 4, 5, and 7). The ERTS image with template attached was mounted on the ZTS illuminator. Then the 1:120,000-scale CIR transparencies were scaled and oriented with the ERTS image on the ZTS mapping surface. The distance between the true image locations scribed on the photographs and the locations of the same points on the ERTS image was measured.

The results showed that the locational accuracy of this ERTS image was approximately 200 m (656 ft), but only when the work lay within one 30-minute quadrangle of the ERTS scene. Thus, we found the positional accuracy to be inadequate (the error is approximately four times greater than acceptable—200 m (656 ft) instead of 50 (164 ft)—for conducting our experiment as originally designed. Instead, we made our interpretation on the center point of the randomly selected 100-m square samples on the overlay where they fell on the ERTS imagery.

### ***Ground Truth***

Two high-altitude aircraft underflights were made by NASA's Earth Resources Aircraft Program in direct support of this study. The first flight was made on June 1, 1972—about 7 weeks before the ERTS-1 launch. A second flight was made on October 2, 1972, following the launch and during the first of three requested seasonal coverages. These two flights were the only aircraft support flights received during the ERTS experiment. Flights requested for April and June 1973 were not flown. This meant that our photointerpretation test data and computer classification accuracy checks had to be based on ground truth acquired for October 1972.

At the time of each aircraft underflight, a two-man crew was on the ground. Over 100 samples selected from 400 in a pre-ERTS photo training set were verified. On each forest point, the tree species, forest type, stand size, and crown closure were recorded. Other information included understory vegetation, ground cover, and soil type, where the latter would be helpful in interpretation. Nonforest points were classified by land use and other supporting information, such as crop type and crop maturity. A 35-mm color photo (negative) was taken at each ground sample point to record existing conditions.

As explained below under Procedures, photo keys were prepared to illustrate the eight land-use categories and used to train interpreters. Ground truth maps were drawn for three small test areas from 1:120,000 CIR transparencies and ground inspections, and later used to check the accuracy of compu-

ter classification maps made from the ERTS CCTs. Land-use data collected on the ground and on small- and large-scale aerial color photographs from previous studies were invaluable in constructing the land-use maps. This was true particularly when correlative seasonal data were needed to compare with ERTS imagery, and aircraft support flights were canceled.

To verify forest disturbances detected on the ERTS scene of April 1973, 40 ground points in Carroll County (other than the 100 land-use sample points verified earlier) were visited in January 1974. Eighteen of these locations were regular Forest Survey plots on which some type of disturbance had been recorded, either during the reinventory of 1972 or by the interpretation of current photography in 1973. Twenty-two additional locations were selected from a listing of 64 "off-plot" disturbances that represented harvesting and silvicultural treatments, natural regeneration, artificial regeneration, and the "other" category. We did not sample the "cleared" category because we concluded that the photo verification for these would be correct.

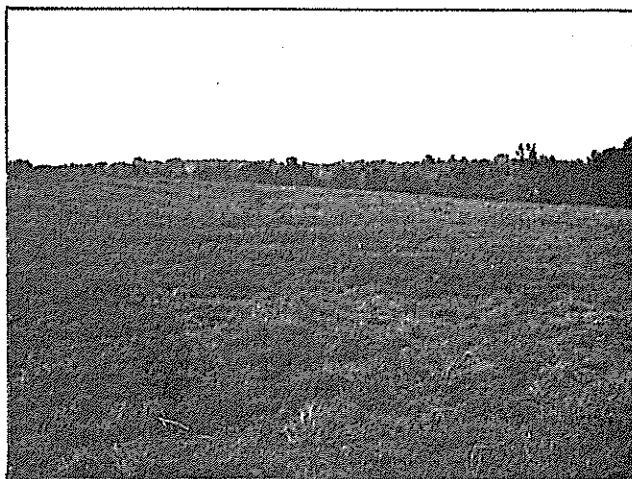
On each ground plot, the type of disturbance was observed and recorded. Also recorded were the conditions of the forest cover and ground cover, years since disturbance, and other information pertinent to interpretation by remote sensing. A photograph was taken to record these ground conditions at the time of year the plot was visited.

### ***Photointerpretation Procedures***

Preliminary studies showed that conventional photointerpretation of single-season ERTS data resulted in low classification accuracy (less than 40 percent). However, when two scenes of different dates were viewed together, the accuracy increased to 67 percent. In these tests, therefore, interpretations were made on this basis.

For the land-use classification, the two interpreters making the tests were given special preliminary training that included looking at several examples of each resource class on high-altitude color infrared (CIR) photography (1:120,000) and on the ERTS color composite, coupled with ground truth (*fig. 3*).

An overlay (*fig. 4*) was prepared showing 292 of an original 400 random sample points selected on 1:120,000-scale photos to test interpreters. (Not all of the 400 points were inside the coverage of the three ERTS scenes used.) The overlay was attached to the April 1973 color composite (ERTS scene 1264-15445) and mounted in the center of a light table. The composite for October 1972 (scene



| Code | Classification |
|------|----------------|
|------|----------------|

|   |           |
|---|-----------|
| 2 | GRASSLAND |
|---|-----------|

|    |        |
|----|--------|
| 21 | GRAZED |
|----|--------|



Description: A closely grazed pasture with vegetation consisting mainly of Bermuda grass (*Cynodon sp.*) and lespedeza (*Lespedeza sp.*). Small blackberry patches and persimmon seedlings are scattered throughout this pasture.

Location: Coweta County, Georgia

Latitude 33°21'N

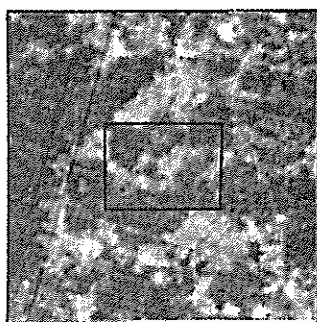
Longitude 84°38'E

Elevation 270.4 meters (900 ft.)

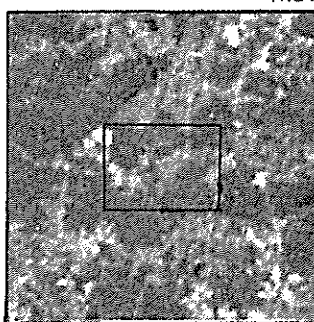
Date: October 7, 1972



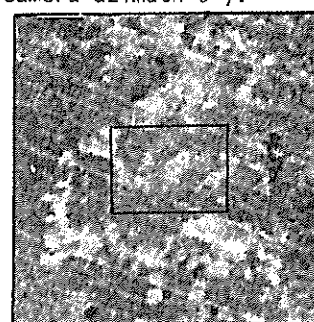
High-altitude color IR--Oct. 2, 1972  
Ground photo angle is marked with an indicator (camera azimuth 6°).



ERTS Scene 1264-15445  
Spring-April 13, 1973



ERTS Scene 1336-15441  
Summer-June 24, 1973



ERTS Scene 1084-15440  
Fall-October 15, 1972

Simulated color IR composites from two bands (5 & 7) of ERTS imagery. The high-altitude photo coverage is outlined on the ERTS photos.

Figure 3--A photointerpretation training aid was prepared to show closely grazed grassland on high-altitude and ERTS photography. Seasonal changes are evident on the three ERTS photos.

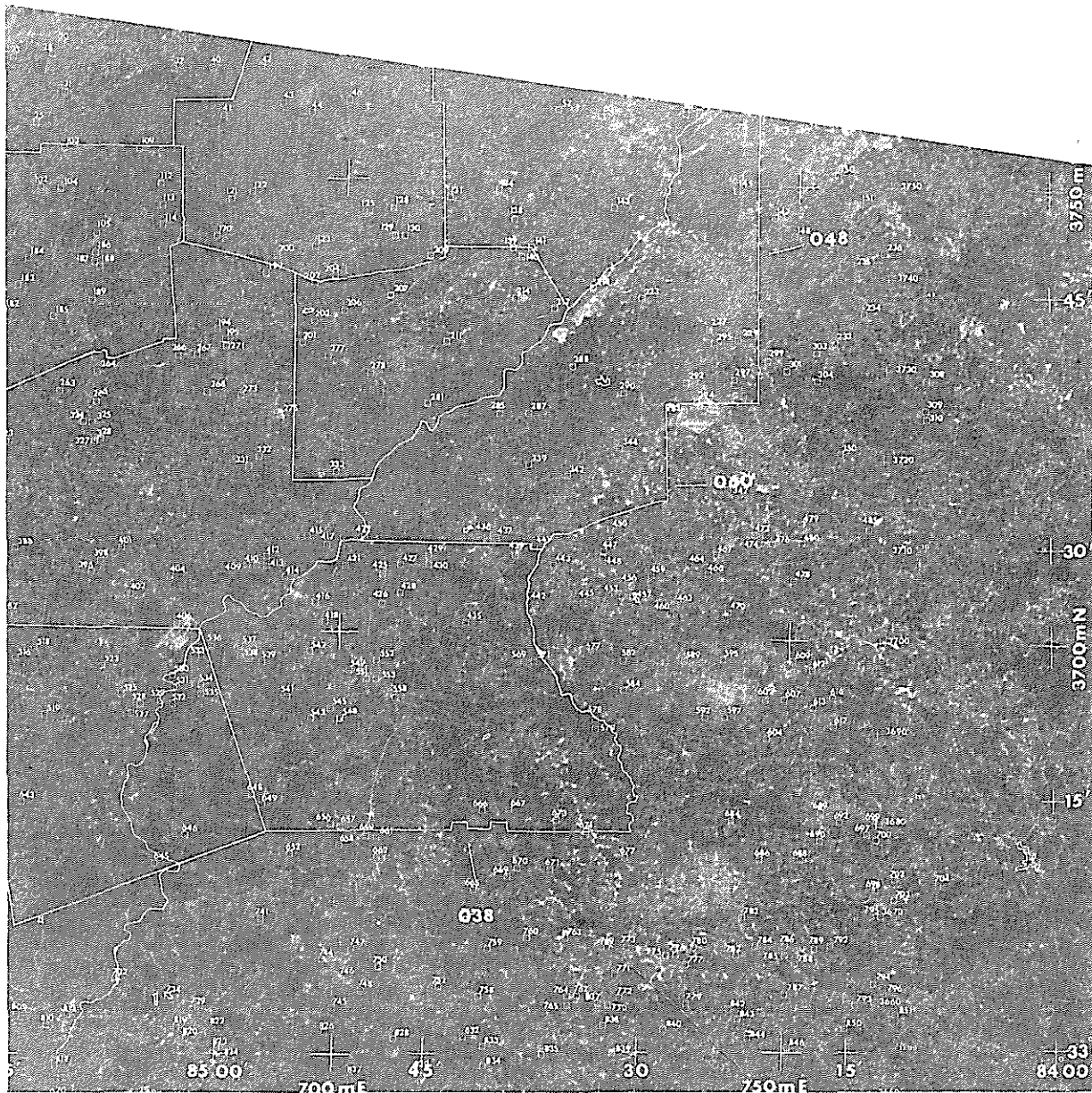
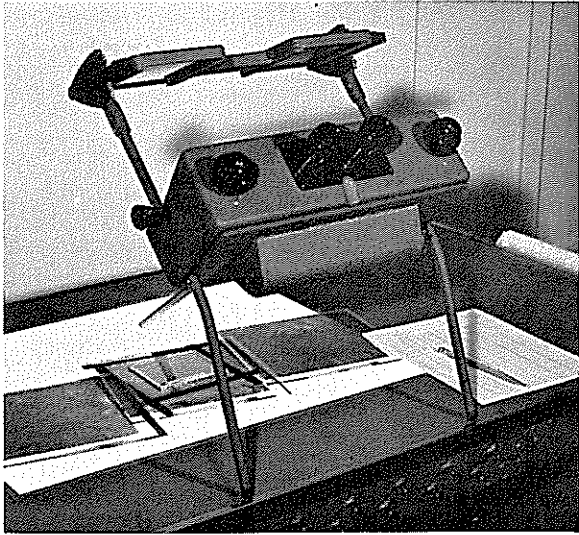


Figure 4—An overlay for the color composite for the ERTS scene for April 13, 1973 was prepared to locate 292 random sample points for identification of eight land-use classes.

1084-15440) was mounted to the left of the April scene and the composite for June 1973 (scene 1324-15441) was mounted to the right. Using an Old Delft stereoscope with 4X magnification, each interpreter examined the center point of each sample square on the April-October combination (fig. 5). When this was completed, the stereoscope was moved to the right to view the April-June combination. Thus two independent interpretations of land-use classification were made by each interpreter.

Interpretation results were summarized to show both the number and the percent of interpretations that were correct, by class, and the number of points misclassified, by class. To determine whether there were significant differences between interpreters or between seasonal combinations, an analysis of variance was made using a system of weights from 1 to 5. A correct call received a weight of 1. Calling a Forest point Nonforest or calling a Nonforest point Forest were the most serious errors and received a weight of



5. This was in keeping with our experimental objective to determine how accurately we could estimate forest area using ERTS data.

For the test of ERTS potential in detection of forest disturbances, we prepared a set of sample points for the test site, Carroll County, Georgia (*fig. 6*). Using 1:120,000 CIR transparencies taken in June 1972 and 1:63,360-scale Department of Agriculture photo index sheets for panchromatic photography dated February 1966, we viewed the two images simultaneously with a Bausch and Lomb Zoom Transfer Scope (ZTS) (*fig. 5*). We circled and numbered 209 disturbed areas on the photo index sheet and recorded the type of disturbance and number of acres for each. Also, 36 points, where no disturbance had occurred, were circled.

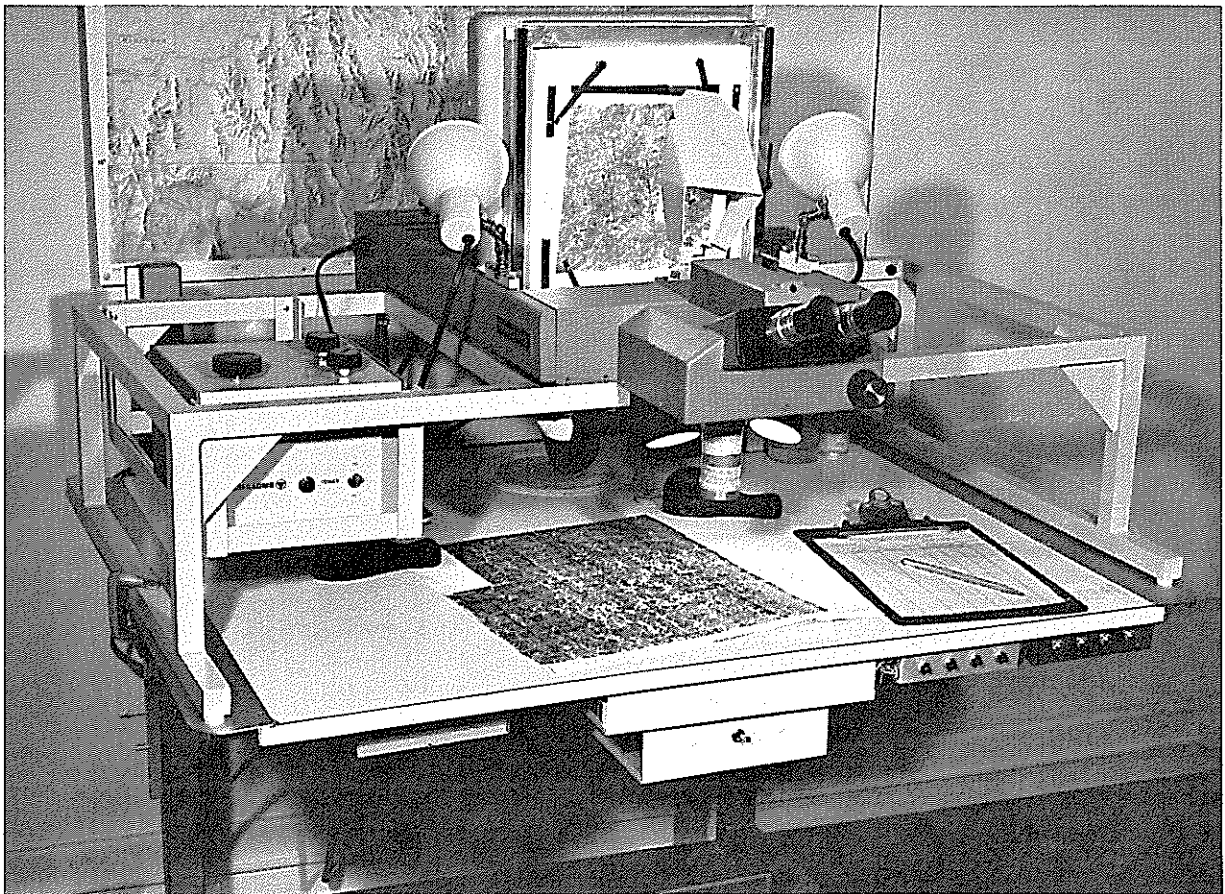


Figure 5—Optical equipment used in photointerpretation varied with the aim of the test. *Above*, for land-use determinations, interpreters used an Old Delft stereoscope to view simultaneously the center point of each test sample unit on the overlay and the corresponding points on April-October and April-June combinations of ERTS color composites. *Below*, to locate forest disturbances, interpreters used a Bausch and Lomb Transfer Scope to view simultaneously the ERTS scene for April 1973 and the 1:63,360-scale photo index sheet for February 1966.



Figure 6—To monitor forest disturbances, Carroll County was outlined on the color composite for April 13, 1973. (Approx. scale 1:500,000)

An experienced photointerpreter, not familiar with the study, was first given a short orientation in the identification of disturbances using photo aids (fig. 7), and an opportunity to practice using the ZTS. He was then asked to examine the 245 locations circled on the February 1966 photo index sheets simultaneously with the April 13, 1973, ERTS color composite (scene 1264-15445). He was instructed to be as objective as possible and was told that not all of the 245 points were real disturbances. He was to record the following information for each area:

*Type of disturbance:* (a) no disturbance, (b) harvesting (tree removal), (c) land clearing, (d) natural regeneration, (e) artificial regeneration, or (f) other (undecided).

*Land-use trend:* (a) no change, (b) forest to agriculture, (c) forest to urban, (d) forest to water, or (e) agriculture to forest.

The results of this interpretation were summarized by disturbance class, land-use trend, and size class. (Size class was determined from 1:120,000-scale photographs on which the disturbances had been

positively identified.) The classes were:

| <u>Acres</u> | <u>(Hectares)</u> |
|--------------|-------------------|
| 1-5          | (0.4- 2.0)        |
| 6-25         | (2.4- 10.1)       |
| 26-50        | (10.5- 20.2)      |
| 51-100       | (20.6- 40.5)      |
| 101-500      | (40.9-202.3)      |
| Over 500     | (Over 202.7)      |

### ***Computer-Assisted Mapping Procedures***

The computer-assisted mapping technique was tested using three test blocks in the Atlanta site, each approximately 8,000 to 10,000 acres (3,240 to 4,050 ha) as shown in figure 2. Under contract, the Laboratory for Applications of Remote Sensing (LARS) at Purdue University mapped the three blocks. Techniques were also developed by the PSW Remote Sensing Work Unit, and the results were compared with those of LARS.

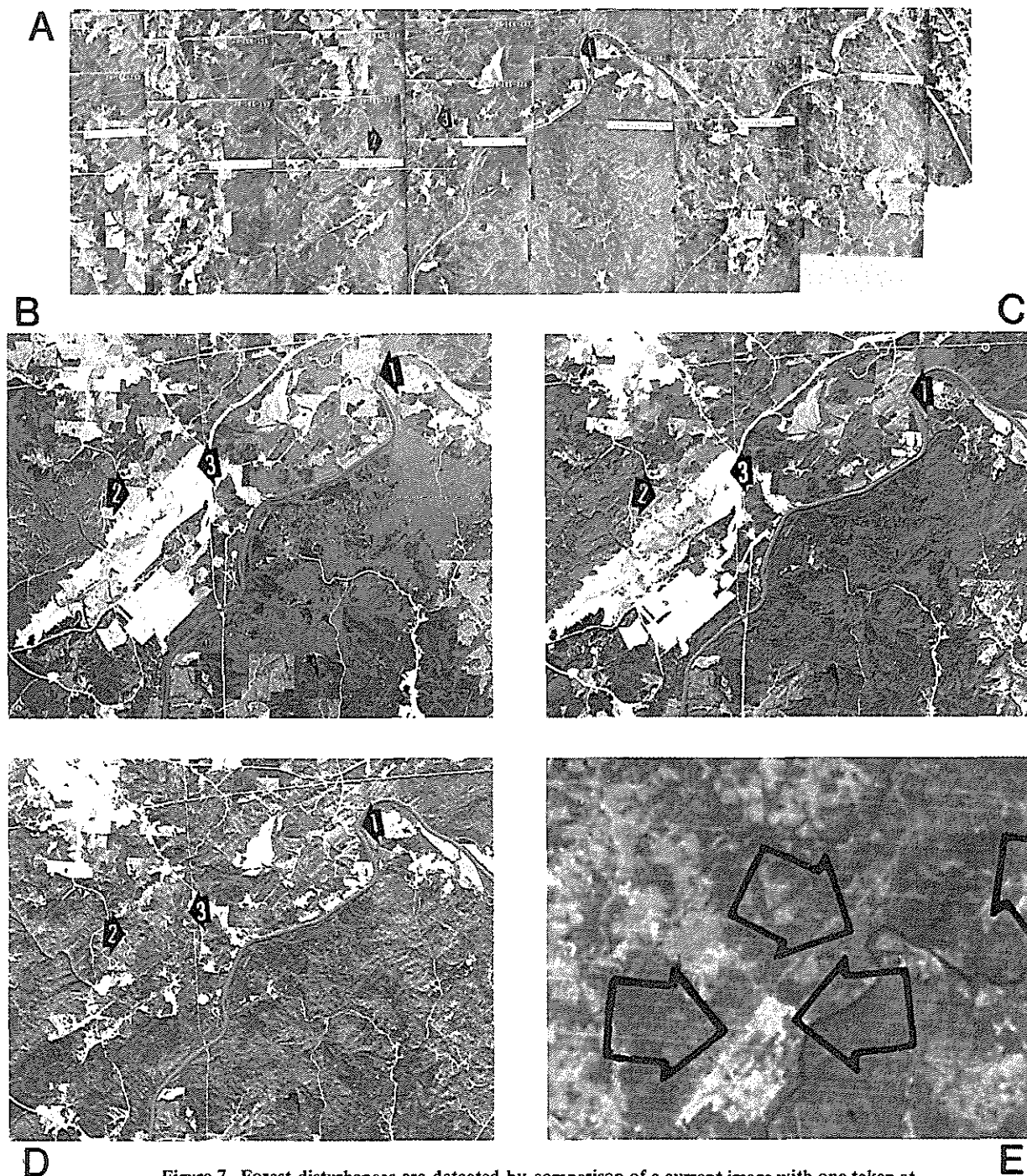


Figure 7—Forest disturbances are detected by comparison of a current image with one taken at an earlier date. Forest areas pointed out on the photo index sheet for February 1966 (A) appear disturbed on color infrared photography for June 1, 1972 and October 2, 1972 (B,C). In November 1971 (D), when the deciduous trees were leafless, the forested areas were not as clearly separable. On the enlargement of a portion of the ERTS scene for April 13, 1973 (E), all three disturbed areas are visible; points 1 and 2 were pulpwood cuttings and point 3 was cleared for a new power station.

## LARS Procedure

For the LARS test, instructions on land-use classification categories to be used, area maps, and photographic aids were furnished by PSW. Ground truth classification maps for two blocks (4 and 14) were also furnished as a source of computer training fields (i.e., training samples). No ground truth was furnished for block 6, because, by the terms of the contract, LARS procedures were to be tested on block 6, using classification techniques developed on blocks 4 and 14.

Because of the complexity and detail of land-use categories in the Atlanta site, LARS used a supervised classification procedure. This meant that computer training fields were selected for each class to be mapped. At least 40 remote sensing units (RSU—a modified digital element) were required in each class to generate valid statistics for each class. This is equal to 10 times the number of features (the number of features equals the number of channels, 4, times the number of dates, 1).

To be selected, the RSU's for training fields had to fall at least two RSU's inside a vegetation-type line. By this criterion, all areas less than 5 acres were automatically eliminated from the selection process. For LARS use, 23 Level III land-use classes were originally developed, but only 12 of these could be used because there was an insufficient number of training fields to select from. The 12 classes were then reduced to 9 after an initial performance test showed that 3 out of the 12 contributed significantly to errors. The final 9 classes with the 8 approximately corresponding PSW classes were:

| <i>Forest Service class (Level II)</i> | <i>LARS class</i>         |
|----------------------------------------|---------------------------|
| Pine                                   | Pine                      |
| Hardwood                               | Hardwood                  |
| Grassland                              | Grazed Grassland          |
|                                        | Undisturbed Grassland     |
| Cropland                               |                           |
| Bare Soil                              | Plowed Fields/Borrow Pits |
| Wild Vegetation                        | Idle                      |
|                                        | Abandoned                 |
|                                        | Transitional              |
| Urban                                  |                           |
| Water                                  | Water                     |

As many training fields as possible were selected in each of the 9 classes, and the number of training RSU's per class was therefore roughly proportional to the class size. A drawback to this procedure was that too few areas remained to meet the requirements for a test set. Thus, to measure classification accuracy, it

was necessary for LARS to use training field performance. Justification for this was that

1. Training field size was roughly proportional to class size.
2. Training field distribution appeared to be related to class distribution.
3. Training fields were selected from the ground truth maps, not aerial photographs.
4. There was no area remaining from which to draw test fields for some subclasses.

## PSW Procedure

The Forest Service computer classification system utilized a CDC 7600 computer at the University of California Lawrence Berkeley Laboratory. Computer input and output were handled by a remote batch terminal, with primary components a Westinghouse 2500 and a line printer, at PSW. An off-line Electronic Associates Incorporated (EAI) 430 data plotter was used to plot land use and forest maps in any number of color combinations, using eight pens.

Basically the classification system consists of groups of computer programs which allow for flexibility in handling an ERTS bulk CCT. Five basic steps in the system between the raw digital data input and the final map product are as follows:

1. Using the raw data for each spectral channel, histograms and gray-scale computer maps are printed out on the line printer. These printouts are used to determine the range in spectral radiance values and to locate the corners of the study area on ground truth maps.
2. Corrections are applied to adjust for inherent distortions in the bulk raw data. These include correcting for missing data and stretching corners of the study area on the ERTS scene to meet corners of the area on the ground truth map.
3. Empirical distribution maps are produced (program EDMAP) to locate ground truth training samples and to screen the four channels of ERTS data as potential discriminators between land-use classes.
4. Three classification procedures are available: (a) a boundary-finding algorithm to locate clusters of spectrally similar and adjacent pixels (digital elements) and assign them to a land use, (b) a procedure that compares the radiance of each pixel with the mean radiance of a sample from each land use, or (c) a linear discriminant analysis which uses maximum likelihood and Gaussian assumptions (as used by LARS). (The computer maps used in this study were made using nearest neighbor theory under procedure (a).)

5. A final color-coded map is made on the off-line plotter and proportions of land area assigned to each land-use class are summarized.

These same procedures were used for the Black Hills test site. A more detailed description of the method is given as Appendix 1.

### Accuracy Evaluation

The accuracy of both the LARS and PSW classification procedures was checked independently at PSW, because we felt that the RSU's used by LARS to develop the original classification algorithm should not be used to check the accuracy of the algorithm.

We checked the LARS classification maps against our ground truth maps in two ways: (1) by area classified in each land-use class and (2) by a point-by-point check of map classifications.

**Area Check**—To be useful to Forest Service programs, the computer procedure must first predict forest land area within specified boundaries with an accuracy better than 95 percent. Furthermore, the procedure should locate the forested areas more than 90 percent of the time. The proportion of area classified in each land-use category was converted to land area and compared with areas in each test block that had been derived from the ground truth maps.

**Point Check**—We looked at randomly selected pixel locations on a 1:24,000 overlay placed on the 1:24,000 LARS computer printout. We examined each point and determined the LARS classification from three independent observations: (1) the individual pixel at the point, (2) the nearest neighboring category when a boundary was within one pixel distance (a subjective decision) and (3) the greatest proportion of a 3-by-3 matrix of pixels surrounding the point. We then compared the LARS classifications with the ground truth found by projecting the negative of the ground truth map onto the 1:24,000-scale random-point overlay with the Zoom Transfer Scope and recording the ground classification at each point. These same procedures were followed to check the accuracy of the PSW classification procedure.

## Results and Discussion

A comparison of results of conventional photo-interpretation (human) with results of the two computer classification systems reported here must recognize the differences in the two test designs. These differences may either enhance or detract from the success of computer classification. For example, the small size of a 10,000-acre (4047-ha) area is no prob-

lem to a computer using digital data, but it does hamper the human interpreter trying to identify specific data points on 1:1,000,000-scale ERTS imagery. On the other hand, if the computer is to be programmed to work with area data, portions of the digital tape must be printed out on a computer gray-scale map, so that specific digital elements at the corners of the area to be worked on can be located by comparison of the gray-scale map with aerial photographs. This time-consuming task is necessary because geometric errors within the ERTS data are too great to allow locating the area by direct use of the tapes by means of a coordinate system.

### Photointerpretation

**Land-use Classification**—Both photointerpreters correctly classified all but a few of the 171 Forest points on the October and April ERTS combination. Their individual scores were 99.4 and 96.5 percent (*table 2*). In Nonforest land categories, accuracy ranged from 25.0 percent for Bare Soil to 76.9 percent for Urban. All four Water sample points were correctly classified by both interpreters; however, the small sample was not representative, and it is unlikely that small ponds less than 0.4 hectare (1 acre) or streams less than 100 m (328 ft) wide will be resolved on ERTS data. By the same reasoning, the high score for Urban classification was due primarily to the large number of samples falling within the metropolitan limits of Atlanta and other cities. Single-lane highways, secondary roads, and power lines are not usually resolved on ERTS unless they are over 100 m wide or follow the same course taken by a scan line of the multispectral scanner (MSS). This fact is even more apparent in the computer classification results.

For the April-June ERTS combination, there was little difference in classification accuracy (*table 2*). Most notable among the differences is a 20 percent increase in accuracy of classifying Grassland, coupled with a similar decrease in the accuracy of classifying Cropland. Almost 45 percent of the Cropland samples were called Grassland. This seems to substantiate the interpreters' observation during the test that Grassland and Cropland cannot be easily separated on the June image because of the strong infrared reflectance from the vegetative ground cover. When the separation was made correctly, it was usually based on the information in the April imagery. When Grassland and Cropland are combined in the analysis as one class, 75 percent of the sample points are correct on the April-June combination; only 44 percent are correct on the October-April combination.

Table 2—Accuracy of Level I and II land-use classification by two photointerpreters for simultaneous viewing of ERTS color composites for October and April and for April and June

| Land-use class<br>(Levels I and II) | Samples<br>per class | October-April<br>percent correct |               | April-June<br>percent correct |               |
|-------------------------------------|----------------------|----------------------------------|---------------|-------------------------------|---------------|
|                                     |                      | Interpreter 1                    | Interpreter 2 | Interpreter 1                 | Interpreter 2 |
| I Forest                            | 171                  | 99.4                             | 96.5          | 97.1                          | 95.9          |
| II Pine                             | 77                   | 67.5                             | 64.9          | 51.9                          | 59.7          |
| Bottomland                          |                      |                                  |               |                               |               |
| Hardwood                            | 28                   | 10.7                             | 21.4          | 21.4                          | 7.1           |
| Upland                              |                      |                                  |               |                               |               |
| Hardwood                            | 59                   | 55.9                             | 30.5          | 64.4                          | 33.9          |
| Cutover                             | 7                    | 100.0                            | 14.3          | 100.0                         | 100.0         |
| I Nonforest                         | 117                  | 96.6                             | 88.9          | 96.0                          | 96.0          |
| II Grassland                        | 40                   | 62.5                             | 57.5          | 85.0                          | 75.0          |
| Cropland                            | 15                   | 33.3                             | 26.7          | 13.3                          | 6.7           |
| Wild Vegetation                     | 15                   | 40.0                             | 40.0          | 20.0                          | 20.0          |
| Urban                               | 39                   | 76.9                             | 66.7          | 76.9                          | 71.8          |
| Bare Soil                           | 8                    | 25.0                             | 50.0          | 50.0                          | 50.0          |
| I Water                             | 4                    | 100.0                            | 100.0         | 100.0                         | 100.0         |

The data on misclassification errors indicate conflicts between Nonforest classes at the different seasons of the year. Of course, some errors are caused by incorrect borderline decisions; this problem plagues photointerpreters even on larger scale aerial photography and is a primary source of error in area estimates based on interpretation of a systematic sample of grid points. On ERTS imagery this type of error is probably more common because of the low resolution and the "blooming" factor caused when one image (lighter in color) bleeds into another. Despite this, only 17 Nonforest points were misclassified as Forest in the October-April combination, and only 11 were called Forest on the April-June combination. By the same token, only 7 and 10 Forest plots were called Nonforest on the two image combinations, respectively. These two types of errors are compensating and would enhance any estimates of forest area made on ERTS by photointerpretation techniques.

The most serious Forest classification errors were identification of Wild Vegetation and Urban as Forest. Wild vegetation in the form of abandoned agriculture and transitional agricultural land are very similar in spectral characteristics to forest land. Also, wooded green strips within suburban metropolitan areas, though technically urban, still appear to be commercial forest land on the low-resolution ERTS imagery. These areas will always be a problem for interpreters unless the resolution of the MSS data is improved.

If only Level I land-use classes are used in the analysis, then the average accuracy of classification for two interpreters is 96 percent. This accuracy level seems to hold for both seasonal combinations, making very unlikely any significant difference for Forest, Nonforest, and Water classification. If these accuracies can be carried over to operational systems, they would be satisfactory as a first-level information source for the most extensive forest inventories. However, errors in locating sample points on the ground for enumerating such things as tree species, tree condition, volume, and growth would be too great. As a result, medium- to small-scale aerial photography would be needed as a first-stage sample. The costs involved for photography would probably far outweigh any gains from using ERTS imagery.

The accuracy obtained for Level II forest classification is also shown in *table 2*. Although there is considerable variation between interpreters, the results indicate that Pine can be interpreted best on the October-April imagery—with an accuracy of about 65 percent. Only 10 to 20 percent of the Bottomland Hardwood and only 30 to 60 percent of the Upland Hardwood could be identified correctly. When the Bottomland is combined with Upland, however, accuracy is increased to approximately 50 percent—still not a very good record. The largest portion of the misclassified Hardwood was called Pine. Seven points that fell within cutover forest land were correctly identified by interpreter 1 on both seasonal combina-

Table 3—An analysis of variance table for six land-use classes,<sup>1</sup> two interpreters, and two seasonal combinations of ERTS scenes<sup>2</sup>

| Source of variation | Sums of squares | Degrees of freedom | Mean squares | F value | Probability level of F |
|---------------------|-----------------|--------------------|--------------|---------|------------------------|
| Interpreters (I)    | 0.1756          | 1                  | 0.1756       | 7.1043  | 0.9824*                |
| Season (s)          | .0179           | 1                  | .0179        | .7249   | .5921                  |
| I X S               | .1089           | 1                  | .1089        | .7642   | .6042                  |
| Land use            | 3.7966          | 5                  | .7593        | 30.7246 | 1.0000**               |
| Error               | .3707           | 15                 | .0247        | —       | —                      |
| Total               | 4.3797          | 23                 | —            | —       | —                      |

<sup>1</sup>Pine, Hardwood, Grassland, Cropland, Urban, Water.

<sup>2</sup>October-April, April-June.

\* Significant at 5 percent level.

\*\* Significant at 1 percent level.

tions. Interpreter 2 mistook cutover areas for Hardwood type on the October-April combination.

An analysis of variance based on weighted interpretation errors showed significant differences in accuracy between interpreters and, as might be expected, highly significant differences in results between land-use classes (table 3). There was no statistically significant difference in results between the two seasonal ERTS combinations used. This was not surprising, on the basis of the data summaries (table 2). Interpreter differences on the other hand are not so easily explained, but the analysis indicates an apparent difference in interpreter ability, particularly for the Agricultural and Urban classes. When all Nonforest classes are lumped together, these errors are of little significance, reinforcing the conclusion that ERTS is most useful as a device for Level I land-use classification.

**Forest Disturbances**—Three important conditions must be met before recognition of disturbances in a forest environment is possible. First a base photograph taken at some earlier date—perhaps 3 to 5 years prior to the proposed inventory—must be available for comparison (fig. 7). Second, the current picture of the same scene must be taken as close to “real time” as possible. This need is particularly acute in areas where changes are occurring most frequently. Third, the two photographs must be compatible in photographic scale. Photos that differ greatly in scale, such as the 1:64,000 photo index sheets and the 1:1,000,000 ERTS imagery, require specialized equipment such as the ZTS to view the imagery simultaneously.

Season of the year is a critical factor in detection of disturbed areas in low-resolution imagery (50 to 100 m), such as ERTS. In high-altitude photography, the better resolution lessens the need for seasonal distinctions as an aid to interpretation. For ERTS, imagery from early spring to late spring is a first choice, and from late fall to late winter, a second choice. During these periods the deciduous trees are either newly leafed out, with high infrared-reflectant foliage in spring, or are leafless in winter, and the discrimination between deciduous and coniferous trees is much better at these times. On the other hand, summer and early fall ERTS images are over-saturated with infrared reflectance from all types of vegetation, and cutover and uncut hardwoods show little difference. Furthermore, site disturbances and the effects of woods roads and log skidways are completely obscured in summer and can be of no help in interpretation.

Of the 209 verified forest disturbances, the interpreter classified 165 or 79 percent on the ERTS color composite (table 4). Another 23 disturbances, or 11 percent, were misclassified. Detection is much more important than the correct identification, however, and 90 percent of all disturbed areas were detected.

Omissions and commissions would be the most serious types of error in a monitoring system. In this study, 21 verified disturbances were not detected on ERTS, about a 10 percent error. Two-thirds of the omissions were less than 25 acres (10.1 ha) and more than half of these were less than 5 acres (2.0 ha). In our limited data, most omissions fall in small land clearings and cutover forest areas. Commission errors—calling something disturbed that was not disturbed—

Table 4—Accuracy of detection of forest disturbances by one photointerpreter on ERTS color composite (1264-15445)

| Disturbance category   | Number of disturbances | Percent correct |
|------------------------|------------------------|-----------------|
| Harvested Forest Land  | 41                     | 71              |
| Land Clearing          | 4                      | 100             |
| No Change              |                        |                 |
| Forest to Agriculture  | 100                    | 80              |
| Forest to Urban        | 23                     | 91              |
| Forest to Water        | 18                     | 83              |
| Natural Cause          | 0                      | —               |
| Regeneration to Forest | 8                      | 25              |
| Other                  | 15                     | 93              |
| All categories         | 209                    | 79              |

are important because in a survey program, each interpretation error would mean one unnecessary field visit. At the approximate cost of \$100.00 per visit, such errors could be expensive unless the field crew could inventory the plot for other information on this occasion. There were 25 commission errors, or in terms of the total number of disturbances, a 12 percent error. Both types of errors, omission and commission, can be reduced by improving the quality of color reproductions, and by giving interpreters additional experience and improved training in the use of low-resolution imagery.

Ground examination of 40 areas called disturbed since 1960 revealed that 33 could be detected and correctly classified on high-altitude photography. These same areas could be detected but not classified on ERTS imagery. The seven misinterpretations were caused by (1) calling dark-toned (wet) fields artificial regeneration, (2) failure to detect ground-fire damage after 1 year, (3) failure to detect single-tree mortality, and (4) failure to detect selective logging or stand improvement cuttings after 2 years.

From the ground check we have learned that the evidence of clearcutting and seed tree cutting can be detected up to 8 years after the harvesting operation. We also learned that there is no time limit for detecting land cleared for nonforest use. Only the size of the clearing is a limitation—less than 0.2 ha (0.5 acre) on high-altitude photography and 1 ha (2 or 3 acres) on ERTS imagery. Nonforest land regenerated to forest land by natural or artificial methods cannot be detected, however, until 3 years after planting. Association with other factors such as fire trails and site preparations can help in interpretation of high-altitude photography, but not low-resolution ERTS imagery.

### Computer-Assisted Mapping

**LARS System**—The results of computer-assisted classification achieved by LARS show surprisingly close agreement with ground truth maps in area of land use. This is particularly true of the Level II classes—Pine, Hardwood, and Water. Table 5 shows the number of ground hectares and the proportion of the total land area mapped by the computer in each class.

When Pine and Hardwood stands were combined for all blocks, it was obvious that LARS slightly underestimated Forest land. It was also clear that with one exception both Pine and Hardwood were underestimated. The one exception was an overestimate of Hardwood (block 4) by 127 hectares (318

acres) or 21 percent. With this one exception, the estimates were all within 15 percent of the ground truth. Even estimates of Pine and Hardwood in block 6, based on an extension of the classification algorithms for blocks 4 and 14, were within 10 percent of ground truth. These results look very encouraging for automating forest land classification on low-resolution imagery.

Excluding the forest land category, however, considerably reduces the accuracy of land-use classification. Grassland, for instance, was underestimated in both blocks 4 and 14, but in block 6 it was overestimated. The errors all exceeded 25 percent. There was no reasonable estimate of Bare Soil in any block. This is difficult to understand because soil has a unique spectral signature. Wild Vegetation was estimated within 20 percent of the ground truth on blocks 4 and 14, but on block 6 the error was almost 90 percent high. This error can be explained in part by the cutover Hardwood stands that occur over large areas and were classed by LARS as Wild Vegetation.

**PSW System**—The PSW computer classification system, with a different classification algorithm and much less sophisticated computer hardware, was reasonably successful in this test (*table 5*). For example, the areas of Pine and Hardwoods were within 25 percent of the ground truth areas, regardless of which block was examined. Total Forest land area was within 3 percent of the ground truth for blocks 4 and 14 and within 15 percent in block 6—the latter despite use of a combination of the training sets from blocks 4 and 14. Unlike the LARS system, the PSW classification overestimated Pine area and underestimated Hardwood, in every study block.

There seemed to be no special pattern for the errors in Nonforest classification. Grassland was underestimated and overestimated. Cropland acreages varied considerably and both Bare Soil and Wild Vegetation were overestimated in all three blocks. Like LARS, PSW badly overestimated Wild Vegetation in block 6 because cutover Hardwood stands had spectral signatures similar to Abandoned and Transitional agricultural land. Urban areas were underestimated, as would be expected because of the resolution limitations of ERTS. Water was underestimated for the same reason. The estimates of Water were fairly good, however, considering the small area of water in these study blocks.

### Comparison of LARS and PSW Systems

The displays of LARS and PSW classification maps in *figures 8* and *9* allow a visual comparison of the

Table 5—Comparison of percent accuracy of area estimates and sample point classification for LARS and PSW computer mapping procedures for three test blocks, ERTS scene 1084-15440, October 15, 1972

| Block and land-use class<br>(Levels I & II) | Ground <sup>1</sup><br>area | Area Accuracy  |      | Number of<br>points | Point accuracy <sup>2</sup> |     |    |
|---------------------------------------------|-----------------------------|----------------|------|---------------------|-----------------------------|-----|----|
|                                             |                             | LARS           | PSW  |                     | LARS                        | PSW |    |
|                                             | <i>Ha</i>                   | <i>Percent</i> |      |                     | <i>Percent</i>              |     |    |
| Block 4                                     |                             |                |      |                     |                             |     |    |
| I Forest                                    | 1713                        | 48.4           | 47.1 | 49.2                | 78                          | 63  | 45 |
| II Pine                                     | 1093                        | 30.9           | 26.0 | 35.9                | 48                          | 63  | 58 |
| Hardwood                                    | 620                         | 17.5           | 21.1 | 13.3                | 30                          | 62  | 23 |
| I Nonforest                                 | 1767                        | 49.9           | 51.6 | 49.9                | 93                          | 56  | 33 |
| II Grassland <sup>3</sup>                   | 917                         | 25.9           | 16.8 | 26.1                | 47                          | 53  | 40 |
| Bare Soil <sup>4</sup>                      | 457                         | 12.9           | 4.8  | 5.7                 | 15                          | 33  | 7  |
| Wild Vegetation                             | 393                         | 11.1           | 30.0 | 18.1                | 31                          | 69  | 35 |
| I Water                                     | 60                          | 1.7            | 1.3  | 0.9                 | 7                           | 70  | 43 |
| Block 14                                    |                             |                |      |                     |                             |     |    |
| I Forest                                    | 2642                        | 66.6           | 63.8 | 68.4                | 128                         | 77  | 56 |
| II Pine                                     | 1476                        | 37.2           | 35.3 | 44.1                | 69                          | 80  | 59 |
| Hardwood                                    | 1166                        | 29.4           | 28.5 | 24.3                | 59                          | 70  | 53 |
| I Nonforest                                 | 1309                        | 33.0           | 35.6 | 31.4                | 61                          | 59  | 41 |
| II Grassland <sup>3</sup>                   | 417                         | 10.5           | 5.0  | 13.1                | 21                          | 43  | 52 |
| Bare Soil <sup>4</sup>                      | 456                         | 10.8           | 6.2  | 6.9                 | 14                          | 57  | 50 |
| Wild Vegetation                             | 436                         | 11.0           | 24.4 | 11.4                | 26                          | 70  | 27 |
| I Water                                     | 16                          | 0.4            | 0.6  | 0.2                 | 6                           | 100 | 67 |
| Block 6                                     |                             |                |      |                     |                             |     |    |
| I Forest                                    | 3229                        | 83.3           | 74.9 | 72.1                | 144                         | 77  | 59 |
| II Pine                                     | 764                         | 19.7           | 18.0 | 24.4                | 20                          | 55  | 42 |
| Hardwood                                    | 2465                        | 63.3           | 56.9 | 47.7                | 124                         | 81  | 61 |
| I Nonforest                                 | 632                         | 16.3           | 24.5 | 27.5                | 28                          | 54  | 32 |
| II Grassland <sup>3</sup>                   | 245                         | 6.3            | 3.2  | 13.4                | 7                           | 43  | 0  |
| Bare Soil <sup>4</sup>                      | 255                         | 6.6            | 2.5  | 3.3                 | 10                          | 20  | 20 |
| Wild Vegetation                             | 15                          | 0.4            | 0.6  | 0.4                 | 2                           | 100 | 50 |

<sup>1</sup> Areas were determined by dot count on ground truth maps at an intensity of two dots per acre.

<sup>2</sup> Classification for a single pixel at the point.

<sup>3</sup> Includes Cropland to compare with LARS.

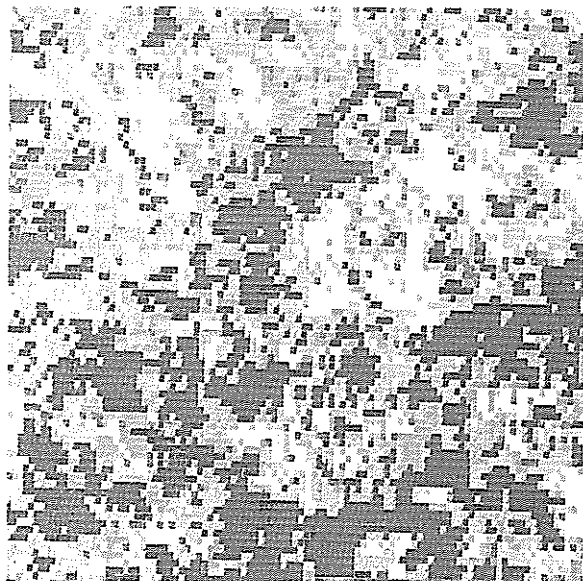
<sup>4</sup> Includes Urban to compare with LARS.

two systems with ground truth maps. Probably the first impression is that agreement is very good. Because the human eye and brain are not capable of scanning, assimilating, and sorting all of the data in a glance, more objective techniques had to be used to evaluate the systems.

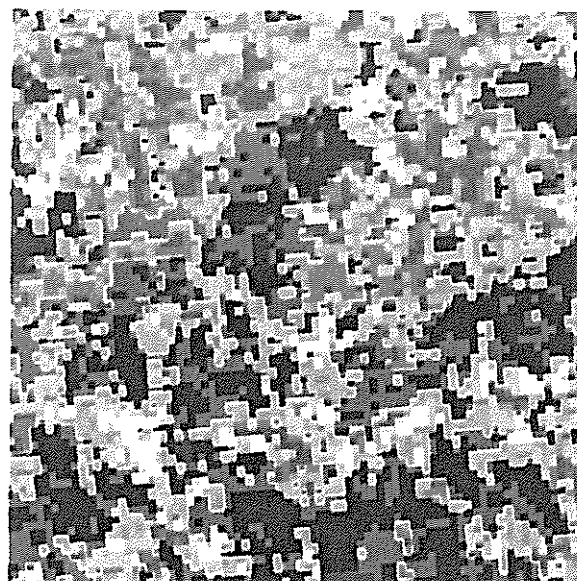
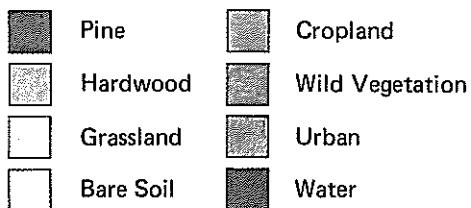
The report of results, above, showed that both systems estimated forest land areas within reasonable limits. Estimates of area by individual Level II classes were poor, however. This implies that ERTS-1 is really a Level I land-use sensor system. It is not surprising then, that when Level I area estimates are compared by class with areas measured on ground truth maps, very good agreement is seen (table 5). For example, Forest areas in both blocks 4 and 14 were within 2 percent of ground truth using either system. LARS

underestimated Forest and PSW overestimated it. Forest area estimates in block 6, made on the basis of training sets from blocks 4 and 14, indicated, however, that both systems underestimated forest land—LARS by 8 percent and PSW by 11 percent. This larger error was probably due to several differences between the blocks. Block 6 had a higher proportion of forest land, a higher proportion of hardwood type, and greater topographic relief, and there were also large areas of cutover forest land. The latter were misclassified as Wild Vegetation. In any future work all of these differences should be better defined for the computer systems.

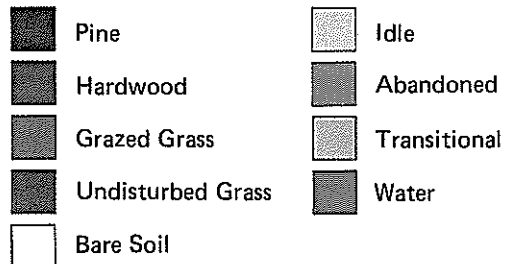
When the classified areas were combined by class for all three blocks (table 5), the PSW estimate of Forest for a 11,383-ha unit (28,129 acres), is 7250 ha



PSW (Berkeley) Computer Map



LARS (Purdue Univ.) Computer Map



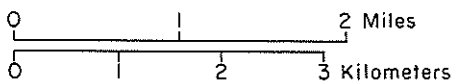
PSW Ground Truth Map Atlanta, Ga. Block 4

Data source:

1:60,000 CIR photo by NASA ERAP Mission 214, Oct. 2, 1972

Classification method:

Photointerpretation (4X) and ground check



#### Computer maps

Data source:

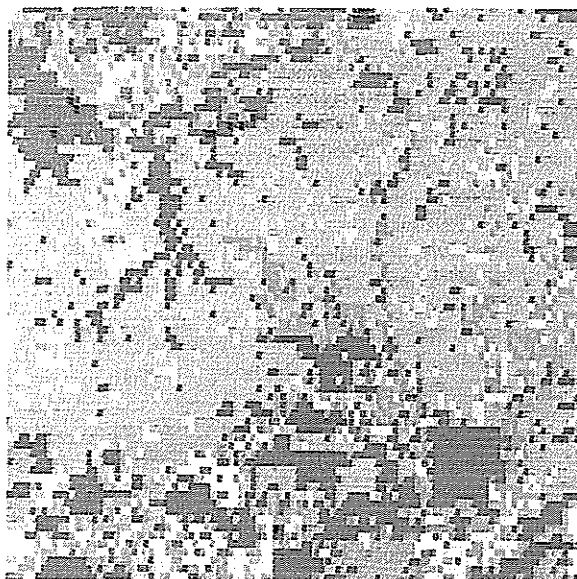
System-corrected CCT's for ERTS-1  
scene 1084-15540, Oct. 15, 1972,  
spectral bands 4,5,6,7

Classification method:

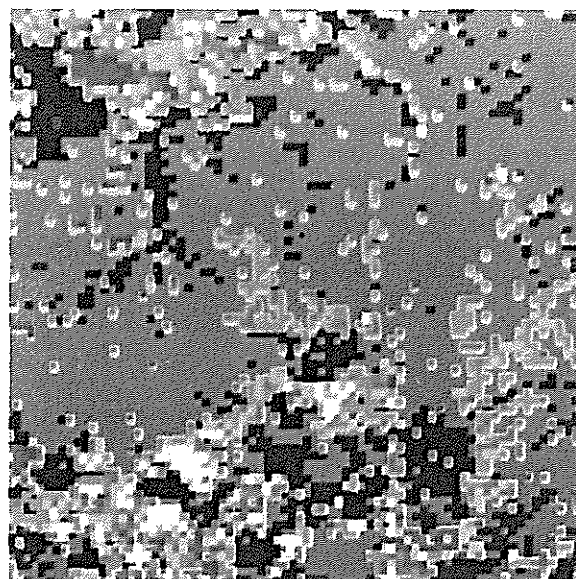
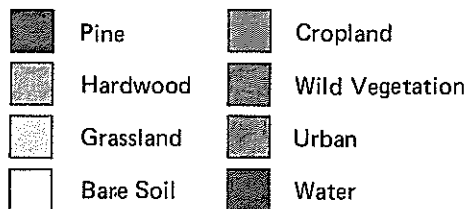
PSW—nearest neighbor procedure

LARS—maximum likelihood theory  
(Gaussian statistics)

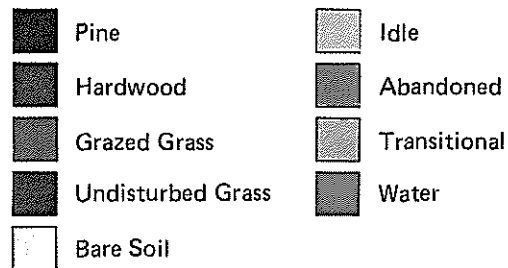
Figure 8—Examples of the output of two computer-assisted mapping systems for block 4, using an October ERTS scene, are shown here for comparison with the ground truth and with each other. The PSW map was produced by an off-line tape-driven plotter with eight colored marking pens. The LARS map was made photographically from a cathode-ray tube display using a filtering technique. Both computer maps were made using training sets selected from each land-use class within the mapped area. Point-by-point evaluations can be made with the ground-truth map.



PSW (Berkeley) Computer Map



LARS (Purdue Univ.) Computer Map



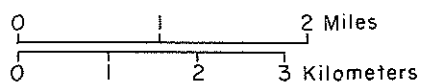
PSW Ground Truth Map Atlanta, Ga. Block 6

Data source:

1:60,000 CIR photo by NASA ERAP Mission 214, Oct. 2, 1972

Classification method:

Photointerpretation (4X) and ground check



#### Computer maps

Data source:

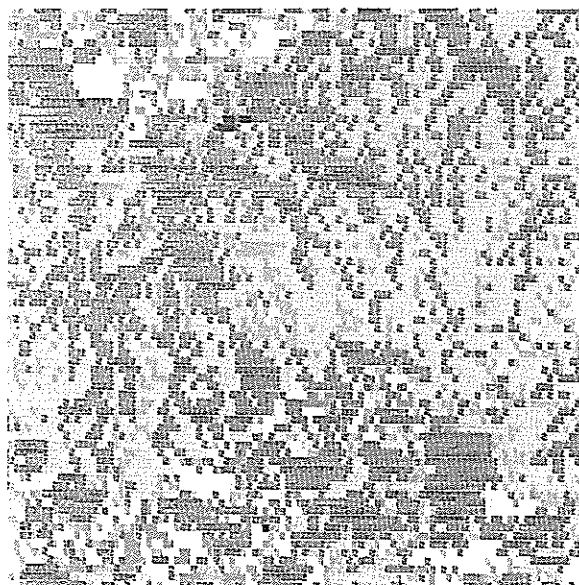
System-corrected CCT's for ERTS-1  
scene 1084-15540, Oct. 15, 1972,  
spectral bands 4,5,6,7

Classification method:

PSW—nearest neighbor procedure

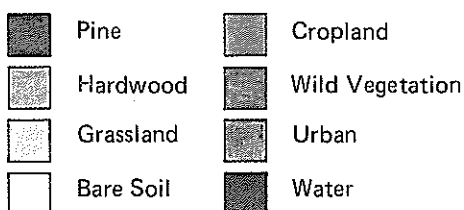
LARS—maximum likelihood theory  
(Gaussian statistics)

Figure 9—The computer-assisted mapping systems illustrated in figure 8 were applied to block 6, using an October ERTS scene. Both computer maps were made using a combination of the training set data for blocks 4 and 14.



PSW Computer Map

Atlanta, Ga. Block 6



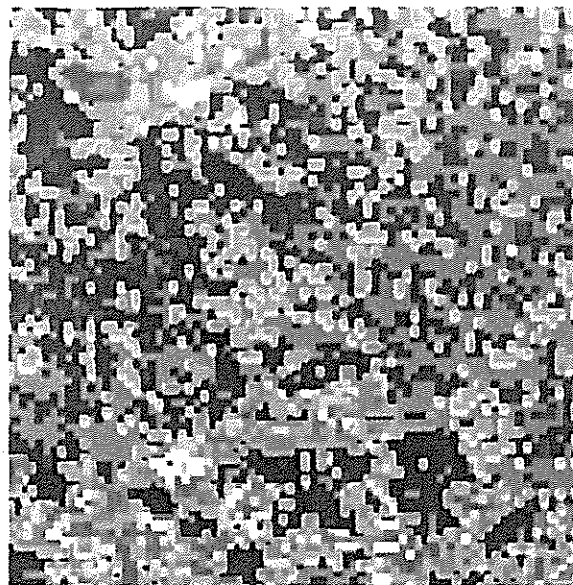
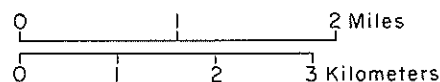
Data source:

System-corrected CCT's for ERTS-1  
scene 1264-15445, April 13, 1973,  
spectral bands 4,5,6,7

Classification method:

PSW—nearest neighbor procedure

LARS—maximum likelihood theory  
(Gaussian statistics)



LARS Computer Map

Atlanta, Ga. Block 6

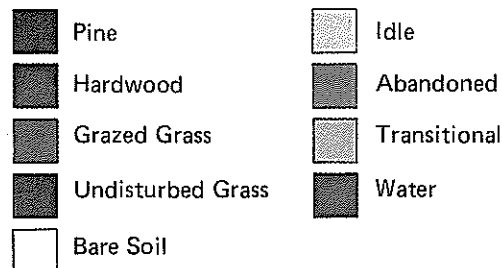


Figure 10—The computer-assisted mapping systems illustrated in figures 8 and 9 were applied to block 6, using an April ERTS scene and two different approaches. The PSW map was made using a combination of training sets based on April scene data for blocks 4 and 14. The LARS map was made using a combination of training sets based on October scene data for the same blocks. When these maps are compared with the ground truth map in figure 9, the errors are quite obvious.

(17,916 acres). The ground truth is 7589 ha (18,725 acres). The difference, -327 ha (809 acres), is only 4 percent. This is a very good estimate for such a small unit area.

The LARS estimate of Forest area was almost as good. The difference from ground truth was -476 ha (-1176 acres) or 6 percent. Both systems underestimated the combined block totals. This may be a systematic error that is characteristic in the ERTS-1 data.

Nonforest classification requires little explanation. After all, if Forest Land and Water can be isolated, then what remains should be Nonforest. The accuracy

of Water estimates is more important, but Water is not a major land use in the three study blocks. With just 94 ha (232 acres) of Water, as measured from ground truth maps, this hardly seems a fair test. These few acres are usually found impounded in small ponds of as little as 0.4 ha (1 acre). Nevertheless, LARS measured 93 ha (231 acres) of Water—one less than the ground truth. The PSW system could measure only 55 ha (137 acres), still a reasonable estimate for a class occupying only 0.8 percent of the total area.

Probably the most stringent test of either system is a point-to-point comparison (table 5). We found that

a single pixel unit was the best basis for checking map classifications in areas such as the Atlanta site, where land use is broken up and spotty. Checks based on proportion of a 3-by-3-pixel matrix were almost as effective, but more time consuming.

Generally speaking, by this test, LARS is correct more often than PSW—the totals for all classes reflect a 20 percent difference. Based on Level II land classification, the overall accuracy probably does not exceed 74 percent. The range in accuracy by classes using LARS is from 20 percent for Bare Soil to 100 percent for Water. If Level I land classes are used, the accuracy for Forest land classification is 90 percent by LARS and 80 percent by PSW.

An attempt was made to classify the three test blocks using CCT's for the April 1973 scene 1264-15445. We wanted to know if the spectral data for April were more discriminating than the October data. The LARS and PSW computer maps for block 6 are shown for purposes of comparison (*fig. 10*). Unfortunately, LARS used the algorithms developed for October to classify April spectral data, and many areas were misclassified. The most noteworthy error is the abundance of Water and Wild Vegetation scattered throughout the Hardwood forest type. At PSW we used algorithms developed for April data, but the results were also poor. At this time of year, west sides of hardwood ridges are darker and apparently look like pine to the computer classifier. Also, the lighter (or brighter) sides of the hardwood ridges were classified as Wild Vegetation in many instances. Thus, computer classification using seasonal data presents difficulties not easily solved. More work is needed to isolate seasonal variations and combine seasonal data to improve computer classifications.

## Applications

The spatial and spectral resolution of ERTS-1 data limit its application in forestry to providing a base for broad resource planning and to monitoring change. In

the Forest Service, the nationwide Forest Survey<sup>3</sup> has the greatest chance of benefiting. The results of this experiment show two possible applications: (1) ERTS could provide an up-to-date area sampling base to measure the forest area in each county within a specified accuracy and (2) ERTS could provide a tool to detect forest and nonforest inventory plot changes, or disturbances, that would permit periodic updates of forest information—particularly in areas where there is a great deal of human activity. To be beneficial, however, ERTS must either provide information that will reduce survey costs or provide information that is needed but cannot be obtained by other means because of the high cost of acquisition.

Forest acreages estimated by computer classification for relatively small areas are better than the accuracies now required by the Forest Survey for counties. Although this is very encouraging, several questions remain unanswered:

1. What is the operational cost of a computer land-use classification system? Present costs of establishing the area base using existing black-and-white photographs are less than 0.0125 cent per hectare (0.005 cent per acre). We could not establish a per-hectare cost based on the research reported here.

2. How can county and other irregular boundary lines be located within the ERTS data to obtain accurate area estimates?

3. How can the ERTS data elements be clustered in a two-stage sampling design that conforms to the Forest Survey design?

4. How can ground samples be selected for the second stage sample?

Future ERTS-type satellites are planned that include a twofold increase in spatial resolution and the addition of a thermal infrared band. With these improvements, it is very likely that the data will find far greater use in forestry.

<sup>3</sup> Forest Survey is a group in the staff unit of Forest Economics and Marketing Research, U.S. Forest Service. It was authorized by the McSweeney-McNary Forest Research Act of May 22, 1928.

# RANGE INVENTORY

## Classification of Plant Communities

Richard S. Driscoll

Richard E. Francis

The primary objective of this test was to determine at what level in an accepted hierarchy of plant community classification ERTS-1 imagery could be successfully used in a central Colorado mountainous area. A further objective was to determine the kind of aircraft support photography that would be needed to extend the classifications to the degree of detail required in range resource inventory.

### Study Area

The study area is between 38° 30' and 39° 30' north latitude and 104° 40' and 106° 10' west longitude and includes approximately 14,000 km<sup>2</sup> (5400 sq mi) (fig. 11). Included within the area was the NASA Manitou Test Site, No. 242, where, from 1969 to 1972, considerable research in aerial photography was done to determine film/filter/scale/seasonal combinations most useful to characterize and quantify plant community systems and components.

This nonurban, nonagricultural area in central Colorado is highly diverse in plant community systems and highly varied in topography. In general, the vegetation changes with elevation, but frequently terrain, slope, and aspect compensate for elevation differences. For example, ponderosa pine (*Pinus ponderosa* Laws.) forests occur mostly on ridges and slopes between approximately 2000 and 2700 m (6500 and 8800 ft), but extend below this zone to 1800 m (5900 ft) and above the zone to 3000 m (9800 ft) depending on local environmental conditions. Other community systems vary similarly.

The vegetation in the area consists of a variety of forests and grasslands (fig. 12). The forests, ranging from approximately 1900 m (6232 ft) above mean sea level to tree line at approximately 3500 m (11,480 ft), include (1) ponderosa pine, (2) Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco), (3) lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), (4) spruce/fir—primarily a mix of

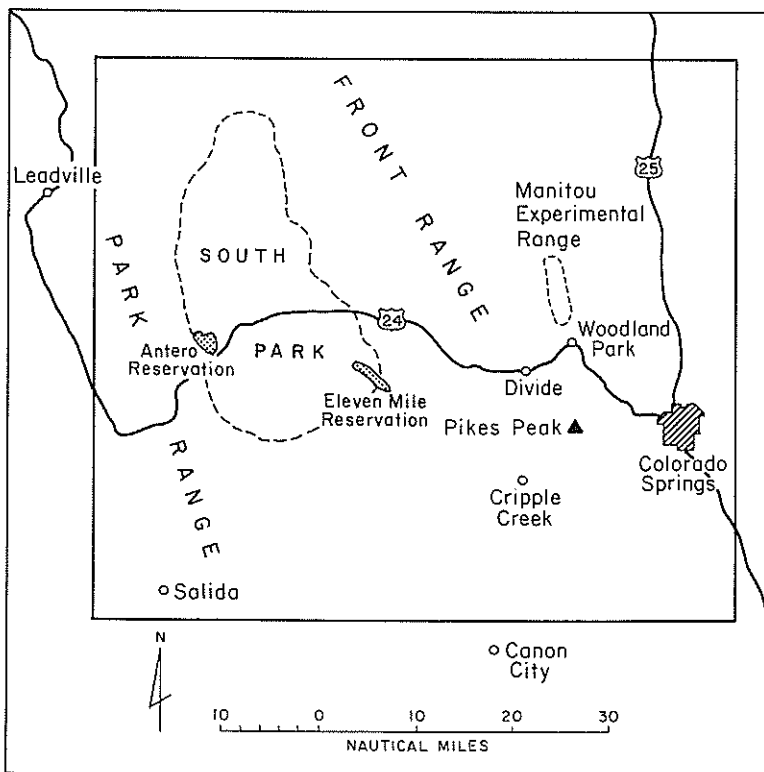


Figure 11—The central Colorado test area includes part of the Colorado Front Range on the east, a large high mountain park (South Park), and part of the Park Range on the west.



Figure 12—The vegetation of the Colorado test site is very complex, including pure stands of species types and subtle gradations between types. Above, the dark tones are coniferous forests and the lighter tones are deciduous forests (quaking aspen). Below, coniferous forest grades into grassland.

Engelmann spruce (*Picea engelmanni* Parry) and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.)—and (5) pinyon-juniper—primarily pinyon pine (*Pinus edulis* Engelm.) and species of juniper, mainly Rocky Mountain juniper (*Juniperus scopulorum* [Sarg.]). Intermingled throughout the area are deciduous forests of quaking aspen (*Populus tremuloides* Michx.). These forests occur as “pure” types, but frequently there are varying mixtures of species in the natural ecotones between forest types or as a result of plant succession related to disturbance by man. In addition, the tree canopy of these forests varies from very open to very dense. The open tree stands permit the development of an extensive herbaceous and/or shrubby understory; little understory exists within the dense forest stands.

Mountain bunchgrass communities, in which Arizona fescue (*Festuca arizonica* Vasey) and mountain muhly (*Muhlenbergia montana* [Nutt.] Hitchc.) are the dominant grasses, occur in the lower elevation areas primarily as parks surrounded by ponderosa pine forests. At higher elevations these dominants are replaced by other species of fescue (Idaho fescue [*F. idahoensis* Elmer] and Thurber fescue [*F. thurberi* Vasey]) and oatgrass (*Danthonia parryi* Schribn.) and are usually associated with the other forest types. In many instances, the gradation from forest to grassland is subtle, and it is difficult, even at ground level, to establish the line of demarcation between the two systems (fig. 12).

Within the central part is South Park, a large, nearly treeless area. The vegetation of South Park is generally of low stature; blue grama (*Bouteloua gracilis* [H.B.K.] Lag.) and slimstem muhly (*Muhlenbergia filiculmis* Vasey) are the most prominent. These and associated species suggest the aspect of a shortgrass prairie. Around the fringes of the Park, and in some places within the Park, where herbaceous communities interface with the forests, mountain bunchgrass communities become prominent.

Wet meadow and stream bank communities are especially well developed in South Park and occur as occasional narrow strips throughout the entire area. Various species of sedges (*Carex* L.), rushes (*Juncus* L.), and bulrush (*Scirpus* L.) predominate either as monospecific or mixed stands in the moist areas. Tufted hairgrass (*Deschampsia caespitosa* (L.) Beauv.) mixed with species of bluegrass (*Poa* L.) form communities in those areas that are not so moist. Throughout the area, generally in association with the meadows, are shrubby communities dominated by species of willow (*Salix* L.) and shrubby cinquefoil (*Potentilla fruticosa* L.).

The main portion of the study area varies in elevation from approximately 2100 to 4300 m (6888 to 14,104 ft) above mean sea level. Variations are dramatic—as much as 400 m per kilometer (2000 ft per mile) in many places. The average elevation of South Park is approximately 2750 m (9020 ft) above mean sea level.

The eastern portion of the study area, associated geologically with the Pikes Peak and Kenosha batholiths, is composed primarily of granitic mountains and outwash. The mountains in the western portion consist of highly intruded sediments; the intrusions are primarily of granite or granite-gneiss material with some schists. Trachytic and andesitic extrusive flows are relatively common, especially in the southwestern part of the area. The western mountains have been highly dissected by glaciation, and the outwash conglomerate deposits are common within and around the mountains. The northern end of the area is framed by the Kenosha batholith and other intrusive materials. The southern part of the area is associated with the Arkansas Hills, an ancient volcanic region from which extensive andesitic flows originated. Also associated with the southern portion are old uplifted sediments. Igneous intrusions and flows are abundant throughout South Park (Weimer and Haun 1960).

Generally, the mountain ranges in the area are oriented on a north-south axis, but many spur fragments, as well as individual units within the major ranges, are oriented east-west. This presents a complex matrix of slope-aspect relationships that influences vegetation patterns and adds to the complexity of processing and interpreting remotely sensed data.

## Classification System

The vegetation classification scheme used to evaluate the effectiveness of the ERTS-1 and supporting aircraft data is ECOCLASS, which was established according to ecological principles of polyclimax concepts (Daubenmire 1952). This system is in current use by the Forest Service to classify plant communities for land management planning, and is in accord with that established by the International Biological Program for classifying terrestrial communities (Peterken 1970). The system defines five categories proceeding from the most general to the most specific, as follows:

V. Formation—The most general class of vegetation, characterized by general appearance: Grassland, Coniferous Forest, Deciduous Forest, etc. The basis of this category is continental in scope, i.e., all of the

United States, and is controlled by continental climatic differences.

**IV. Region**—Subdivisions of the formation, associated regionally and therefore determined by subclimates within continental climates: Montane Grassland, Temperate Mesophytic Coniferous Forest, Alpine Grassland, etc.

**III. Series**—A group of vegetation systems within the Region category, with a common dominant climax species: Ponderosa Pine Forest, Fescue Grassland, Herbaceous Meadow, etc.

**II. Habitat Type**—Units within a series, each with relatively pure internal biotic and abiotic structure: Ponderosa Pine—Arizona Fescue habitat type, Arizona Fescue-Mountain Muhly habitat type, etc. *These are the elemental units of the classification scheme upon which primary management is based.* These units are frequently related to climax vegetation, or to vegetation held in a relatively stable state of high succession by proper management.

**I. Community Type**—A system that appears relatively stable under management and may be equivalent to the habitat type. Usually the biotic components are dissimilar, but abiotic components are analogous to habitat type.

The whole study area is considered to be within one general physiographic province, the Central Rocky Mountains, in which representatives of three Formation classes occur: Grasslands, Coniferous Forests, and Deciduous Forests. Within these classes, three Region and eight Series categories were defined for this study:

| <u>IV - Region</u>   | <u>III - Series</u>                                                       |
|----------------------|---------------------------------------------------------------------------|
| 1. Coniferous Forest | 1. Ponderosa Pine<br>2. Lodgepole Pine<br>3. Douglas-fir<br>4. Spruce/Fir |
| 2. Deciduous Forest  | 1. Aspen                                                                  |
| 3. Grassland         | 1. Shortgrass<br>2. Mountain Bunchgrass<br>3. Wet Meadow                  |

## **ERTS Data**

Three ERTS-1 color composites, secured from the Goddard Space Flight Center, included most of the test site and were selected for analysis: Scenes 1028-17135, August 20, 1972; 1334-17142, June 22, 1973; and 1388-17134, August 15, 1973. The color composites used ERTS multispectral channels 4 (green), 5 (red) and 7 (near infrared). These three scenes were selected because (1) the 1972 scene was

the first relatively (95 percent) cloud-free image of the area and was imaged at a time when most vegetation in the area was at peak growth, and (2) the 1973 scenes were relatively (90 percent) cloud free and represented a time when most vegetation was in either primary growth stages (June) or at peak growth (August), allowing us to determine if seasonal plant growth effects assisted classification. The color composites were used for visual interpretation and microdensitometric analyses.

In addition, ERTS multispectral scanner digital tapes of two of the scenes were secured for computer-assisted analysis. Selected portions of the August 1972 data were analyzed in cooperation with the Earth Resources Department, Colorado State University, and selected portions of the August 1973 data were analyzed in cooperation with LARS, Purdue University.

## **Ground Truth**

Color and color infrared (CIR) aerial photographs were secured to assist in interpreting the ERTS-1 imagery for plant community classification. Two aircraft missions, one in mid-June and one in mid-September 1972, were flown by the NASA aircraft support program, to provide photography representing plant phenological conditions corresponding to the selected ERTS scenes. Aerial photo scales were approximately 1:50,000, 1:100,000, and 1:400,000. In addition, CIR photographs at scales of approximately 1:2,000, 1:10,000, 1:20,000 and 1:40,000 were taken from U.S. Forest Service aircraft over parts of the area, to correspond to the August 1972 ERTS scene, so as to aid in determining photo scales required for specific plant community systems.

## **Photointerpretation Procedures**

Within the total study area, five units, each approximately 576 km<sup>2</sup> (225 sq mi), were selected for intensive investigation (*fig. 13*). These units were not necessarily replications because the plant community classes in one unit were not completely represented in all other units. All five units were used for visual and microdensitometric interpretation. Only two, units 2 and 4, were used for computer-assisted interpretation.

## **Visual Interpretation**

The June and August 1973 ERTS color composites were used for visual interpretation. Vegetation type maps, topographic maps, the ERTS-support

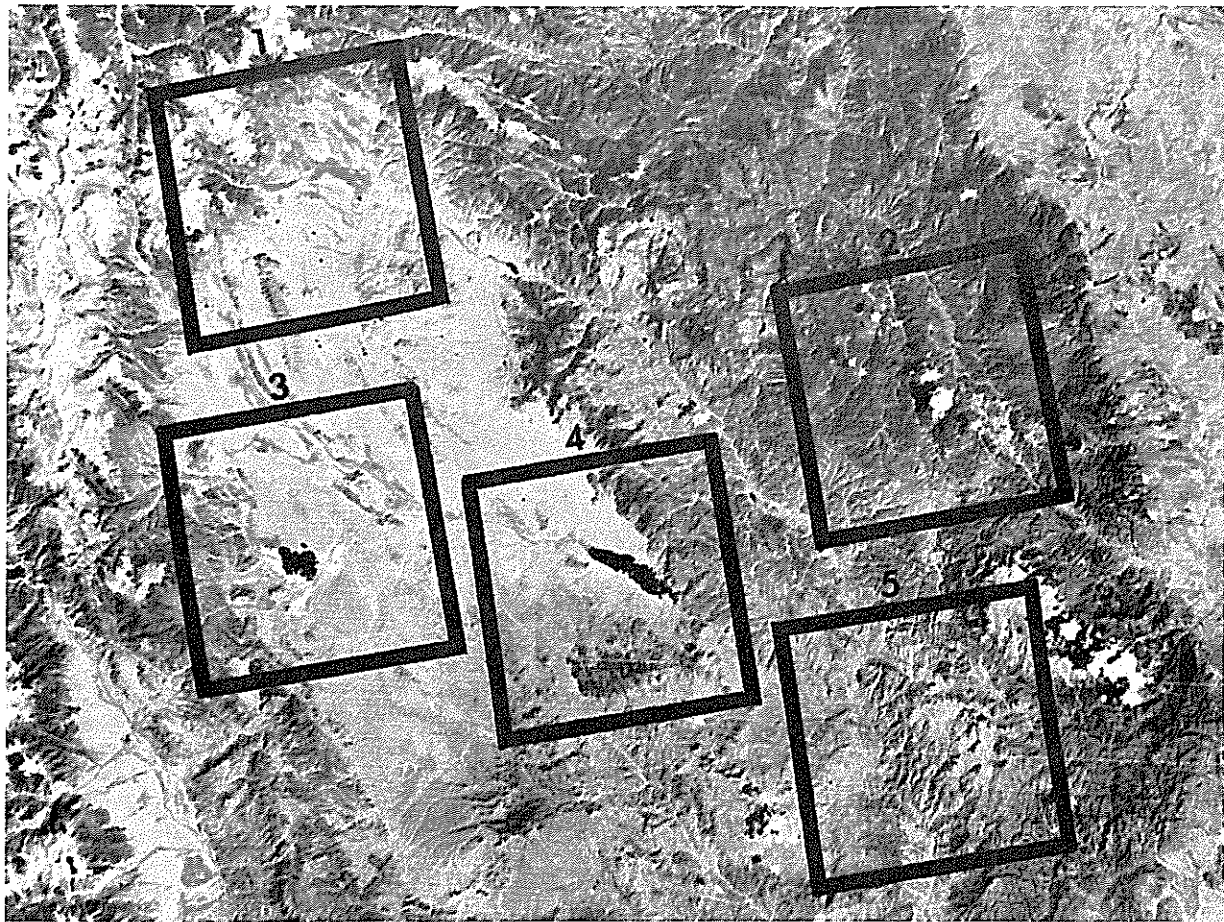


Figure 13—In this ERTS frame (scene 1028-17135) the five units selected for intensive investigation within the Manitou Test Site are outlined. Pike's Peak is at the northeast corner of unit 5. The units are aligned in a true north-south orientation; the skewness in the ERTS imagery is caused by the orbital path of the satellite and the rotation of the earth. White patches in the scene are clouds.

aerial photographs, and ground inspection were used to select sample "cells," or specific areas, for visual interpretation of both the ERTS-1 and support aerial photographs. The sample cells were initially selected and plotted on vegetation type maps and topographic maps to represent an area approximately 500 m<sup>2</sup> (1640 sq ft). The size of the cell selected was determined by two factors: (1) the originally advertised resolution and geographic fidelity of the bulk-data ERTS products, and (2) expected positional errors in both the satellite and data collection systems and in the system used to transfer sample cells from maps to the ERTS-1 and supporting aerial photographs. Ten percent of the sample cells were verified using aerial photographs and ground search. As only three of the field-verified cells required reclassification, the remaining classifications were assumed to be acceptably accurate. No fewer than 20 training and testing cells

were selected for each vegetation class, and 660 cells in all were used.

For visual interpretation of the color composite ERTS-1 imagery, transparent overlays were constructed showing sample cell locations for the total study area and for each of the five units (*fig. 14*). The Universal Transverse Mercator (UTM) coordinate representing the location of each cell was precision-plotted to a scale of 1:100,000. These overlays were then photographically reduced on 0.004 mil clear positive film to the 1:1,000,000 scale matching the ERTS-1 format. The plotted cell size at this scale represented an area 900 m<sup>2</sup> (2952 sq ft), larger than the size stated earlier, to minimize edge effect of cell wall lines. In addition, 50-km (31.07-mile) UTM coordinates were plotted to assist in positional location of the overlay on the ERTS frames.

These same cell locations were used to interpret

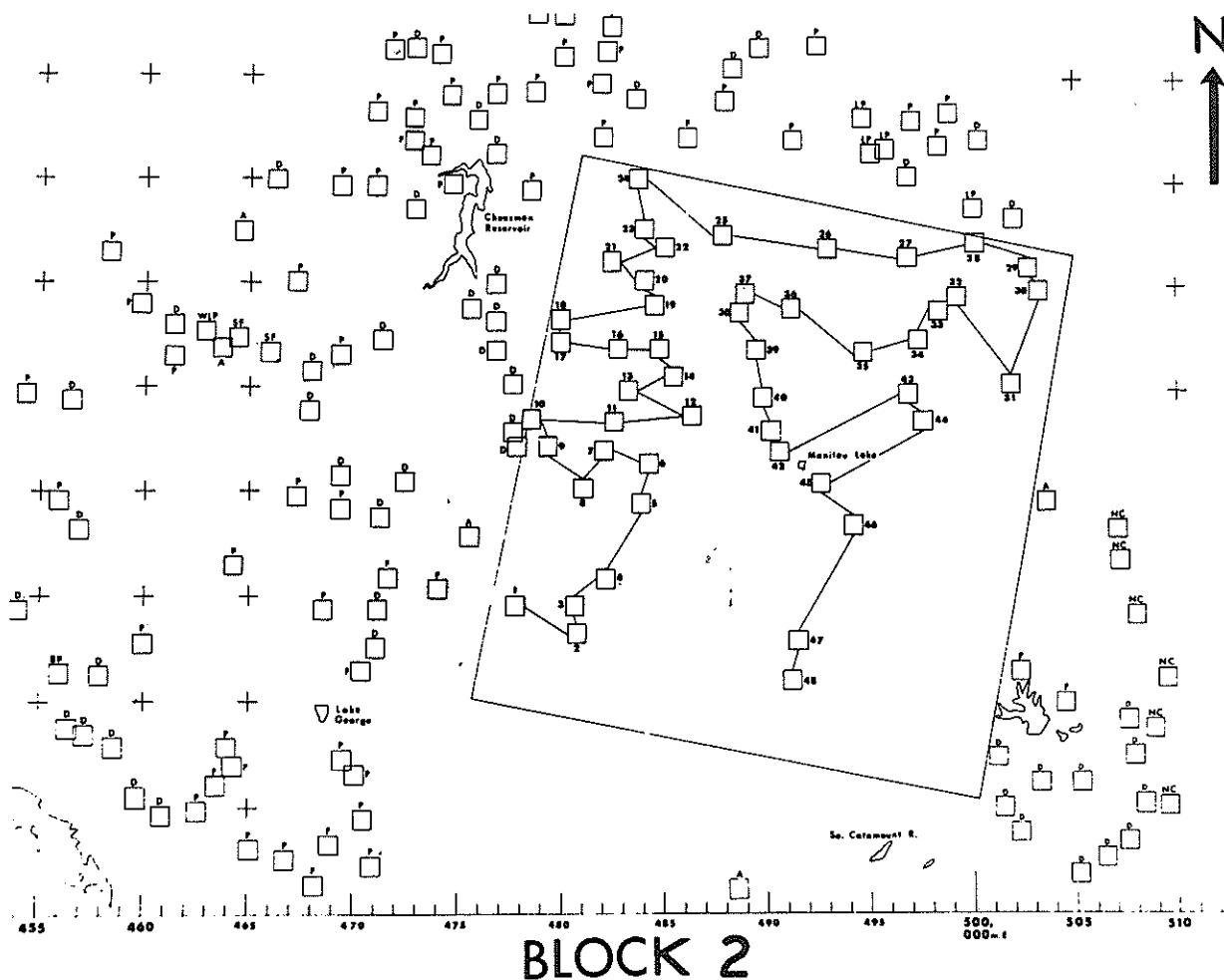


Figure 14—An overlay of sample cells was prepared for visual interpretation of ERTS color composites. Each small square represents an area approximately  $900 \text{ m}^2$  (2952 sq ft). The interpreters named the class they believed represented by the signature of the center of the square— $300 \text{ m}^2$  (984 sq ft).

the aircraft support photographs. Sample cell locations were transferred directly from the vegetation and topographic maps to the aerial photographs.

In data analysis, a factorial design for analysis of variance was used to test for differences between the appropriate factors of film type, photo scale, flight date, photointerpreter, and vegetation class. All factors were considered to be fixed effects. The highest order interaction term was used as the error term to obtain the F statistic.

#### Microdensitometric Interpretation

A scanning microdensitometer (fig. 15) was used to evaluate the June and August 1973 ERTS-1 color infrared composites for classifying the plant communities. This instrument examines a small piece of

the imagery at spectral levels selected to be compatible with the apparent spectral characteristics of the photographic materials. It then measures the optical density of the image by means of an optical system coupled with a photomultiplier-logamplifier measuring device. The hypothesis tested by this portion of the study was that the optical image densities of the plant communities classified to the Region and Series levels were sufficiently discrete to allow discrimination among them.

A red filter was inserted into the light-beam path to enhance the infrared vegetation signatures. The effective circular aperture covered an image area of 41,500 square microns, which on the ERTS image was a circle with a diameter approximately equivalent to the side dimensions of the sample cells used for visual interpretation.

The same sample cells used for visual interpretation were measured by the microdensitometer. Optical image density measurements were made of each sample cell by aligning the scanner light beam with the cell location, with the assistance of the overlay. Prior to making the measurements, the apparent optical density of the transparent overlay measured by the machine was compensated for to remove this effect from the apparent image density values. Values from all sample cells were obtained.

### ***Computer-Assisted Mapping Procedures***

In machine processing of the ERTS computer-compatible tapes (CCT'S), two sets of imagery were used—20 August 1972 and 15 August 1973. Only units 2 and 4 (fig. 13) were used for this portion of the work. The 1972 imagery was analyzed in cooperation with the Earth Resources Department, Colorado State University, to investigate the effects of topography on classification performance. These effects in conjunction with machine processing of the ERTS-1 imagery had been theoretically recognized, but detailed investigation had not been done (Hoffer and others 1973). The August 1973 imagery was processed in cooperation with LARS, Purdue University, to evaluate the ERTS-1 imagery for classifying the plant communities to the Region and Series Levels.

To determine effects of topography on classification, a photolike image mosaic of units 2 and 4 at

approximately 1:90,000 scale was generated from the CCT's using the microfilm capability of the CDC-6400 computer at Colorado State University. An initial classification of all vegetation classes was performed. Topographic maps, vegetation type maps, and 1:100,000-scale CIR aerial photographs were used to select and delineate on this mosaic representative vegetation class areas to "train" the computer to recognize the different classes. Also, training areas for Water, Clouds, and Cloud shadows were selected. The size of these training fields varied because of the natural meandering of the vegetation class boundaries.

The Ponderosa Pine class delineated in the ERTS CCT's by the initial selection procedure was used for detailed investigations on effects of slope steepness on the apparent spectral signatures of the class. Nine computer training fields of equal area were selected to represent different slope steepness classes. A single field was selected for each of three levels of slope. Slope steepness classes were:  $0^{\circ}$  to  $15^{\circ}$  (low),  $15^{\circ}$  to  $30^{\circ}$  (medium), and greater than  $30^{\circ}$  (high), as determined from topographic maps.

For the initial classification, we used a supervised program RECOG (Smith and others 1972), a multi-phase program patterned after the LARSYS approach (Purdue University 1968), to produce gray-scale maps. Each digital element was forced by RECOG to be classified as one of the plant community classes. The training fields for the slope classes of the Ponderosa Pine class were then located with the aid of aerial photos on the gray-scale maps. Standard statistical t and F tests were used to determine any significant

Figure 15—A microdensitometer (General Aniline and Film Corp. Model 650) was used to measure point-sample image density values of the various plant community systems. The operator is aligning the ERTS sample cell in the view screen before reading the apparent optical image density.



relationships between spectral response and slope steepness.

Classification by LARS used a mixed supervised and unsupervised procedure following the general LARSYS approach. The basic analysis had five phases: (1) locating the area to be studied, (2) selecting computer training fields to be clustered, (3) clustering the fields, (4) combining the statistics into spectral classes which appeared to relate to the classes under test, and (5) classifying the area. Initially, the data were deskewed to correct for earth rotation and satellite orbit paths (Anuta 1973). This put the data in a true orientation for nearly direct correspondence to topographic maps and aerial photos. Also, the computer-generated recognition maps were printed to 1:24,000 scale so that one digital element of ERTS-1 data represented one recognition map symbol. The training fields were selected to provide representative samples of the vegetation classes, so as to train the computer. The computer was then used to classify the total area. Evaluation of this final classification at both levels, Region and Series, was performed by systematically sampling approximately 10 percent of a portion of the computer classification maps representing the unit 2 (Manitou) and unit 4 (Eleven Mile) areas. That portion of each area corresponded to the area covered by one 1:50,000-scale CIR aerial photo.

Two complete computer classifications were done—one at the Region level and one at the Series level. In addition to the vegetation classes at each level, classes for Barren, Water, Cloud Shadows, Clouds, and "bad" data were introduced. Thus, the finished product resulted in classification of all ERTS-1 digital data cells of the selected areas.

Sample cells used for evaluation consisted of a series of 2-by-2 digital element matrices with a two-element buffer on each side to minimize the effect of possible positional errors. The computer-assisted classification of each sample cell within each matrix was compared with the vegetation classes interpreted from the same sample cell locations on the 1:50,000-scale CIR aerial photographs and vegetation type maps. To do this, transparent acetate grids were scaled to match the evaluation sample cell matrices to the aerial photographs and vegetation maps. Special attention was given to those evaluation sample cells at the vegetation class boundaries and small, meandering vegetation types. In some instances, such as long and relatively narrow Wet Meadow areas, evaluation matrices were subjectively selected to assist in determining not only classification accuracy but positional accuracy. This was done to determine the influence of edge effects on the computer-assisted classification

for the nonuniform patterns of the natural vegetation occurring within the test site.

## Results and Discussion

The three procedures—(1) visual interpretation, (2) microdensitometric interpretation, and (3) computer-assisted analysis—provided similar results. In general, plant community classification by computer-assisted analysis to the Region level was acceptable (more than 80 percent accuracy) for most classes. Classification to the Series level was not acceptable (less than 80 percent accuracy). Further work should improve classification at each level, provided variable terrain features such as slope and aspect, and variations in live plant cover in relation to spectral response, are taken into account. The results of classification to either the Region or Series level by the visual and microdensitometric techniques indicated no date dependency between late spring (June) and midsummer (August) ERTS-1 imagery. Variations in these results are discussed below.

Classification to the Region level through visual interpretation of late spring (mid-June) and late summer (mid-September) aerial photos was neither date- nor scale-dependent. Results of interpretation to the Series level were varied as discussed below.

### Visual Interpretation

**Region Level**—Satellite color composites and aircraft photographs provided highly acceptable levels of classification accuracy for the Conifer and Grassland classes regardless of date, film type, photoscale, or interpreter (table 6). The lowest level of accuracy (for either class) was 88 percent for one interpreter using the June 1973 ERTS color composite, but this was still within the established limits of acceptability. Interpretation of the Deciduous class using either the satellite composites or aircraft photographs was dependent on date and scale. For the satellite

Table 6—Accuracy of visual classification of vegetation at Region level from ERTS color composites and from aerial photography

| Vegetation class<br>(Region level) | ERTS | Aerial<br>photography |
|------------------------------------|------|-----------------------|
| — Percent correct —                |      |                       |
| Conifer Forest                     | 95.4 | 98.2                  |
| Deciduous Forest                   | 62.6 | 64.8                  |
| Grassland                          | 96.4 | 99.0                  |

imagery, the best date ( $p = 0.95$ ) among the three used was August 1973, with an interpretation accuracy for the Deciduous class of 92 percent. Accuracy for that class in the June imagery was only 31 percent. At that time of year in the Manitou area, the leaves of the trees were only one-fourth to one-half developed and therefore were not producing maximum spectral responses required for classification, considering the resolution of the imagery being used.

Interpretation of the Deciduous class from aerial photography was less accurate than it was from the ERTS composites. The 1:50,000 scale CIR photographs provided 83 percent correct identification of that class as compared to the 92 percent for the ERTS composites. Here the interpreters were looking for more detail in the aerial photos, even to individual trees, and consequently there was more chance for error in classification decisions because of intermixing of the Deciduous class with the other classes.

In most instances there were significant differences ( $p = 0.90$ ) among interpreters for both the satellite color composites and the aerial photos. The differences were not of sufficient magnitude to alter the classification results. The interpreter most knowledgeable about the vegetation and its distribution in the test site provided the most accurate classifications.

The majority of commission errors for the Conifer classifications was to the Deciduous class, and few commission errors were made to the Grassland class. Deciduous was most often misclassified as Conifer, with a small percentage classed as Grassland in the satellite imagery. Misclassifications from the satellite imagery were due largely to the inability of the interpreters to interpret correlative information, such as changes in terrain relief which play major roles in distribution of the vegetation classes from that imagery. This problem made interpretation difficult between the Deciduous class and the Wet Meadow component of the Grassland category. Those two classes occur occasionally at interfaces around the edges of South Park. The misclassifications between Conifer and Deciduous were caused by the usual intermixing of species between the two classes.

There were no overall significant differences in results between the satellite composites and the aerial photos for classification of the three Region categories provided August imagery was used. On the basis of these results, the satellite composites were satisfactory for classifying those general plant community systems.

**Series Level**—The satellite color composites visually interpreted provided acceptable classification of the Aspen and Ponderosa Pine classes. However, inter-

Table 7—Accuracy of visual classification of vegetation at Series level from ERTS color composites, by interpreter

| Vegetation class<br>(Series level) | Interpreter       |     |     |      |
|------------------------------------|-------------------|-----|-----|------|
|                                    | A                 | B   | C   | Mean |
|                                    | —Percent correct— |     |     |      |
| Aspen (August 1973)                | 83                | 100 | 94  | 92   |
| Ponderosa Pine (June 1973)         | 61                | 95  | 88  | 81   |
| Shortgrass                         | 98                | 98  | 100 | 99   |
| Wet Meadow                         | 82                | 76  | 91  | 83   |
| Mountain Bunchgrass                | 41                | 22  | 88  | 50   |

pretation for these classes required imagery from different times of the growing season. For Aspen, highest accuracy (92 percent) was achieved using the August 1973 imagery (table 7). It must be noted that Aspen was the only Deciduous class identified in this work. There were no other deciduous forests in the study area. Whether or not the class can be separated from other Deciduous classes where it occurs with them in other parts of the United States cannot be stated.

Ponderosa Pine was identified 81 percent of the time from all other vegetation classes, all interpreters considered (table 7). One interpreter was much less accurate than the others, however, with a score of 61 percent as compared to 95 and 88 percent. Most of the commission errors of the low interpreter were to the Douglas-fir class. In most areas of the test site, these classes occur in close association, especially near ridgetops and on north slopes. In these areas, the two classes were very similar in canopy cover and visual image differences were subtle. The low-accuracy interpreter had difficulty in making the necessary distinctions.

Classification of Shortgrass and Wet Meadow was acceptably accurate from the satellite color composites regardless of which date was used (table 7). There were significant differences ( $p = 0.99$ ) among interpreters for classifying Wet Meadow. One interpreter had difficulty in discriminating that class from Shortgrass and Aspen, especially in the June imagery. At that time of year, when the vegetation was partially developed seasonally, there were relatively subtle demarcations between the three classes, as viewed in the satellite imagery, where they occur in close proximity.

Only one interpreter provided an acceptable level of classification for Mountain Bunchgrass using the satellite composites (table 7). He was well acquainted with the test site, especially that area where the Mountain Bunchgrass system was most prevalent. Therefore he could make judgments based on this

knowledge, even though the image signature of the sample cells—primarily color—was highly variable. For example, the color image signature of Mountain Bunchgrass ranged from medium blue to pale reddish purple, but the interpreter called both color signatures to the correct vegetation class. This result supports the conclusion that, at least with visual interpretation, the individual interpreter must be acquainted with the landscape to provide acceptable interpretations of the vegetation resources.

Results were also variable for interpretation at the Series level with the multiscale aerial photographs. In general, the best ( $p = 0.95$ ) classification was obtained using the 1:50,000 scale CIR photos exposed in middle to late summer (table 8). Only the Shortgrass, Wet Meadow, and Aspen classes, however, were correctly identified to the established accuracy standards. There were significant differences ( $p = 0.99$ ) among the interpreters in classification of most categories. Again, the interpreter who was most familiar with the landscape and its vegetation was most accurate. On the basis of his results alone, five of the eight classes were classified with sufficient accuracy.

Ponderosa Pine was classified more accurately on the satellite composites than on the aerial photographs. Normally, mature forests of that type are quite open-grown, with 40 to 60 percent crown cover, which presents many holes in the forest canopy to a remote sensor. Also, these forests, as compared to other forest classes, generally occur on drier sites, with relatively sparse understory vegetation and larger amounts of exposed soil surface. Consequently, a higher reflectance response is presented to the sensors, and a consequently brighter integrated image is recorded by the sensor, especially with increases in altitude to the height of the ERTS satellite. On the aerial photographs, the canopy holes were clearly visible, and since the apparent reflectance of the conifer trees among classes was similar, the interpreters made more commission errors on the photos when attempting classification of Ponderosa Pine.

Generally, commission errors for the forest classes were similar for both satellite imagery and aerial photos. The apparent major reason for these commission errors was overlapping of areas on the ground where the species classes grow. This caused class mixing, with similar photo textures on the aerial photos and similar color signatures on both satellite and underflight data. The low resolution and lack of stereoscopic coverage of the satellite imagery did not permit interpretation of topographic features important in relation to changes in the plant community classes. The task was further complicated by heavy

Table 8—Accuracy of vegetation classification at the Series level from 1:50,000 CIR aerial photographs, for two dates

| Vegetation class<br>(Series level) | Photo date                  |             |
|------------------------------------|-----------------------------|-------------|
|                                    | June 1973                   | August 1973 |
|                                    | — Percent correct (range) — |             |
| Mountain                           |                             |             |
| Bunchgrass                         | 70 (40-100)                 | 74 (44-100) |
| Shortgrass                         | 89 (83-92)                  | 89 (83-92)  |
| Wet Meadow                         | 100                         | 100         |
| Aspen                              | 83 (75-100)                 | 83 (75-100) |
| Douglas-fir                        | 36 (27-41)                  | 65 (42-77)  |
| Lodgepole Pine                     | 51 (47-67)                  | 44 (22-67)  |
| Ponderosa Pine                     | 65 (53-86)                  | 71 (57-81)  |
| Spruce/Fir                         | 72 (59-77)                  | 67 (64-75)  |

shadows in steep north slope situations. No commission errors were made into the Grassland classes for the aerial photos because of the added advantage of stereo coverage and better resolution than the satellite imagery.

Commission errors for the Grassland classes were similar for both the satellite imagery and the aerial photos. An exception was that no commission errors were made to the Forest classes on the aerial photos. This was due to the added advantage of stereo coverage and better resolution to allow interpretation of topographic relief and apparent vegetation height.

Most of the commission errors for Mountain Bunchgrass on the satellite imagery occurred through confusion with Shortgrass. Without the aid of stereo coverage and subsequent topographic relief, it was very difficult to determine where the mountain perimeter began in order to correctly classify the Mountain Bunchgrass class. Commission errors for Wet Meadow were about equally divided between Aspen, Mountain Bunchgrass, and Shortgrass. Both high density Wet Meadow and Aspen had very similar color signatures and therefore were most often confused where the two classes occurred side by side. It was especially difficult to separate these two classes in those instances because of the lack of interpretable topographic relief in the satellite imagery. Also, low-density Wet Meadows had a color signature similar to those of high-density Shortgrass and Mountain Bunchgrass and therefore confused the interpreters.

Commission errors for Mountain Bunchgrass were lower on the aerial photos than on the satellite imagery. The stereo coverage allowed the interpreters to relate to topographic features, particularly the interface between the forested mountains and the grasslands. Commission errors to the Shortgrass class for Mountain Bunchgrass were still relatively large,

however, because of the continuum between the two Series classes.

The 1:50,000-scale aerial photographs were not entirely satisfactory to develop a multistage sampling scheme in the Manitou area. Vegetation in the area is highly complex, the plant community patterns are intricate, and the similar apparent spectral responses within and among plant community systems did not allow discrimination among all Series classes.

Larger scale, 1:20,000, aircraft CIR photos are required to subsample the Region classes for specific Series categories (*fig. 16*). The crown shapes of trees and the subtleties of Grassland class boundaries become more discrete at this photo scale than at smaller scales. This provides more precise definition of the location of Series boundaries to estimate the areal extent of Series units, and allows definition of some Habitat Types. An example of Habitat Type separation is seen in the figure. The coarse-textured image in the stream area at the bottom of the photo represents a Willow Habitat Type in contrast to the smooth textured Sedge/Bulrush Habitat Type in the same area. Also, tree crown cover, foliage cover classes of Grassland systems, and by interpolation, herbaceous foliage in the openings of the forest can be determined.

The last level of information in a multistage sample to obtain estimates of Series or Habitat Type parameters is secured using 1:2000 (*fig 16*) or larger scale photography. Individual tree crown diameter and tree height are measured to estimate timber stand volume. Relative amounts of plant cover and bare soil for Grassland units can be estimated. Measures of density and dispersion of some individual species in Grassland units can be estimated provided 1:600-scale sampling photography is used. Statistical measures of these parameters were limited and are not specifically reported here, because of the uncertainty of when ERTS data was in fact taken, and the malfunctions of some ground instruments. Previous research substantiates, however, that such parameters about plant communities can be estimated.

### Microdensitometric Interpretation

**Region Level**—Standard *t* tests for unpaired plots with unequal sample sizes indicated highly significant differences in the apparent image density among all Region classes regardless of which of the two ERTS-1 frames were used (*table 9*). Consequently, at the Region level of classification, those categories could be classified by microdensitometric techniques with a high degree of accuracy regardless

Table 9—Mean optical image density for Region and Series vegetation classes from ERTS-1 color composites for two dates: June 20 and August 15, 1973

| Classification level, date, and class | Sample size <sup>1</sup> | Mean image density <sup>2</sup> |
|---------------------------------------|--------------------------|---------------------------------|
| Region                                |                          |                                 |
| June                                  |                          |                                 |
| Deciduous Forest                      | 36                       | 2.141                           |
| Coniferous Forest                     | 307                      | 2.232                           |
| Grassland                             | 66                       | 1.079                           |
| August                                |                          |                                 |
| Deciduous Forest                      | 44                       | 1.983                           |
| Coniferous Forest                     | 408                      | 2.294                           |
| Grassland                             | 69                       | 0.991                           |
| Series                                |                          |                                 |
| June                                  |                          |                                 |
| Mountain bunchgrass                   | 21                       | 1.079                           |
| Shortgrass                            | 27                       | 1.069                           |
| Wet Meadow                            | 18                       | 1.093                           |
| August                                |                          |                                 |
| Mountain bunchgrass                   | 22                       | 0.979a                          |
| Shortgrass                            | 27                       | 0.931b                          |
| Wet Meadow                            | 20                       | 1.086ab                         |
| Series                                |                          |                                 |
| June                                  |                          |                                 |
| Spruce/Fir                            | 53                       | 2.300abc                        |
| Lodgepole Pine                        | 31                       | 2.254ab                         |
| Douglas-fir                           | 83                       | 2.238abc                        |
| Ponderosa Pine                        | 139                      | 2.199ab                         |
| Aspen                                 | 36                       | 2.141a                          |
| August                                |                          |                                 |
| Spruce/Fir                            | 119                      | 2.341ab                         |
| Lodgepole Pine                        | 55                       | 2.296ab                         |
| Douglas-fir                           | 90                       | 2.323ab                         |
| Ponderosa Pine                        | 144                      | 2.236ab                         |
| Aspen                                 | 44                       | 1.983a                          |

<sup>1</sup> Sample size for a class varies between dates because clouds or cloud shadows obscured sample points in the June imagery.

<sup>2</sup> For all Region classes, differences between all combinations at each date were highly significant ( $p = 0.99$ ). For Series classes, any two values with common letters are significantly different ( $p = 0.95$ ).

of whether late June or mid-August imagery was used. Similar results have been obtained using small-scale aerial photos (Driscoll and others 1974). The validity of these results with the ERTS photographic products needs to be evaluated, however, using additional imagery of the same or other locations taken during other years.

**Series Level**—Results of microdensitometric interpretation for classification at this level varied. For the three Grassland classes, there were no significant differences in image density estimated from the June imagery among any of the classes (*table 9*). At that time of year, the grassland vegetation was in the pri-

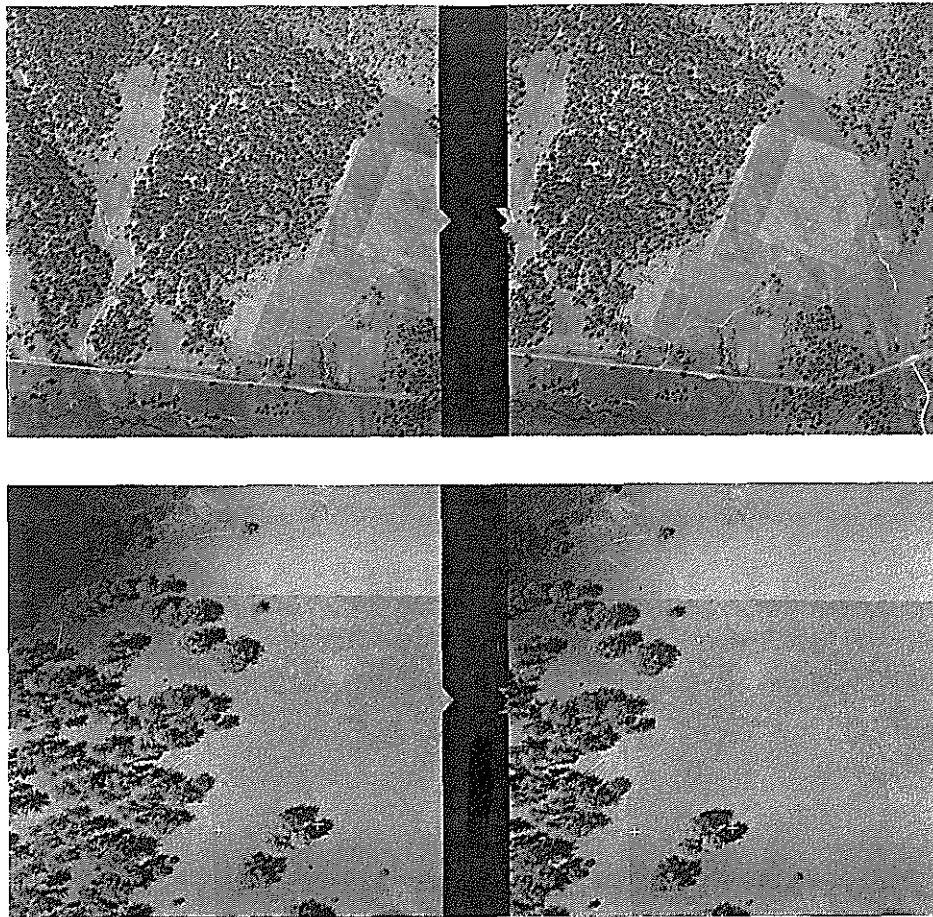


Figure 16--These stereo pairs at different scales illustrate the imagery required for classification and mapping at various levels. The 1:20,000 CIR stereo pair, *top*, allows classification to the Series and in most instances, the Habitat Type level of ECOCLASS. This material is used to subsample the Regional stratification done with ERTS imagery. On the 1:2,000 stereo pair, *bottom*, tree heights and crown diameters can be measured. Here the boundary between Ponderosa Pine and Mountain Bunchgrass (Series level) is shown. Relative amounts of herbaceous plant cover and bare soil in the Mountain Bunchgrass unit can be estimated provided the original photography is used.

mary stages of growth, there was little green foliage cover and most of the grassland scene was dead plant material and bare soil. Hence, there was no discrimination among the Series classes.

There were significant differences in the mean optical image densities of the Grassland classes in the August imagery (*table 9*). The mean density values between Mountain Bunchgrass and Wet Meadow, and Shortgrass and Wet Meadow, were sufficiently different ( $p = 0.95$ ) to make acceptably accurate discrimination between the groups highly probable. At that time of year, the dense Wet Meadow herbaceous vegetation was at peak growth. This allowed for a high scene contrast between the Wet Meadow and the

much drier upland Grassland classes. There was no significant difference between Mountain Bunchgrass and Shortgrass. These results were similar to those obtained with the computer-assisted analysis evaluations, described in the next section. The reason for this lack of discrimination between the two classes in the ERTS-1 imagery is not fully understood. Mountain Bunchgrass stands are usually of higher stature with more lush vegetation than the Shortgrass stands. Total live herbage cover is similar for both classes, however (35 percent Shortgrass; 45 percent Mountain Bunchgrass). Consequently, the spectral response to the ERTS-1 sensors appears to be influenced more by the amount of live vegetation cover than by the

structure of that cover. Also, the amount of vegetation cover in relation to other material (bare soil and plant litter) in the scene would influence the scene spectral response. In parts of both units, more than half the total samples had less than 50 percent live foliage cover, and this could be the threshold in spectral response at which live dry grassland cover has much influence on the spectral signature detected by the ERTS-1 sensors. These are the new concepts that need to be tested to improve recognition of Grassland classes by microdensitometry in areas similar to this test site.

Series classifications by optical density levels of the forest units were also variable within and among the two ERTS-1 scenes (table 9). Aspen and Ponderosa Pine were discriminated from the other Forest Series classes for both dates on the basis of optical image density. There was a significant difference ( $p = 0.95$ ) between Douglas-fir and Spruce/Fir on the June imagery but not on the August imagery. The reason for this difference is not completely understood, but perhaps changes in sun azimuth and elevation between the two dates of the ERTS-1 imagery unequally affected the spectral response of the forest types.

Lodgepole Pine and Spruce/Fir were not differentiated at either date. These two kinds of forests normally grow in very dense stands and in similar terrain locations on north-and-east-facing slopes at relatively high elevations. The combined effects of

dense canopy cover and mountain shadows at the time the ERTS-1 imagery was obtained resulted in very similar spectral signatures. Corrections for mountain shadows and apparent minor differences in spectral responses relative to the ERTS-1 sensors may improve classification. These ideas need to be investigated since similar classification problems were encountered at the Series level using the digital tapes.

### Computer-Assisted Mapping

**Region Level, Training Samples**—Training-sample classification was accurate at the Region level for both the Manitou and Eleven Mile Units (table 10). For all categories, classification accuracies were in excess of 97 percent.

The main sources of error within the Manitou unit were between the Grassland and Barren and between the Coniferous and Deciduous classes. The primary reason for the confusion between the Grassland and Barren classes was the low cover of vegetation in some of the Grassland areas. The high reflectance of nonvegetated areas dominated the response of live vegetation within the same digital element, and as a result, the total signature was assigned to the Barren category. The confusion between the Coniferous and Deciduous classes was due to a mixing of these Region classes (fig. 12). The plant components of the Deciduous class (quaking aspen in this case) frequent-

Table 10—Accuracy of performance of computer-assisted analysis at the Region level, for training class and total evaluation, by vegetation class for two study units

| Unit<br>vegetation<br>class | Training class performance |                    | Total evaluation performance |                                 |
|-----------------------------|----------------------------|--------------------|------------------------------|---------------------------------|
|                             | Number of<br>samples       | Percent<br>correct | Number of<br>samples         | Percent<br>correct <sup>1</sup> |
| <b>Manitou</b>              |                            |                    |                              |                                 |
| Grassland                   | 382                        | 97.1               | 257                          | 84.4                            |
| Deciduous Forest            | 78                         | 98.7               | 21                           | 23.8                            |
| Coniferous Forest           | 1294                       | 97.6               | 1239                         | 86.1                            |
| Barren                      | 60                         | 98.3               | —                            | —                               |
| Cloud                       | 384                        | 99.2               | —                            | —                               |
| Cloud Shadow                | 340                        | 98.5               | —                            | —                               |
| Water                       | —                          | —                  | 3                            | 66.7                            |
| All classes                 | 2538                       | 93.0               | 1520                         | 84.9                            |
| <b>Eleven Mile</b>          |                            |                    |                              |                                 |
| Grassland                   | 1193                       | 97.7               | 433                          | 80.1                            |
| Deciduous Forest            | 173                        | 97.7               | 94                           | 51.1                            |
| Coniferous Forest           | 1137                       | 99.2               | 739                          | 66.0                            |
| Water                       | 1090                       | 99.3               | 60                           | 95.0                            |
| Barren                      | 41                         | 100.0              | 54                           | 1.9                             |
| All classes                 | 3634                       | 98.7               | 1380                         | 68.2                            |

<sup>1</sup> Calculated as number correctly classified/total number of samples for each class.

ly occur in different amounts within the Coniferous class, and these mixes, or ecotones, apparently align themselves spectrally to one or the other of the primary classes. The class of such ecotones is often difficult to determine on the ground without detailed ecological investigation.

In the Eleven Mile unit, the confusion in training sample classification was primarily between the Grassland and Coniferous classes and the Deciduous and Grassland classes. The errors between the Grassland and Coniferous classes were not significant, and were probably due to a mixing of the two categories at the boundaries (*fig. 12*). Such occurrences were more frequent in the Eleven Mile unit than in the Manitou unit. The errors between the Deciduous and Grassland classes were related to the Wet Meadow component of the Grassland class and the Deciduous class. Both these units were highly reflective and produced similar spectral responses in the ERTS-1 sensors at the time the scene was exposed (August 1973).

**Series Level, Training Samples**—Training sample classification was accurate for all classes for both the Manitou and Eleven Mile (*table 10*) units. To achieve this, however, some false Series classes had to be generated. For example, Ponderosa Pine did in fact include that Series class, but where foliage cover of ponderosa pine exceeded 70 percent, the class was forced into a "Mixed Conifer" category. The Mixed Conifer not only included high-foliage-cover ponderosa pine, but also Douglas-fir and some lodgepole pine. Apparent spectral responses of those units were so similar that they could not be separated in the ERTS-1 digital data analysis. Therefore, even on the basis of training sample classification, the ERTS-1 imagery used for this work and analyzed according to the procedures described is not suitable for classification to the Series level—the individual kind of forest or grassland.

This evaluation indicated how well the training classes were selected, and not necessarily the accuracy of the total classification. The total classification considered all areas within a set boundary of each unit and included the training areas used to establish the statistics for the total classification.

**Region Level, Total Classification**—Performance on the Manitou unit was acceptable for two categories. Grassland and Coniferous Forest (*table 10*). The Deciduous Forest and Water categories were not accurately classified. In the Water category, however, the area contained only one small water body (approx. 2 ha—5 acres). The Deciduous Forest was identified, but additional digital elements distributed

throughout the area were incorrectly classified as Deciduous Forest. Most of these were associated with Grassland and Coniferous Forest class edges.

The Region classification evaluation of the Eleven Mile unit showed that only the Grassland and Water categories were classified with sufficient accuracy to be acceptable (*table 10*). The Deciduous Forest was confused with Grassland, primarily as a result of misclassification between the Deciduous Forest and the Wet Meadow component of the Grassland Region. The accuracy of the Coniferous Forest classification was only 66 percent, owing to the mixing of spectral response described earlier.

In general, classification to the Region level with ERTS-1 digital data is not accurate enough for operational use by itself. Ecotonal situations among Region classes resulted in serious misclassifications, especially between the Deciduous and Coniferous Forests. Also, frequent misclassification between the Deciduous Forest—here Aspen—and the Wet Meadow component of the Grasslands should be expected. It is possible that earlier (June) or later (September) imagery would improve classification of the Deciduous Forest system.

**Series Level, Total Classification**—Accuracy was sufficient to provide useful information only for the Shortgrass and Water classes (*table 11*) for the Eleven Mile unit. Accuracy for Mountain Bunchgrass (73.8 percent) for the Manitou unit approached the established standards, but it would be risky for the resource manager to base decisions on these results. The accuracy for Mountain Bunchgrass in the Eleven Mile unit was only 1 percent, perhaps because of the small sample size, only 136 points, used in the training statistics. As 66 percent of the computer-classified points of Mountain Bunchgrass in the Eleven Mile unit were verified by photointerpretation to be Shortgrass, the two Series classes are evidently not separable in ERTS-1 digital data, even though accuracy for Mountain Bunchgrass was fairly high in the Manitou unit, where there was no Shortgrass.

Classification at the Coniferous Forest Series level could not be evaluated accurately because of mixing in the training sample classification, described earlier.

Aspen was not classified with sufficient accuracy to provide usable information to the resource manager. This class was called Wet Meadow because the spectral responses of the two units were similar—as noted earlier in discussion of the Region level results. Aspen was also confused with various Coniferous Forests units, because an unknown threshold density of Aspen growing within the Coniferous Forest units resulted in a spectral signature that was closer to

Coniferous Forest than to "pure" Aspen.

The relationships of the computer-aided classification and ground-truth interpretation from aerial photographs provide insight for using the ERTS-1 digital data for this purpose (*fig. 17*). It should be noted that within those units classified as Ponderosa Pine (341.1) in the ground-truth map, there are varying amounts of tree density, as indicated by crown closure (foliar cover) of the trees. Also, the class occurs on slopes of varying steepness and aspect. The effect of slope aspect is especially apparent in relation to the position of Douglas-fir (341.2) to the terrain features. It occurs either on steep north slopes (the northwest quarter on the ground-truth map) or mixed with Ponderosa Pine (the west central area on the ground-truth map). Generally, the gradation between the two classes on the ground is quite sharp, but the tree crown density is very similar. Consequently, the chance of misclassification between the two classes is high.

Edge-effect errors can be observed in detailed examination of the computer map in *figure 17*. One

source of edge-effect error was that a particular digital element of the ERTS-1 scanner often included the boundary between two vegetation classes. This effect is most noticeable around the black cloud shadow. An anomalous Ponderosa Pine class classification occurs at the edge of the shadow, when in fact there is no ponderosa pine in that area. Similar anomalies can be recognized in the white halos around the edges of the light blue areas—the white areas were coded to clouds or snow, whereas no clouds or snow occurred in the area. The effect was also very noticeable on close examination of the digital gray-scale classification maps for evaluation of the Wet Meadow. In the Manitou unit, this class frequently occurs as narrow stringers of vegetation within the Forests (computer map, *fig. 17*). On the gray-scale map, Wet Meadow was misclassified because there was mixing of this and other classes in the scene, creating a spectral signature not related to any of the classes in the scene. For example, Wet Meadow was classified as Aspen where no aspen trees occurred.

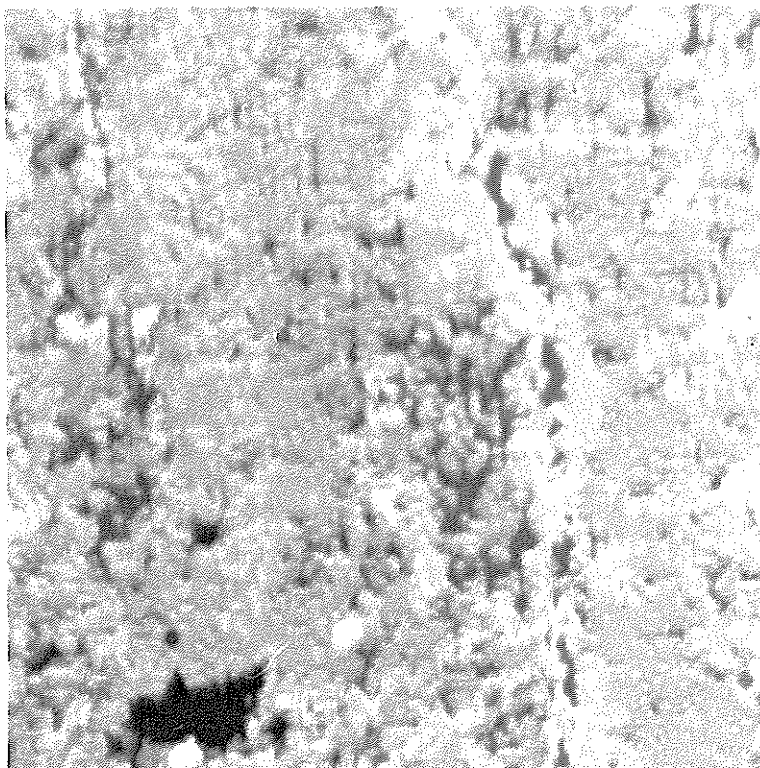
It must be concluded that the resolution of

Table 11—Accuracy of performance of computer-assisted analysis at the Series level, for training class and total evaluation, by vegetation class for two study units

| Unit and vegetation class  | Training class performance |                 | Total evaluation performance |                              |
|----------------------------|----------------------------|-----------------|------------------------------|------------------------------|
|                            | Number of samples          | Percent correct | Number of samples            | Percent correct <sup>1</sup> |
| Manitou                    |                            |                 |                              |                              |
| Mountain Bunchgrass        | 268                        | 97.0            | 244                          | 73.8                         |
| Wet Meadow                 | 144                        | 97.4            | 11                           | 72.7                         |
| Aspen                      | 78                         | 98.7            | 21                           | 23.8                         |
| Ponderosa Pine             | 333                        | 91.9            | 930                          | 38.4                         |
| Mixed Conifer <sup>2</sup> | 874                        | 95.4            | 294                          | 44.9                         |
| Lodgepole Pine             | 87                         | 100.0           | 17                           | 29.4                         |
| Barren                     | 60                         | 98.3            | —                            | —                            |
| Cloud                      | 384                        | 99.2            | —                            | —                            |
| Cloud Shadow               | 340                        | 93.5            | —                            | —                            |
| Water                      | —                          | —               | 3                            | 66.7                         |
| All classes                | 2538                       | 96.5            | 1520                         | 45.3                         |
| Eleven Mile                |                            |                 |                              |                              |
| Mountain Bunchgrass        | 136                        | 91.9            | 183                          | 0.5                          |
| Shortgrass                 | 863                        | 97.6            | 188                          | 87.8                         |
| Wet Meadow                 | 194                        | 80.9            | 62                           | 41.9                         |
| Aspen                      | 173                        | 97.7            | 94                           | 51.1                         |
| Ponderosa Pine             | 672                        | 99.3            | 369                          | 66.9                         |
| Mixed Conifer              | 465                        | 99.1            | —                            | —                            |
| Barren                     | 41                         | 100.0           | 54                           | 1.9                          |
| Water                      | 1090                       | 99.3            | 60                           | 95.0                         |
| All classes                | 3634                       | 97.5            | 1380                         | 50.8                         |

<sup>1</sup>Calculated as number correctly classified/total number of samples for each class.

<sup>2</sup>The Mixed Conifer class includes part of the Ponderosa Pine, all of the Douglas-fir, and part of the Lodgepole Pine classes.



#### Computer Map

| Color       | Class                      |
|-------------|----------------------------|
| Red         | Wet Meadow                 |
| Light gold  | Mtn. Bunchgrass            |
| Dark gold   | Mixed Conifer <sup>1</sup> |
| Light green | Lodgepole Pine             |
| Dark green  | Ponderosa Pine             |
| Pink        | Aspen                      |
| Blue        | Barren                     |
| Black       | Cloud Shadow               |
| White       | Cloud                      |

<sup>1</sup> Includes Ponderosa Pine/Douglas-fir, Lodgepole Pine/Douglas-fir, and high-density (foliage cover) Ponderosa Pine



#### Ground Truth Map

| Color         | Class                                    |
|---------------|------------------------------------------|
| 315.1         | Mtn. Bunchgrass                          |
| 316.1         | Wet Meadow                               |
| 321.1         | Willow Meadow                            |
| 325.1         | Mtn. Mahogany Shrub                      |
| 319.1         | Seeded Grassland                         |
| 341.1         | Ponderosa Pine                           |
| 341.2         | Douglas-fir                              |
| 341.1 - 341.2 | { Ponderosa Pine/<br>Douglas-fir complex |
| 341.3         | Lodgepole Pine                           |
| 342.1         | Aspen                                    |
| 210.1         | Ponds                                    |
| 520.1         | Mtn. Home Development                    |
| 520.2         | Campgrounds                              |

Figure 17—Series classification was attempted in the test of computer-assisted mapping of ERTS scene 1388-17134, August 1973. The ground truth map was made from aerial photography. Some features important to wildland management, the 520 units, are identifiable on the ground truth map but could not be found in the ERTS imagery.

ERTS-1 digital data is excessively coarse to provide the on-the-ground data required for management decisions, at least on the basis of results of the computer-assisted analysis provided. Ways to account for some of the error sources were examined in depth, however, for one class, Ponderosa Pine, within the Manitou unit, where the effects of slope steepness on apparent spectral responses were determined.

There was a significant relationship between spectral response and slope steepness. This response was evident in all four ERTS-1 channels for each of the three slope classes (fig. 18). In all channels, there was a linear trend of increasing spectral response with increasing slope steepness. The linear equations to describe these functions were determined to be as follows:

$$\begin{aligned} Y_4 &= 20.16 + 1.38x \\ Y_5 &= 16.39 + 1.79x \\ Y_6 &= 24.62 + 1.87x \\ Y_7 &= 12.77 + 1.26x \end{aligned}$$

where  $Y_i$  represents the relative spectral radiance in band  $i$  as recorded by the ERTS-1 multispectral scanner, and  $x$  is the slope category.

Classification analysis for the selected Ponderosa Pine sets was accomplished using two methods to determine potential improvement in classification by accounting for slope steepness. First, a spectral signature derived from one of the low-slope units and the original computer training statistics for Ponderosa Pine was used. The analysis was then repeated by adjusting the mean spectral response of the original computer training statistics to the regression equations above. It is not entirely clear how the training statistics should be adjusted according to terrain changes in the imagery (Smith and Oliver 1974; Kreigler and Horwitz 1973). In this study, however, the average values for medium slope were used for all three slope classes.

Classification accuracies obtained for the different slope-class training fields, applying the original spectral signatures utilized in the initial Series classification task, are given in table 12. In general, the classification performance decreased and commission errors between the Coniferous Series classes increased as slope class increased. This trend is an indication, at least for Ponderosa Pine, that spectral signatures derived from one slope class will not extrapolate to all slope classes. After the means were adjusted according to the regression equations and using the values derived for the medium slope class, classification performance increased and commission errors decreased (table 12). It appears evident that in accounting for

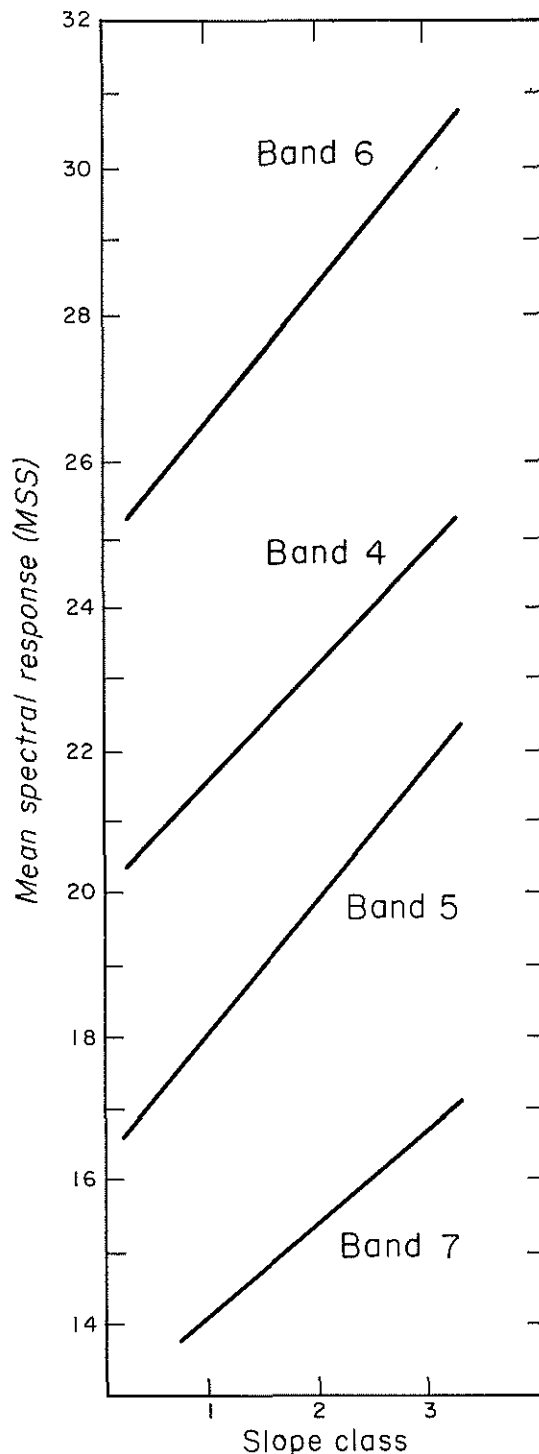


Figure 18—The mean spectral response for a Ponderosa Pine area is represented here by slope classes: 1 = 1-15 degrees, 2 = 15-30 degrees, 3 = 30 degrees. As slope steepness increases in relation to a fixed sun and sensor position, spectral response increases linearly.

Table 12—Computer recognition of selected Ponderosa Pine sites for three slope classes, before and after signature adjustment

| Accuracy           | Slope category |        |      |
|--------------------|----------------|--------|------|
|                    | Low            | Medium | High |
| Percent correct:   |                |        |      |
| Before adjustment  | 81             | 57     | 33   |
| After adjustment   | 83             | 73     | 80   |
| Commission errors: |                |        |      |
| Douglas-fir        |                |        |      |
| Before adjustment  | 10             | 10     | 16   |
| After adjustment   | 17             | 14     | 10   |
| Lodgepole Pine     |                |        |      |
| Before adjustment  |                | 4      |      |
| After adjustment   |                | 3      |      |
| Spruce/Fir         |                |        |      |
| Before adjustment  | 7              | 16     | 14   |
| After adjustment   | 0              | 2      | 2    |

terrain variances, corrections for both slope and aspect should improve classification accuracy. Intuitively, we can conclude that adjusting for variances in amount of live plane cover and other variables in the scene such as plant litter and kind and amount of bare soil exposed should improve classification. These concepts need to be studied in depth.

### Applications

The applications of ERTS-1 multispectral scanner imagery for rangeland classification are apparent from this research. Rangeland classification includes forested areas as well as grasslands and shrublands where trees are absent or rare. Existing maps of vegetation at the Region level, most of which are more than 10 years old, are outdated, because of changing land-use patterns or catastrophic events since the original maps were developed. Using satellite data, changes could be monitored with a high degree of probable success, based on the results achieved in classifying vegetation to the Region level by any of the three techniques used in this study. For example, areas of forest land covering more than 1 hectare (2.5 acres) that have been devastated by fire, purposefully cleared for urban or rural land development, or logged for timber harvest, could be removed from or added to a resource base depending on requirements of the resource manager. Burned or logged would be inserted into a livestock grazing or wildlife habitat resource

base, since the initial reaction of those areas to such treatment is increase in herbaceous or shrubby vegetation. These areas would revert to a timber base, once forest regeneration was established. Areas cleared for land development would be removed from all natural resource bases since sustained use for any of the resources is curtailed. Similar severe changes in grassland and shrubland communities classified to the Region level could also be monitored.

In the United States—South Park is an example—and elsewhere in the world there are places where vegetation has either not been mapped or mapped only cursorily. Large expanses of grassland can be mapped with ERTS-1 type data to a high degree of accuracy, and Series-level classes, such as Wet Meadows, can be delineated, provided the width of the high-contrast unit exceeds the width of the apparent ERTS-1 digital element by at least one digital element. Edge effects, vegetation shadows, and terrain shadows, however, prevent determinations of accurate area estimates when vegetation occurs in narrow strips, relative to ERTS-1 resolution.

ERTS-1 imagery is useful as a first level of stratification for multistage sampling of natural vegetation resources. In forested areas similar to those in the Manitou area, Region classes would be the minimum level in the ECOCLASS hierarchy that could be delineated unless concern were limited to the Aspen or Ponderosa Pine Series classes. These can be defined with an acceptable degree of accuracy.

Aerial photo scales of 1:20,000 are required for detailed mapping to the Series level; these large scales are needed to separate such conditions as variance in canopy cover of forest trees and kinds of Habitat Type in Grassland.

Photo scales of 1:2,000 and larger are required to evaluate Habitat Types, especially in Grassland, for plant cover. Our original experiment on classification and quantification of plant cover had no time replication. This experiment needs to be repeated for the same or similar areas using similar procedures to allow full evaluation of the experimental results. More experimental evidence is needed before the results can be applied in a fully operational program. In addition, continued research is needed to determine effects of terrain features, such as slope and aspect, and plant community characteristics, such as amounts of live vegetation cover, plant litter, and bare soil surface, on the apparent spectral response of specific targets as affected by sun elevation and azimuth.

# FOREST STRESS DETECTION

Frederick P. Weber

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## Ponderosa Pine Mortality from Mountain Pine Beetle

Stress detection in our Nation's wildlands and forests is a multiagency task, costing several million dollars each year in aerial and ground surveys. In the National Forest System, the stress comes primarily from insects or disease, and its impact is evaluated by a count of killed or damaged trees.

The purpose of the third phase of the ERTS testing program was to determine the potential usefulness of low-resolution satellite systems to detect and monitor forest stress. We felt that despite the rather poor spatial resolution indicated in the specifications for the multispectral scanner (MSS) subsystem, stress might be detected by spectral separation of the foliage discoloration resulting from tree damage. We also believed we might be able to detect change in the forest canopy by comparing imagery from successive 18-day cycles of the satellite. Therefore, we established the null hypothesis that the ERTS MSS data could not be used to detect stress in forests, and then attempted to disprove it. As a site for the investigation, we chose the Black Hills, where a 7-year cooperative effort in detection of damage by the mountain pine beetle had been carried on.

The mountain pine beetle (*Dendroctonus ponderosae* Hopk.) is a threat to ponderosa pine (*Pinus ponderosa* Laws.) throughout the central Rocky Mountain region, and the Black Hills in particular. Aircraft have been used since the mid-1920's to detect and appraise damage caused by the mountain pine beetle. The first remote sensing research to improve aerial detection and appraisal of mountain pine beetle damage in the Black Hills was established in 1952 (Heller and others 1959). After an epidemic outbreak of the mountain pine beetle in the northern Black Hills in 1963-64, the Forest Service Remote Sensing Research Work Unit took aerial color photographs at a scale of 1:7920 over the northern Black Hills. The resulting high-resolution color transparencies were used to train forest resource managers to locate infestation spots and to count dead trees. In 1965 a formal agreement between NASA and the Department of Agriculture launched the Remote Sensing Research Work Unit on 7 years of stress detection research. This work provided invaluable experience in the requirements for insect damage detec-

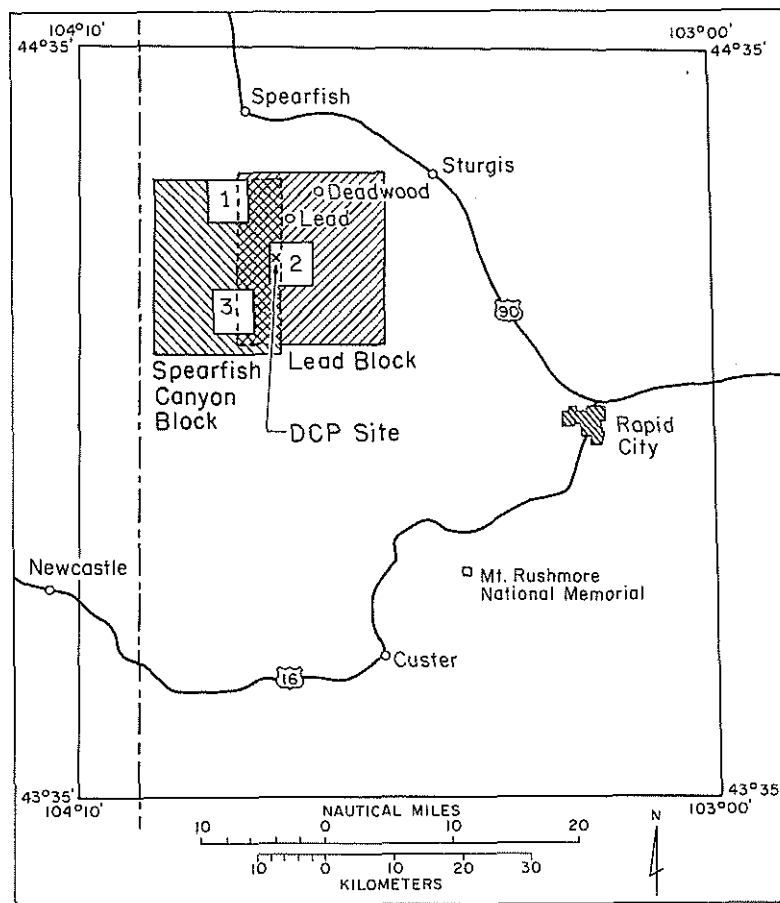
tion. Detailed studies established guidelines for aerial photography and also sorted out complex physiological and environmental relationships affecting interpretation of multispectral data (Weber 1969, 1972; Weber and others 1973).

### Study Area

The Black Hills test site (fig. 19) is an area of 10,200 km<sup>2</sup> (3938 sq miles) in western South Dakota and eastern Wyoming. The focus of the site is an elliptical dome extending over 0.75 million ha (1.85 million acres). The most important tree species, providing more than 95 percent of the total commercial sawtimber volume, is ponderosa pine. Geologically, the Black Hills National Forest portion of the test site is an exposed crystalline core surrounded by sedimentary formations. The central formation, at an elevation between 1200 and 1700 meters (4000 and 5600 ft), is highly dissected, with large areas of exposed soil and surface rock. Surrounding the central core are sedimentary formations of Paleozoic limestone. The topography here is gently rolling, especially in the northwestern Black Hills, where the limestone forms a plateau generally above 1800 meters (5900 ft). The eastern part of the Black Hills contains the same formations but generally at lower elevations. The radial-dendritic drainage pattern of the permanent east-flowing streams in this area is strongly evident on satellite imagery. Immediately outside the ponderosa pine zone, which surrounds the Black Hills, is a circular valley formed from reddish Triassic and Permian soft shale and sandstone. The "red valley," as it is called locally, is highly visible on some ERTS-1 imagery.

The intensive investigation area shown in figure 19 covers 653 km<sup>2</sup> (252 sq miles) surrounding the gold-mining town of Lead, South Dakota. Two overlapping study blocks contain three smaller sub-blocks. The Lead block, 41,293 ha (102,036 acres), includes sub-block 2 and the eastern side of sub-blocks 1 and 3. The Lead block contains many moderate- and small-sized mountain pine beetle infestations and is important as a transition area where little beetle activity is noticeable during endemic conditions. This area

Figure 19—The Black Hills National Forest test site is composed of two study sites, the Lead block and the Spearfish Canyon block. Within the blocks are three sub-blocks used as intensive study sites. Instrumentation for radiance data collection was located in sub-block 2 (DCP).



is first affected, however, during an expanding bark beetle population and thus is a good barometer area for an impending epidemic outbreak. Sub-block 2 is a representative area within the Lead block. The Spearfish Canyon block, 35,648 ha (88,087 acres), is on the west side of the intensive study area. Traditionally it contains a full spectrum of mountain pine beetle activity. Here it is common to have high beetle populations, with large volumes of timber killed on the north side of the area; on the southwest side little residual beetle activity occurs, and mortality problems are sporadic—showing up only during a widespread epidemic. Sub-block 3 to the south is representative of the latter condition. Sub-block 1, by contrast, has been an area of perpetual activity for the last 12 years, and contains the critical mass of the bark beetle population. Beetle populations have remained constantly high in the area and it is apparently a source of beetles which aggravate the control problem in two surrounding National Forest management areas. Sub-block 1 contains the largest infestations, which we hoped to detect and map on ERTS-1 imagery.

## Classification System

Interpretation of all Black Hills test site imagery, both in viewing color composites and in analyzing computer classification maps, is based on the hierarchical classification of Black Hills ecosystem cover types. Early in the 7-year remote sensing program we attempted to use an existing classification of the Black Hills ecosystem into 13 habitat units.<sup>4</sup> Although it is very thorough and is especially useful for classifying wildlife habitat, it is not well suited for interpretation of aircraft or satellite imagery. The classification hierarchy shown in *table 13* was devised specifically for such use, and covers the entire Black Hills test site. At Levels II and III, it differs from the classification systems used in the forest and range inventory studies described earlier in this report. A selected grouping of nine cover-type classes, those underscored in *table 13*, was used as a basis for mapping the three sub-blocks in these tests.

<sup>4</sup> Personal communication, John F. Thilenius, Rocky Mountain Forest and Range Exp. Stn.

Table 13—Black Hills National Forest classification hierarchy for remote sensing imagery<sup>1</sup>

|                                   |
|-----------------------------------|
| I Forest                          |
| II Conifer                        |
| III Dead ponderosa pine           |
| Pine, healthy, <50% crown closure |
| Pine, healthy, >50% crown closure |
| Spruce                            |
| II Deciduous <sup>2</sup>         |
| III Pure hardwood                 |
| Predominantly hardwood            |
| I Nonforest                       |
| II Grassland <sup>2</sup>         |
| III Wet pasture, on water course  |
| Dry pasture, well drained         |
| II Bare Soil <sup>3</sup>         |
| III Rock outcrop                  |
| Gravel quarry                     |
| Mine tailings                     |
| II Transition                     |
| III Logging clearcut              |
| Burn area                         |
| Soil, rock, sparse vegetation     |
| Infestation area                  |
| Other disturbance                 |
| II Urban                          |
| III Town                          |
| Isolated building(s)              |
| Utilities                         |
| Improved highway                  |
| Forest road                       |
| I Water                           |
| II Water                          |
| III Lakes and ponds               |
| Reservoir                         |
| Streams and creeks                |

<sup>1</sup>Classes used in computer-assisted mapping are underscored.

<sup>2</sup>Included rock outcrop for computer mapping.

Table 14—Classification of infestation by average spot size (longest dimension)

| Infestation class (meters) | Average number of trees |
|----------------------------|-------------------------|
| Less than 10               | 1 to 3                  |
| 10 to 25                   | 4 to 10                 |
| 26 to 50                   | 11 to 20                |
| 51 to 100                  | 21 to 50                |
| 101 to 300                 | 51 to 100               |
| More than 300              | 100+                    |

A classification of infestations by size was also set up. Before the ERTS experiment in the Black Hills began, the Remote Sensing Research Work Unit had classified infestations into strata based on the number of trees identified in an infestation spot on aerial photographs. For microscale photography and satellite imagery, spot size in meters was a more useful measure (table 14). In the sub-blocks, only those spots greater than 50 meters (165 ft) in the longest dimension were typed.

## ERTS Data

The difficulties of obtaining cloud-free ERTS imagery for dates suitable to the test objectives limited our scope in this study. We were obliged to use a scene for August 20, 1972 (scene 1028-17121) covering the Lead block (fig. 20) and one for September 8, 1972 (scene 1047-17175) covering the Spearfish Canyon block (fig. 21). Ideally, one scene covering the entire study area at two dates—August or September

Table 15—Tree mortality caused by mountain pine beetle for the years 1972 and 1973, sub-blocks 1, 2, and 3<sup>1</sup>

| Infestation size class (meters) | Total number dead trees |      |             |       |             |      |
|---------------------------------|-------------------------|------|-------------|-------|-------------|------|
|                                 | Sub-block 1             |      | Sub-block 2 |       | Sub-block 3 |      |
|                                 | 1972                    | 1973 | 1972        | 1973  | 1972        | 1973 |
| Less than 10                    | —                       | 148  | —           | 276   | —           | 218  |
| 10 to 25                        | 2702                    | 2653 | 2552        | 6811  | 1583        | 3682 |
| 26 to 50                        | 1198                    | 1207 | 252         | 3060  | 81          | 1003 |
| 51 to 100                       | 1079                    | 435  | —           | 870   | —           | 609  |
| 101 to 300                      | 715                     | 845  | —           | 325   | —           | 110  |
| More than 300                   | —                       | 1050 | —           | —     | —           | —    |
| Total                           | 5694                    | 6338 | 2804        | 11342 | 1664        | 5622 |
| Ratio, 1972/73                  | 1.11/1                  |      | 4.04/1      |       | 3.38/1      |      |

<sup>1</sup>Area of sub-block 1: 3949.2 ha (9758.6 acres), 2: 4142.0 ha (10,235.1 acres), 3: 4087.5 ha (10,100.4 acres).



Figure 20—The color composite for scene 1028-17121, August 20, 1972, covers the Lead block of the Black Hills test site. Scale is 1:160,000.

1972 and 1973—should have been used to allow change detection as a feature of the interpretation. No clear-weather images were obtained in August or September 1973, however. The best single scene received of the entire Black Hills test site was taken on June 22, 1973, but June is the worst possible time to detect stress from beetle attack in the Black Hills. Old kills have lost most of their discolored foliage by June and those from the preceding summer have just started visible fading.

By the nature of the plan by which ERTS data is supplied, we did not know until late in 1973 that no comparison would be possible on the ERTS scenes. Hence, our ground truth studies were made in both 1972 and 1973.

### ***Ground Truth***

The trend and spread of the mountain pine beetle in the northern Black Hills was monitored for research purposes with 1:32,000 scale color infrared (CIR) aerial photography taken the end of August or early September 1972 and 1973 by the Remote Sensing Research Work Unit. Other yearly surveys are conducted by the Forest Service, Rocky Mountain Region. These generally provide estimates of beetle damage for the entire Black Hills National Forest.<sup>5</sup>

Tree mortality counts within the three sub-blocks

<sup>5</sup> Cahill, Donn B. Information on file, U.S. Forest Service, Rocky Mountain Region, Division of Timber Management.

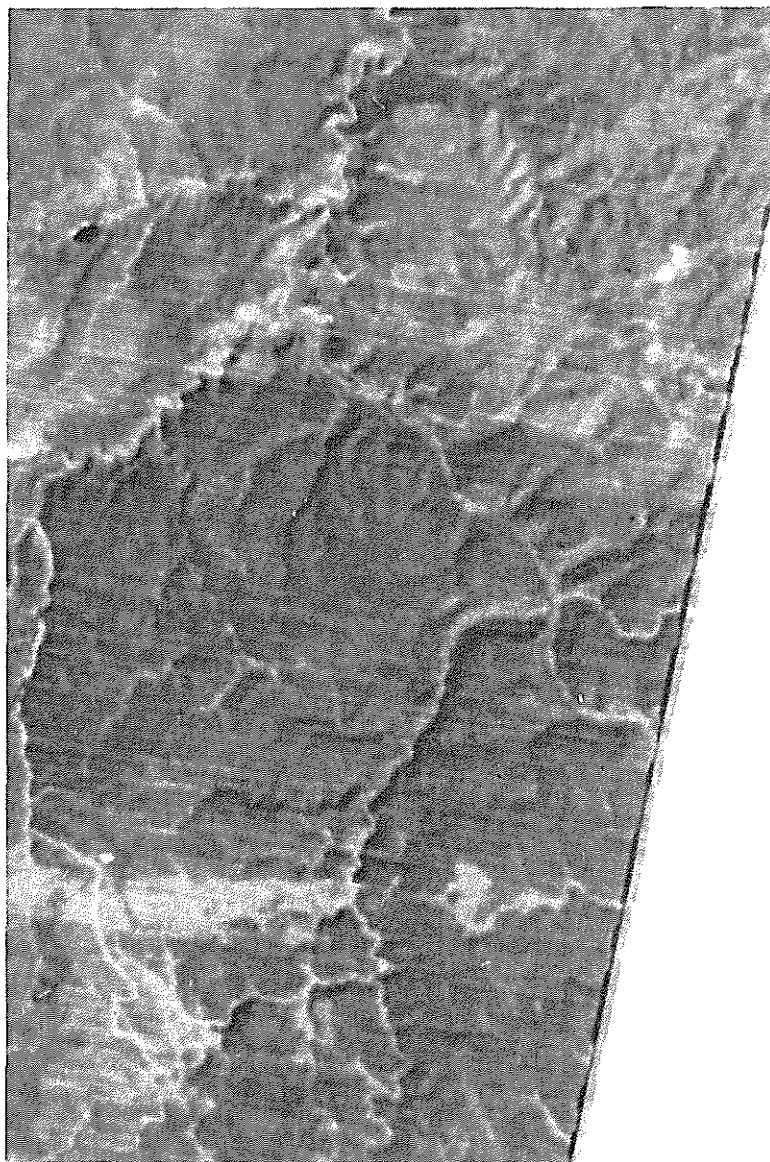


Figure 21—The color composite for scene 1047-17175, September 8, 1972, covers the Spearfish Canyon block of the Black Hills test site. The null area wedge of the scene occupies 18 percent of the block. It was not considered in the computer-assisted analysis. Scale is 1:160,000.

for 1972 and 1973 are shown in *table 15*. These data encompass the period of the ERTS-1 experiment, but only the 1972 mortality could be used in the ERTS data test, because cloud-free ERTS scenes proved unavailable for 1973. Trees which faded during the summer of 1972 were counted on the CIR resource photography taken in early September of that year. These trees had been attacked by the bark beetles the previous summer. Mortality counted for 1973 is therefore the result of infestation during July and August of 1972.

An expanding epidemic is evident in a comparison of the totals in *table 15*. Whereas sub-block 1 had high mortality counts for both 1972 and 1973, a threefold to fourfold increase in mortality is seen in

sub-blocks 2 and 3 from 1972 to 1973. The mortality counts in sub-block 2 for 1973 are conservative—many faded trees were removed by salvage logging during July and August 1973, before the photographs were taken.<sup>6</sup>

Infestations varied greatly between sub-blocks (*fig. 22*). In sub-block 1, in 1972, there was aggregation of smaller prior infestations into several very large infes-

<sup>6</sup> A detailed report, *Ponderosa Pine Mortality from Mountain Pine Beetle: Photointerpretation Prediction Model* by Thomas H. Waite is available on request to Director, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, California 94701.

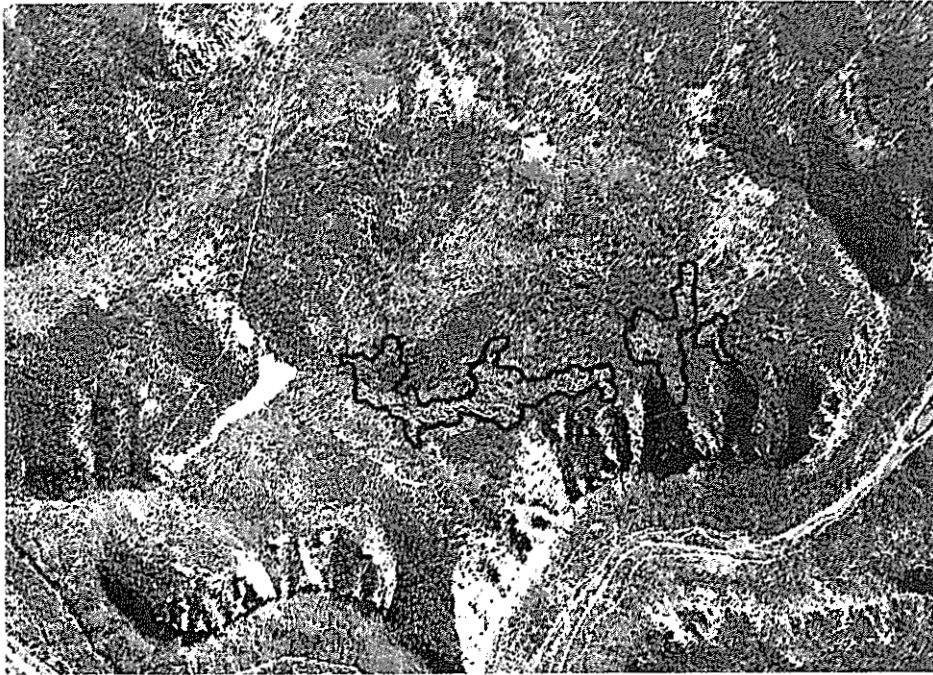


Figure 22—Infestation spots on the two intensive study sites were identified on September 1972 color infrared aerial photographs, scale 1:32,000. Sub-block 1 contained 14 infestation spots greater than 50 m in the longest dimension. Two of the largest spots were in the southwest corner of the sub-block (*top*). Sub-block 2 contained 56 identifiable spots, most of them less than 50 m long. Some of these are shown in the photo (*bottom*) of the southwest corner of the block. The 1973 photography showed aggregation of many of these small spots into infestations more than 50 m long.

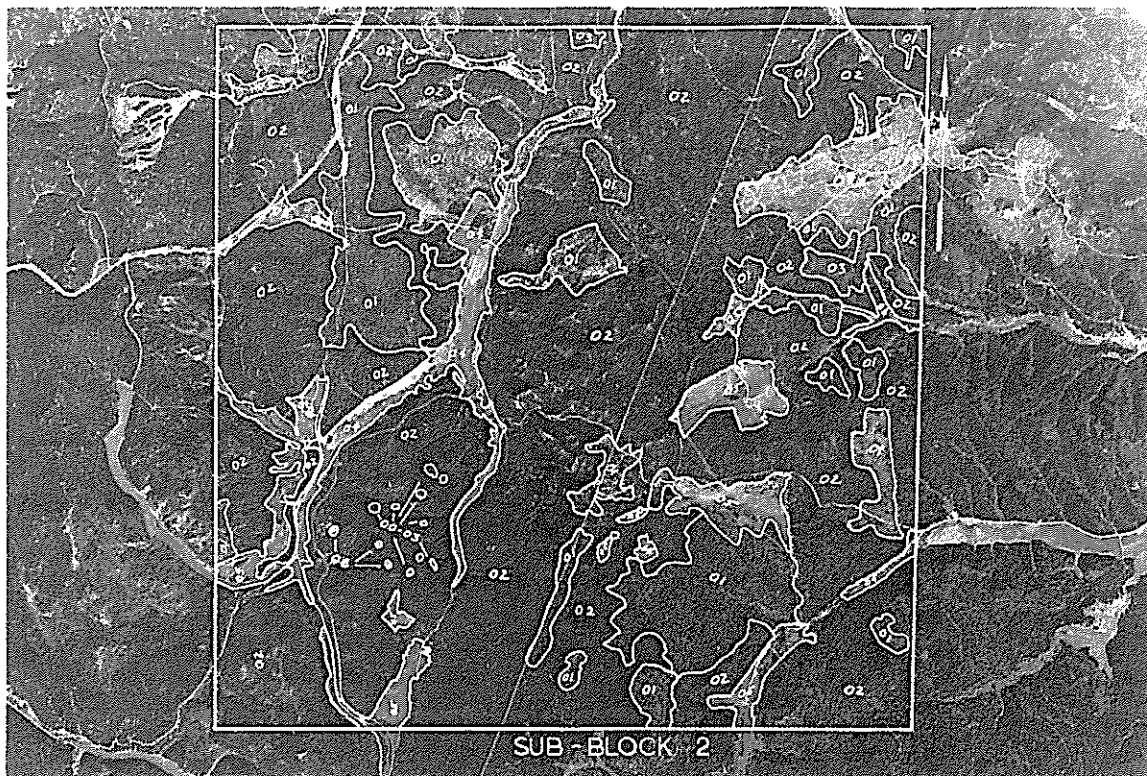


Figure 23—A cover type map was drawn for sub-block 2 from 1:32,000 color infrared resource photographs taken September 8, 1972. Scale is 1:70,000.

tation centers. By contrast, most of the numerous infestation spots in sub-block 2 were less than 50 m (165 ft) in size in 1972. With an expanding epidemic of the mountain pine beetle in the area of sub-block 2, the 1973 resource photographs revealed considerable aggregation of the smaller spots, so that many infestations over 50 m were created (*table 15*).

From the CIR photography for 1972, sample points representing each of the nine cover-type classes shown in *table 13* were selected from the entire test site for the ERTS photointerpretation test. Sample point choice was based on the availability of the area for ground check, distribution of the samples throughout the study area, and distinctiveness of the sample point with respect to the surrounding landscape. A map was prepared in the form of an acetate overlay showing the sample points as microdots.

For use as a basis for evaluation of the computer-assisted mapping, a type map (*fig. 23*) was drawn using the nine cover type classes (*table 13*). The type maps for the three sub-blocks were first drawn on acetate overlays using the 1:32,000-scale CIR resource photographs. Distortions in the original type map were rectified by superimposing a 1:110,000-

scale color infrared transparency, taken by NASA on September 14, 1972, onto the first type map, using the Zoom Transfer Scope. The final type map thus had good geometric fidelity and positional accuracy.

### ***Radiance Data Collection***

An important part of the Black Hills study was an attempt to monitor information as received by ERTS, through data transmission from the ground to the satellite. These experiments are briefly described here.

#### **Procedures**

A ground-based data-collection system was installed within sub-block 2 (*fig. 19*) in the northern part of the Black Hills. Four subsites, one each in healthy ponderosa pine, dead pine, pasture grass, and rock outcrop, were selected within range of three ERTS data collection platforms (DCP's). Each DCP included a transmitter and antenna to transmit biophysical and environmental measurements directly to the ERTS satellite when it was within receiving range of the test site. Under the control of NASA, data were

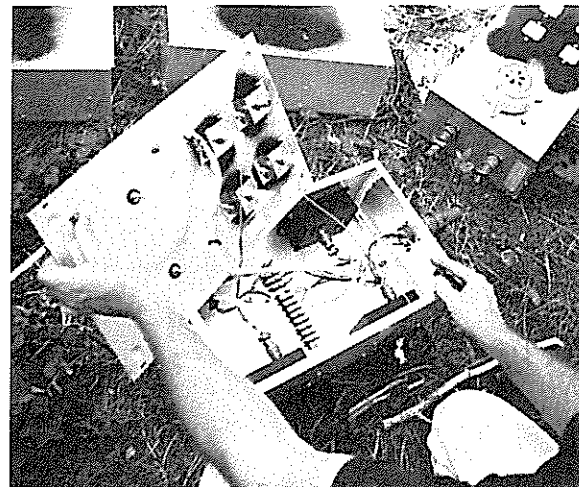


Figure 24—Instruments and equipment for the data collection experiments were set up at four sites within sub-block 2. Shown at the top of the tower (*left*) are the data collection platform (DCP), antenna, incident-energy spectrometer, multiplexer, and light-activated switch. At the end of the 4-m boom arm is the reflected-energy spectrometer. Alkaline battery power packs are at the base of the tower. The interior of a field spectrometer is shown at *right*.

retransmitted from the satellite to a ground station. The nature and scope of this paper does not permit a lengthy discussion of the instrumentation used at the site; however, it is sufficient to say that the entire system allowed collecting continuous data from 24 separate instruments at each of the DCP's.

The most important biophysical and environmental measurement in terms of ERTS data analysis was absolute target reflectance or scene radiance. To measure scene radiance, five spectrometers (*fig. 24*) were built as reported by Weber, 1973. The spectrometers operated in four spectral bands matching the ERTS-1 multispectral scanner subsystem. One of these units was set up to monitor radiance reflected from healthy pine. These data are discussed here. The remaining spectrometers were set up to monitor dead pine, pasture grass, rock outcrop, and irradiance incident on the scene. These data were either extremely variable or were irrelevant to the discussion that follows and will not be considered further in this paper.

The configuration for a data collection system operating independently at one subsite is shown in *figure 24*. A DCP and antenna are located at the top of the tower along with a spectrometer and light activated switch which limited data collection and transmission to daylight hours. Because there were only three transmitters to handle five subsites, data from pasture, rock outcrop, and incident-energy spectrometers were multiplexed through one DCP. Data

from all the spectrometers were relayed via the NASA Data Processing Facility (NDPF) at Greenbelt, Maryland and then to Berkeley.

One question that this experiment was required to answer was, "What effect does the earth's atmosphere have on radiance measured by the ERTS MSS?" Since, in this experiment the field spectrometers were mounted just above the trees, radiance reflected from the forest and measured by these spectrometers is not affected by the intervening atmosphere. Thus, a comparison of the radiance measurements from the field spectrometers and from the ERTS-1 multispectral scanners should show the effects of atmosphere on radiance transmissions.

To compare the radiance data from ground spectrometers with radiance data from orbital altitude, it was necessary to locate uniform targets that could be found on the ERTS CCT's. For this we felt that healthy pine forest with a closed canopy was the most homogeneous of all the target types used in the experiment. Thus, with the aid of aerial photographs and computer display of the data, the sample areas were selected from the CCT's for scene 1028-17121, August 1972. The mean and standard deviation of the count values for nine data points from each of three sample areas were calculated for each MSS channel (*table 16*). These means were pooled and converted to radiance values (*table 17*) so that these could be compared to radiance data collected on the ground.

Table 16—Multispectral scanner mean count values<sup>1</sup> for closed-canopy pine type taken from computer-compatible tape printouts of ERTS-1 image 1028-17121, August 1972

| Sample no. | MSS 4 |      | MSS 5 |      | MSS 6 |      | MSS 7 |      |
|------------|-------|------|-------|------|-------|------|-------|------|
|            | Mean  | S.D. | Mean  | S.D. | Mean  | S.D. | Mean  | S.D. |
| 1          | 16.9  | 0.8  | 11.2  | 1.1  | 23.7  | 1.4  | 13.4  | 1.0  |
| 2          | 16.3  | .5   | 11.3  | .5   | 24.8  | 1.0  | 13.9  | .9   |
| 3          | 17.1  | .3   | 11.2  | .7   | 24.1  | 2.1  | 13.4  | 1.7  |

<sup>1</sup>Means and standard deviations derived from nine data points for each sample.

The ground radiance data was collected for four clear days as closely representative as possible of the dates when the ERTS data was collected, and at the same time of day.

### Results and Discussion

When the radiance values for pine forest from ERTS-1 data are compared with radiance values for healthy pine measured just above tree tops (table 18), some effects of the atmosphere become apparent. For MSS channel 4 there is a 50 percent increase in the radiance when measured from ERTS-1 as compared to the ground. This is probably the result of back-scattered solar irradiance and scattering into the view path of radiance from other parts of the scene. At the longer spectral wavelengths of MSS channel 5, the scattering is less, as indicated by a 30 percent increase when ERTS-1 measured radiance is compared with ground-measured radiance. The relatively low ground radiance values in spectral bands MSS 4 and MSS 5 made any radiance scattered into the view path more significant in terms of percent increase.

By contrast, spectral bands MSS 6 and MSS 7 have reduced radiance at orbital altitudes as compared

Table 17—Radiance reflected from healthy pine as measured by ground spectrometer<sup>1</sup> for four clear days in September 1973 at the time of day when the ERTS-1 scene used in this study was imaged.

| Date     | Radiance <sup>1</sup>      |        |        |        |
|----------|----------------------------|--------|--------|--------|
|          | MSS 4                      | MSS 5  | MSS 6  | MSS 7  |
|          | — mw/cm <sup>2</sup> -sr — |        |        |        |
| Sept. 18 | 0.2195                     | 0.1200 | 0.3888 | 1.1935 |
| Sept. 22 | .2195                      | .1321  | .4206  | 1.2722 |
| Sept. 27 | .2195                      | .1276  | .4111  | 1.2128 |
| Sept. 29 | .2151                      | .1350  | .4206  | 1.2474 |
| Mean     | .2184                      | .1287  | .4103  | 1.2315 |

<sup>1</sup>Radiance shown for each day is an average of five to nine separate measurements.

with ground measurements. A 17 percent reduction is revealed for MSS 6 and a 20 percent reduction for channel MSS 7. At the longer wavelengths of these spectral bands, scattering is not an important factor, so there is little stray radiance to be added to the view path. Absorption by the intervening atmosphere becomes the dominant factor operating on the radiance as measured from ERTS-1.

For a feature such as closed-canopy pine forest, the effect of atmosphere on radiance measurement from ERTS is to increase the apparent radiance in bands MSS 4 and MSS 5 and to decrease the apparent radiance of the feature in bands MSS 6 and MSS 7.

A number of unanticipated problems arose during this experiment, some of which could be resolved and some that could not. Since the measurement of biophysical and environmental conditions is important to successful evaluation of multispectral data, some of these problems should be mentioned for consideration in planning future research.

Most important is the calibration of field spectrometers. Unless calibrations are checked periodically during the course of an experiment, there can be errors in the data that cannot be corrected. For instance, the spectrometer units used in this experiment were calibrated September 1, 1973 before being placed in the field. The calibration was checked again in April, 1974 after the instruments were returned from the field. For several of the individual channels, the system calibration had changed very significantly (table 19) and makes the spectral data suspect if not collected close to calibration. Since the data used in the radiance comparisons in this paper were collected close to the calibration date, these data are assumed to be correct. Because of the lack of baseline data on many of the components, it is not possible to deter-

Table 18—Comparison of radiance values from ERTS tapes for scene 1028-17121, August 1972, and radiance values collected on the ground 1 year later (September 1973)

| MSS Band | Mean radiance                           |        | Difference |     |
|----------|-----------------------------------------|--------|------------|-----|
|          | ERTS <sup>1</sup>                       | Ground |            |     |
|          | — mw/cm <sup>2</sup> -sr <sup>2</sup> — |        | Percent    |     |
| 4        | 0.33                                    | 0.22   | +0.11      | +50 |
| 5        | 0.18                                    | .13    | +.05       | +38 |
| 6        | 0.34                                    | .41    | -.07       | -17 |
| 7        | 0.99                                    | 1.23   | -.24       | -20 |

<sup>1</sup>Count averages in Table 16 were converted to radiance values.

<sup>2</sup>Milliwatts per square centimeter of source area per steradians of unit solid angle.

Table 19—Relative response of the ground-based spectrometers for each scanner (MSS) channel, determined by calibration before placement in field use and after return from field use

| Spectrometer | Relative response |       |       |       |
|--------------|-------------------|-------|-------|-------|
|              | MSS 4             | MSS 5 | MSS 6 | MSS 7 |
| RS-2M-1      |                   |       |       |       |
| Before       | 0.89              | 1.88  | 2.04  | 1.69  |
| After        | 0.93              | 2.16  | 2.66  | 2.13  |
| RS-2M-2      |                   |       |       |       |
| Before       | 0.88              | 1.79  | 2.16  | 1.75  |
| After        | 1.59              | 4.13  | 1.79  | 1.82  |
| RS-2M-5      |                   |       |       |       |
| Before       | 0.56              | 0.38  | 0.43  | 0.31  |
| After        | 0.12              | 0.16  | 0.20  | 0.12  |

mine in each case the cause of the change in system response. However, it appears that much of the change can be traced to deterioration of the spectral bandpass filters. These filters, made of sandwiched combinations of interference and absorption filters, were not adequately edge-sealed by the manufacturer to withstand the field environment.

Another problem that cannot be resolved with the instrumentation used in this experiment is the effect of target size. In most instances, the ground spectrometers were located above single trees or small targets representing various condition classes. On the other hand, the satellite imagery data points integrate approximately one acre. Variation in radiance within one acre can be considerable in some classes and the integration of radiance values may not represent the same small target integrated by the ground spectrometer. In the closed-canopy pine type the variation within an acre may be minimized and this is why we chose to use this type for our evaluation of ERTS radiance values.

Despite the problems, we derived useful radiance data from the study. In future work with satellite data, adjustments can be made for errors in satellite radiance values when the radiance levels on the computer-compatible tapes are analyzed. By this means, information can be gained leading to improvements in computer-assisted classification of land use.

### Photointerpretation Procedures

Three visual interpretation methods were used to analyze the ERTS-1 imagery. In the first, the interpreter classified the cover types on both the color composites and the black-and-white single-channel images (scale 1:1,000,000). For the second, the inter-

preter used only the bulk color composites to detect disturbances. For the third approach, a team of foresters from the Black Hills National Forest viewed color composites projected on a wall screen, and identified both disturbances and ecological site classes.

In the first approach, an interpreter viewed the transparencies with a Bausch and Lomb Zoom 70 microscope mounted on a Richards light table. A viewing scale of 1:83,000 (determined as the optimum obtainable with all instruments) was achieved by means of 10X eyepieces and a 1.2:1 zoom ratio. The interpreter identified the cover type classes at sample points indicated on the acetate overlay previously prepared from aerial photography. Neither of the two ERTS scenes used for the test covered the entire test site free of clouds. If a sample area was not covered on the ERTS imagery or was obscured by clouds, it was not considered in the analysis of interpretation results.

In a second viewing, the interpreter used a Variscan rear-projection viewer, scanning the image at a magnification ratio of 3:1 or 1:333,000-scale. As each sample point was identified, the magnification ratio was changed to 12:1 to give the scale of 1:83,000.

For the second interpretation approach, the interpreter was joined by two district rangers. Using the Zoom 70 as described above, they scanned the color composites and identified any type of disturbance within the test site, including bark beetle infestations, classifying it at Level III within the Level II Transition class (table 13). The interpreters relied mainly on deduction in classifying disturbances, although some identifications were probably made on the basis of knowledge of the existence of disturbed areas.

For the third approach, perhaps the most productive, a team was made up of two Forest Service researchers who are working in the Black Hills, two members of the Black Hills National Forest planning team, and the author-interpreter. The ERTS image was projected on a screen with an overhead projector at a viewing scale of 1:83,000. (A rear-projection viewer with a large screen, such as the Variscan, could also be used.) The team was instructed to first identify the cover type sample points and then proceed with a full interpretation of the scene. The only restrictions were that interpretation be limited to the Black Hills National Forest and that the classification system (table 13) be used. All disagreements in classification among the members of the team were resolved by reference to the 1:32,000- and 1:110,000-scale resource photography.

## **Computer-Assisted Mapping Procedures**

Although mountain pine beetle infestation spots were small in relation to the resolution of the ERTS multispectral scanner, we hoped to achieve a measure of success in mapping dead and dying pine trees through analysis of the computer-compatible tapes (CCT's). Statistical analysis of spectral characteristics can often yield results unavailable to an interpreter through image viewing alone.

To analyze the two ERTS scenes we had available (late August and early September 1972) we used two different computer classification systems—one devised by the PSW group and the other devised by our contractor, LARS. The two groups worked independently toward the same goals, and their results were compared for accuracy of classification and for the utility of the resulting maps.

General but nonrestrictive guidelines were offered to both groups. The minimum classification suggested for the Black Hills was the selected nine classes shown in *table 13*, but PSW and LARS were encouraged to attempt application of the full hierarchy while maintaining accuracy. A uniform color display of 1:32,000 scale was suggested; the actual scale used was 1:24,000.

The computer-assisted classification and mapping capability developed by PSW and LARS is described elsewhere in this report (see p. 16 and Appendix 2). Adaptations were made for classification of the Black Hills ERTS-1 scenes. The computer training materials provided were detailed type maps of the three sub-blocks. Computer coordinates for the corners of the blocks and the sub-blocks were also provided. The classification system developed on the sub-blocks was tested on the two large blocks—Lead and Spearfish Canyon.

Computer-assisted classification results for the Black Hills test site were evaluated by means of a grid system overlay based on computer-coordinate intersections (see *page 17*). The starting point for the grid was critical: it had to be a location that could be pinpointed for both blocks and on computer displays for both LARS and PSW. A suitable starting point for each block was found, and the grid intersections were laid out at intervals of six rows and six columns of pixels. The intent was to create a cell, or matrix, of 9 pixels, focused at each grid intersection, and surrounded by a buffer zone, 1 pixel wide, to allow for positional inaccuracies of the ERTS-1 data. As constructed, the grid with the 9-pixel cells permitted a possible 25 percent sample for performance evalua-

tion of the entire block. Cells were selected for the evaluation only if they were determined to occupy an area of pure cover type. To make this determination, a carefully scaled reproduction of the computer grid was placed over the 1:110,000-scale color infrared resource transparencies. The cover type of each of the 17,000<sup>+</sup> cells was determined on the photographs, and those cells of pure cover type were selected. The cell classification determined from the photographs was compared with the classification for the same cells on the LARS and PSW outputs. A cell was considered correctly classified if five or more pixels were correct. The cell was called incorrect if five or more elements were placed in a single but incorrect cover type class. The cell was called mixed and incorrect if there was no majority classification of pixels within the cell.

## **Results and Discussion**

### **Photointerpretation**

Quantitatively, there were only minor differences in the interpretation results between ERTS black-and-white transparencies and the color composite transparencies. Interpretative method and viewing instrument did not noticeably affect results. The significant difference was that the bulk color composite transparencies could be interpreted more quickly. They took up only 20 percent of the time needed for the four individual black-and-white transparencies for the same scene. The expectation in using the black-and-white transparencies had been that their better resolution of the individual images might allow better detection, and that mountain pine beetle infestations might be detectable on the red band image, whereas they might be masked in the color composite. Infestations were not detected, however, regardless of image product or method of interpretation. For example, sub-block 1 contained several infestations over 300 meters (984 ft) in longest dimension (*fig. 22*) which were never detected on ERTS imagery.

In the first of the three interpretative approaches, interpreters classified cover types. The classification results using both the Zoom 70 microscope and the Variscan viewer were the same—41 correct out of 63 sites for a total of 65 percent. All sample areas for three of the nine cover types—Wet Pasture, Bare Soil, and Water—were interpreted correctly. Poorest results were in the classification of Hardwood and Dry Pasture, which were correctly identified only 20 percent of the time. Each time a Hardwood or Dry Pasture site was classified incorrectly, it was called Wet Pasture. Although Conifer sites were identified correctly

100 percent of the time at Level II in the hierarchical system, attempts at separation based on stand density (Level III) introduced 50 percent commission errors. That is, half of the total Pine sites were placed in the wrong density class.

Based on these results, one could expect to do a near-perfect job of classifying the Black Hills cover types on ERTS-1 color composites if stratification is limited to 5 classes: Conifer, Grassland (including Deciduous Vegetation), Bare Soil and Rock, Water, and Transition. The Variscan rear-projection viewer was preferred by the interpreters over the Zoom 70 microscope, although the results were the same.

In the second approach, detection of disturbances was attempted. A total of 30 major disturbances were identified and their boundaries delineated by the three interpreters, independently. The interpretive expertise of the two district rangers was evident in their ability to identify the cause of the disturbance without reference to management records.

The 30 disturbances clearly visible on ERTS imagery and delineated by three separate interpreters were as follows: (1) fires, 18; (2) logging, 3; (3) tornado damage, 3; and (4) disturbance from multiple causes, 6. Unexpectedly, the interpreters clearly delineated timber sale boundaries of active logging areas. These areas were not clearcuts, but pine stands thinned from about 21.8 m<sup>2</sup> (235 sq ft) of basal area to about 7.4 m<sup>2</sup> (80 sq ft). The thinned areas had a distinct bluish gray tone (high response on MSS channel 4) on the ERTS color composites. This level of interpretation might occur if the interpreters are experienced in the area, but it is doubtful that others would consistently identify active logging areas (other than clearcut areas).

Records showed that three of the disturbances correctly identified as caused by fire had occurred before 1900. (The oldest fire boundary, clearly identified on ERTS-1 scene 1028-17121, was the Polo fire which occurred on the Nemo District in 1890.)

In the team approach to interpretation, we discovered that the definition lost in the image display by an overhead projector was more than compensated for by the team interaction.

At Level II, the team correctly interpreted Conifer Forest, Grassland, Bare Soil, and Water 100 percent of the time. Transition and Urban classes were interpreted correctly 83 and 50 percent of the time, respectively, whereas only 20 percent of the Deciduous Forest sample areas were correctly identified.

It was difficult to rate the team results at other levels, but team members were confident that most of the Level III units in the classification hierarchy

could be identified throughout the forest. A notable exception was deciduous vegetation, although on-the-ground experience of one or more of the interpreters usually resulted in an accurate classification. The interpreters felt that results would have been better if a winter scene had been available for viewing with the summer images.

There were obvious benefits in the multidisciplinary representation in the team. For example, a forester and a geologist working together decided that deciduous vegetation in an old burn area coincided very well with boundaries of a particular soil type. The balance of the burn had revegetated to ponderosa pine over a different soil type.

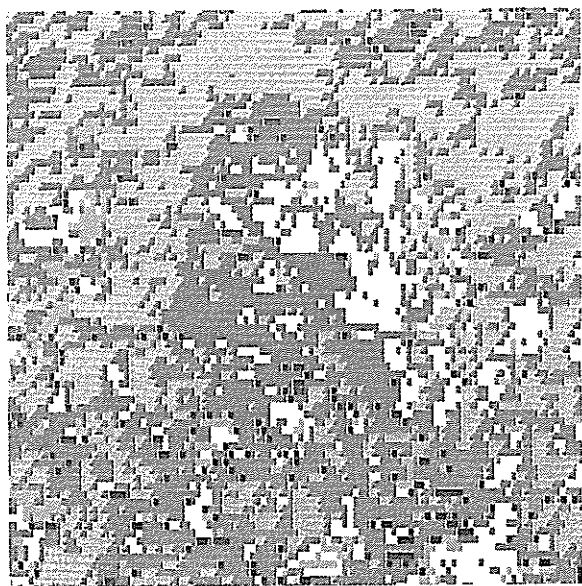
### Computer-Assisted Mapping

The results of computer classification from the sub-blocks were expected to be good, as these sub-blocks were used in training the computer. The larger blocks were classified by extension of signatures developed for the sub-blocks, and less accurate classification results might be expected.

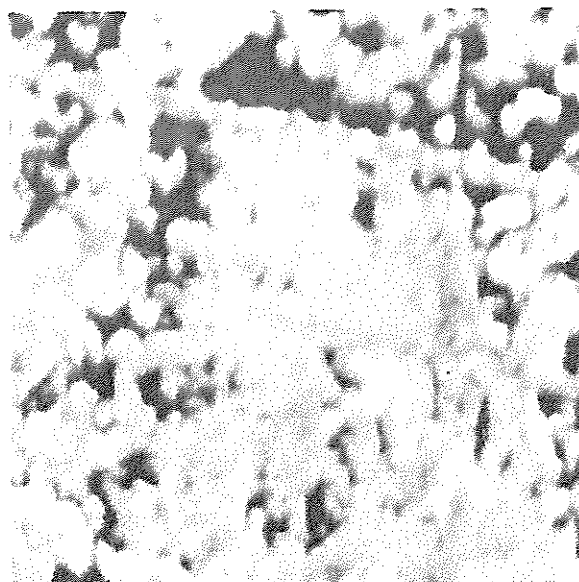
The classification maps of LARS and PSW (*fig. 25*) may be compared to the ground truth map for sub-block 1. The displays differ in quality mainly because the PSW classification map is the product of a multicolor pen plotter whereas the LARS map comes directly from a photo printer display. Although the LARS color photo map is difficult to use, the actual results of the classification as taken from output of the 1:24,000-scale rectified line printer are more readable (*fig. 26*).

In assessing the classification performance for sub-block 1 (see *table 20*) our focus is on the classification of dead beetle-killed pine. Sub-block 1 contained the largest infestation and the highest number of dead trees in 1972 (*table 15*). The LARS classification did not identify any dead pine. Although the PSW results show 3 percent of the cover type in Dead Pine, a careful assessment of each pixel classified as Dead Pine showed no coincidence with the ground truth classification. Thus, we must conclude that in this test, computer-assisted processing of ERTS-1 multispectral scanner tapes was *not* successful in detecting mountain pine beetle stress in the Black Hills ponderosa pine ecosystem.

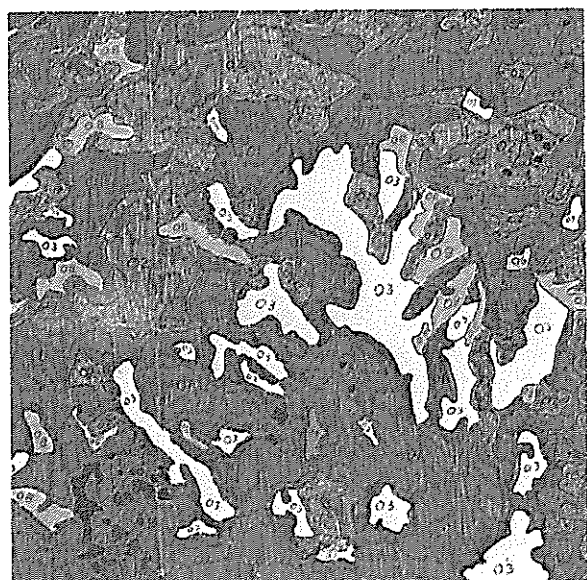
Computer-assisted classification maps for sub-block 2 may be compared with the ground truth map (*fig. 27*). In contrast to sub-block 1, which contained the large infestations, sub-block 2 contained only small spots, which we did not expect the computer to detect (see *fig. 23* for an aerial photograph of sub-block 2, and *fig. 22* for location of the mountain pine



PSW (Berkeley) Computer Map



LARS (Purdue Univ.) Computer Map

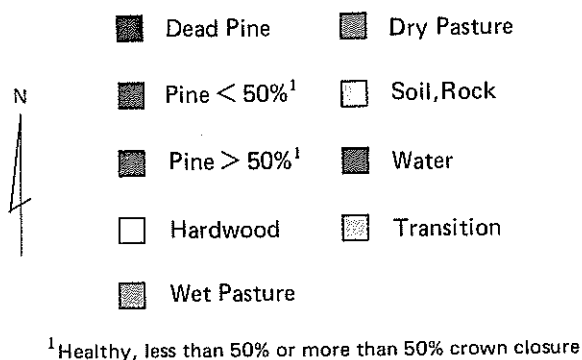
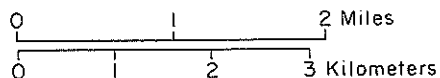


PSW Ground Truth Map Black Hills, S.D. Sub-block 1

Data source:

1:32,000 CIR photo by PSW, Sept. 8, 1972

Classified by photointerpretation and ground checks



#### Computer maps

Data source:

System-corrected CCT's for ERTS-1 scene  
1047-17175, Sept. 8, 1972, spectral bands  
4, 5, 6, 7

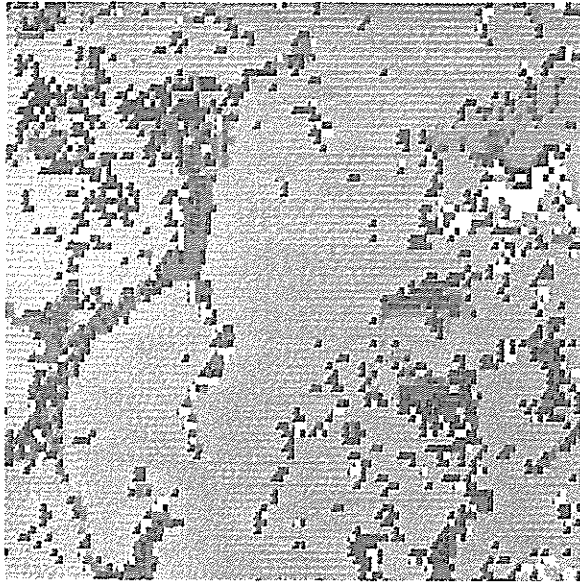
Classification method:

PSW—nearest neighbor procedure  
LARS—maximum likelihood theory  
(Gaussian statistics)

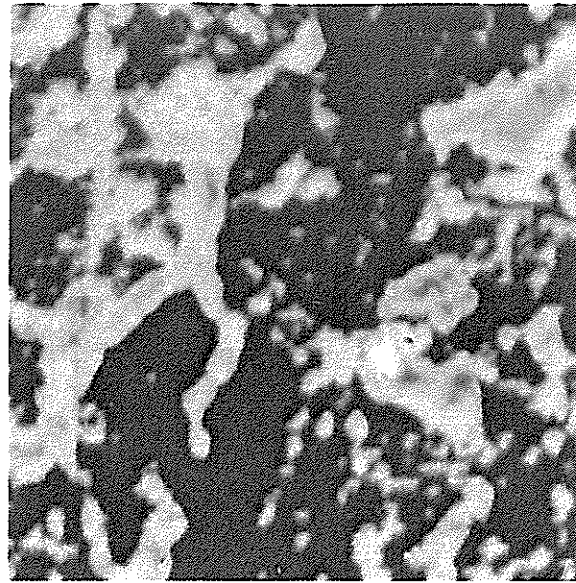
Figure 25—The results of computer-assisted classification are shown here for sub-block 1, along with the ground-truth map for comparison. The PSW classification display (made with eight color pens) was used for the classification performance evaluation. The LARS map, photographed from the digital display unit, was not suitable for the performance evaluation; the line-printer output shown in figure 26 was used instead.



Figure 26--The LARS computer-assisted classification of the Spearfish Canyon block covered sub-block 1 and 96 percent of sub-block 3 at a scale of 1:24,000. The small squares are the 186 nine-element cells selected from the aerial photographs as representing pure cover type, for evaluation of classification performance. One of these units, *right*, is enlarged to show the computer symbols used to represent the classification categories.



PSW (Berkeley) Computer Map



LARS (Purdue Univ.) Computer Map

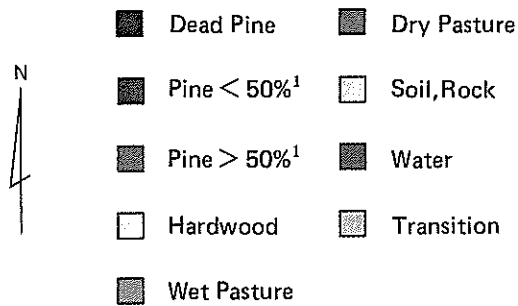
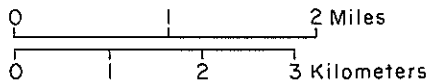


PSW Ground Truth Map Black Hills, S.D. Sub-block 2

Data source:

1:32,000 CIR photo by PSW, Sept. 8, 1972

Classified by photointerpretation and ground checks



<sup>1</sup> Healthy, less than 50% or more than 50% crown closure

#### Computer maps

Data source:

System-corrected CCT's for ERTS-1 scene  
1028-17121, Aug. 20, 1972, spectral bands  
(PSW) 4,5,6,7 (LARS) 5,6,7

Classification method:

PSW—nearest neighbor procedure  
LARS—maximum likelihood theory  
(Gaussian statistics)

Figure 27—The results of computer-assisted classification are shown here for sub-block 2, with the ground truth map for comparison. As for sub-block 1, the PSW display was used for the classification performance evaluation but the LARS map was not; instead, the line-printer output for the sub-block was used. The cluster of infestation spots shown in the lower left corner of the ground truth map correspond to the small infestation spots shown in the center of the photograph of sub-block 2 in figure 22.

Table 20—Computer-assisted classification performance by PSW and LARS as compared with ground truth, for the ERTS data covering three intensive study sites (sub-blocks) within the Lead and Spearfish Canyon blocks

| Sub-block, classification level, and cover type | Ground truth |         | PSW  | LARS |
|-------------------------------------------------|--------------|---------|------|------|
|                                                 | Hectares     | Percent |      |      |
| Sub-block 1 (III):                              |              |         |      |      |
| Dead ponderosa pine                             | 55.3         | 1.4     | 3.1  | 0    |
| Pine, healthy, < 50% <sup>2</sup>               | 2290.6       | 58.0    | 47.4 | 29.6 |
| Pine, healthy, > 50% <sup>2</sup>               | 916.2        | 23.2    | 33.1 | 36.2 |
| Hardwood, < 25% pine                            | 501.5        | 12.7    | 11.4 | 8.5  |
| Wet pasture                                     | 7.9          | 0.2     | 0    | 4.5  |
| Dry pasture                                     | 3.9          | 0.1     | 0    | 7.0  |
| Sub-block 1 (II)                                |              |         |      |      |
| Conifer                                         | 3262.1       | 82.6    | 83.6 | 65.8 |
| Deciduous                                       | 501.5        | 12.7    | 11.4 | 9.5  |
| Grassland                                       | 11.8         | 0.3     | 0    | 11.5 |
| Bare soil, rock                                 | 15.8         | 0.4     | 0    | 7.0  |
| Transition                                      | 158.0        | 4.0     | 5.0  | 6.2  |
| Water                                           | 0            | 0       | 0    | 1.0  |
| Sub-block 2 (III):                              |              |         |      |      |
| Dead ponderosa pine                             | 8.3          | 0.2     | 0    | 0    |
| Pine, healthy, < 50% <sup>2</sup>               | 666.9        | 16.1    | 12.7 | 26.0 |
| Pine, healthy, > 50% <sup>2</sup>               | 2924.3       | 70.6    | 72.9 | 62.8 |
| Hardwood, < 25% pine                            | 29.0         | 0.7     | 3.7  | 1.0  |
| Wet pasture                                     | 149.1        | 3.6     | 4.1  | 3.6  |
| Dry pasture                                     | 248.5        | 6.0     | 2.8  | 1.8  |
| Sub-block 2 (II):                               |              |         |      |      |
| Conifer                                         | 3599.5       | 86.9    | 85.6 | 89.7 |
| Deciduous                                       | 29.0         | 0.7     | 3.7  | 1.0  |
| Grassland                                       | 397.6        | 9.6     | 6.9  | 5.4  |
| Bare soil, rock                                 | 4.1          | 0.1     | 0    | 0.1  |
| Transition                                      | 111.8        | 2.7     | 3.8  | 3.4  |
| Cloud                                           | —            | —       | 0    | 0.1  |
| Shadow                                          | —            | —       | 0    | 0.3  |
| Sub-block 3 (III):                              |              |         |      |      |
| Dead ponderosa pine                             | 4.1          | 0.1     | 0    | 0    |
| Pine, healthy, < 50% <sup>2</sup>               | 964.7        | 23.6    | 22.6 | 12.9 |
| Pine, healthy, > 50% <sup>2</sup>               | 2673.2       | 65.4    | 71.2 | 69.7 |
| Hardwood, < 25% pine                            | 4.1          | 0.1     | 0    | 0.1  |
| Wet pasture                                     | 61.3         | 1.5     | 2.5  | 1.8  |
| Dry pasture                                     | 32.7         | 0.8     | 0    | 2.6  |
| Sub-block 3 (II):                               |              |         |      |      |
| Conifer                                         | 3642.0       | 89.1    | 93.8 | 82.6 |
| Deciduous                                       | 4.1          | 0.1     | 0    | 0.1  |
| Grassland                                       | 94.0         | 2.3     | 2.5  | 4.4  |
| Bare soil, rock                                 | 0            | 0       | 0    | 3.0  |
| Transition                                      | 163.5        | 4.0     | 3.7  | 3.5  |
| Water                                           | 0            | 0       | 0    | 1.0  |
| Null                                            | 183.9        | 4.5     | 0    | 5.4  |

<sup>1</sup>Total area of sub-block 1: 3949.2 ha (9758.6 acres), 2: 4142.0 ha (10,235.1 acres), 3: 4087.5 ha (10,000 acres). 1 ha = 2.47 acres.

<sup>2</sup>Percentage = crown closure.

beetle infestations). Although we found considerable variation between LARS-PSW and ground truth in the classification performance at Level III for sub-block 2 (table 20), there was remarkable agreement at Level II. Allowing for errors in the ground truth determination, especially at Level III, we could judge that classification performance of both systems is reasonably successful at Level II and acceptable at Level III for sub-blocks. For both sub-blocks 2 and 3 (table 20), the PSW system appeared better for classifying cover type density of ponderosa pine.

The results for classification of the blocks by PSW and LARS are shown in table 21. In reconciling the classifications to the ground truth for the Lead block, one must remember that ground truth does not recognize the classes Cloud or Cloud Shadow. Ground truth is derived from aerial photographs in which no clouds appear; in the ERTS-1 imagery, several scattered clouds appear over the block. The area in question is only about 1 percent, however, and its effect on the classification is slight.

The PSW classification of the Lead block showed greater loss of accuracy than the LARS performance, as compared with the sub-block results. In the simple comparison of areas occupied by cover type, the LARS classification agrees well with the ground truth at both Level II and Level III. As in the photointerpretation, confusion existed between deciduous and grassland cover type, and if these were considered one class the performance would be reasonable.

The area classification results for the Spearfish Canyon block (table 21) are a different matter. While the PSW classifier appears to do a better job in identifying ponderosa pine density classes, the overall result is a 10-percent overestimate of conifer type in Level II. Considering the entire Level III classification, neither of the computer systems was good, while the Level II results showed improvement. Again, if the Level II LARS classification had combined deciduous and grassland as one class, the results would have been good.

A check of classification performance was made for the blocks using nine-element computer cells of pure type (fig. 26). Here the pixel-by-pixel correctness of the classification, rather than area estimates, was compared. The performance evaluation (table 22) showed that the LARS classification for the Lead block was 68.8 percent and the PSW 63.2 percent at Level III. For both, the problem appeared to be with the transition cover type. A total of 10.4 percent of all pixels classified in the Lead block were used in this evaluation.

The Level III classification performance for the

Table 21—Computer-assisted classification performance by PSW and LARS compared with ground truth, for the ERTS-1 data covering the Lead and Spearfish Canyon blocks<sup>1</sup>

| Block,<br>classification level,<br>and cover type | Ground truth         | PSW  | LARS |
|---------------------------------------------------|----------------------|------|------|
| Lead block (III):                                 | Hectares — Percent — |      |      |
| Pine, healthy, < 50% <sup>2</sup>                 | 13,420.1             | 32.5 | 32.1 |
| Pine, healthy, > 50% <sup>2</sup>                 | 22,545.8             | 54.6 | 53.3 |
| Hardwood, < 25% pine                              | 1,858.2              | 4.5  | 2.1  |
| Wet pasture                                       | 743.4                | 1.8  | 4.8  |
| Dry pasture                                       | 949.7                | 2.3  | 2.6  |
| Lead block (II):                                  |                      |      |      |
| Conifer                                           | 36,172.4             | 87.6 | 85.4 |
| Deciduous                                         | 1,858.2              | 4.5  | 2.1  |
| Grassland                                         | 1,693.0              | 4.1  | 7.4  |
| Bare soil, rock                                   | 41.3                 | 0.1  | 0.1  |
| Transition                                        | 1,486.5              | 3.6  | 3.9  |
| Water                                             | 41.3                 | 0.1  | 0    |
| Cloud                                             | —                    | —    | 0.6  |
| Shadow                                            | —                    | —    | 0.5  |
| Spearfish Canyon block (III):                     |                      |      |      |
| Dead ponderosa pine                               | 285.2                | 0.8  | 0    |
| Pine, healthy, < 50% <sup>2</sup>                 | 14,793.9             | 41.5 | 20.5 |
| Pine, healthy, > 50% <sup>2</sup>                 | 7,557.4              | 21.2 | 42.5 |
| Hardwood, < 25% pine                              | 2,566.6              | 7.2  | 4.1  |
| Wet pasture                                       | 1,069.4              | 3.0  | 3.6  |
| Dry pasture                                       | 320.8                | 0.9  | 5.2  |
| Spearfish Canyon block (II):                      |                      |      |      |
| Conifer                                           | 22,636.4             | 63.5 | 63.0 |
| Deciduous                                         | 2,566.6              | 7.2  | 4.1  |
| Grassland                                         | 1,390.3              | 3.9  | 8.8  |
| Bare soil, rock                                   | 1,069.4              | 3.0  | 3.0  |
| Transition                                        | 1,425.9              | 4.0  | 3.4  |
| Water                                             | 178.2                | 0.5  | 0.5  |
| Null <sup>3</sup>                                 | 6,380.9              | 17.9 | 17.2 |

<sup>1</sup> Area of Lead block: 41,292.7 ha (102,036.1 acres), Spearfish Canyon: 35,647.7 ha (88,087.0 acres). 1 ha = 2.47 acres.

<sup>2</sup> Percentage = crown closure

<sup>3</sup> Area excluded by the ERTS scene edge.

Spearfish Canyon block was much better than that for the Lead block. Here a total of 8.2 percent of the pixels classified was used in the evaluation. The 80.1 percent correct for LARS and 76.0 percent for PSW is good, even though both systems suffered from commission errors in differentiating conifer cover type density (table 22).

The Level II classification performance for both LARS and PSW was better (table 22), although much more spectacularly so for the Spearfish Canyon block than for the Lead block. A performance of 90 percent or better is very good, but apparently the lack of a good classifier for transition cover type in the Lead block imagery was a great handicap.

## Applications

It appears from the results reported that the usefulness of ERTS-1 imagery is limited to providing information for broad area planning and not for providing specific unit estimates of cover-type acreages. Furthermore, the level of classification for which satisfactory accuracies were obtained has questionable utility for the land planner and forest manager. Undeniably, the synoptic view of the entire Black Hills such as was received for June 22, 1973, can provide something of value otherwise unavailable to the land planner or forest manager. We are, however, uncertain of how far that use extends in providing quantitative information for developing unit plans or impact statements.

Table 22—Computer-assisted classification performance by PSW and LARS based on correct identification of samples, for the ERTS-1 data covering the Lead and Spearfish Canyon blocks

| Block,<br>classification level,<br>and cover type | Number of<br>samples | Percent correct |       |
|---------------------------------------------------|----------------------|-----------------|-------|
|                                                   |                      | LARS            | PSW   |
| Lead block (III)                                  |                      |                 |       |
| Pine, healthy, < 50% <sup>1</sup>                 | 35                   | 71.4            | 63.2  |
| Pine, healthy, > 50% <sup>1</sup>                 | 117                  | 97.4            | 99.2  |
| Hardwood, < 25% pine                              | 12                   | 66.7            | 16.7  |
| Wet pasture                                       | 6                    | 83.3            | 50.0  |
| Dry pasture                                       | 9                    | 66.7            | 77.8  |
| Over-all performance <sup>2</sup>                 | 253                  | 68.8            | 63.2  |
| Lead block (II) <sup>4</sup>                      |                      |                 |       |
| Conifer                                           | 152                  | 99.3            | 96.7  |
| Deciduous                                         | 12                   | 66.7            | 16.7  |
| Grassland                                         | 15                   | 86.7            | 86.7  |
| Bare soil, rock                                   | 2                    | 50.0            | 0     |
| Transition                                        | 72                   | 20.8            | 27.8  |
| Over-all performance                              | 253                  | 74.3            | 71.9  |
| Spearfish Canyon block (III)                      |                      |                 |       |
| Pine, healthy, < 50% <sup>1</sup>                 | 42                   | 45.2            | 76.2  |
| Pine, healthy, > 50% <sup>1</sup>                 | 102                  | 95.1            | 83.3  |
| Hardwood, < 25% pine                              | 27                   | 74.1            | 81.5  |
| Wet pasture                                       | 3                    | 66.7            | 0     |
| Dry pasture                                       | 3                    | 66.7            | 0     |
| Over-all performance <sup>2</sup>                 | 186                  | 80.1            | 76.9  |
| Spearfish Canyon block (II)                       |                      |                 |       |
| Conifer                                           | 144                  | 93.8            | 99.3  |
| Deciduous                                         | 27                   | 74.1            | 81.5  |
| Grassland                                         | 6                    | 100.0           | 0     |
| Bare soil, rock                                   | 4                    | 100.0           | 0     |
| Transition                                        | 4                    | 100.0           | 100.0 |
| Water                                             | 1                    | 100.0           | 0     |
| Over-all performance                              | 186                  | 91.4            | 90.0  |

<sup>1</sup> Percent = crown closure

<sup>2</sup> Over-all performance for Level III was calculated with Bare soil, Transition, and Water classes included.

## Eucalyptus Mortality from Low Temperature

An opportunity arose in February 1973 to apply the ERTS data use techniques to detection of severe stress in the hills of the Oakland-Berkeley area of California. Very large targets of discolored eucalyptus trees (4 km) were available for in mid-December 1972, the San Francisco Bay Area was subjected to a period of extremely cold weather—an average of  $-8^{\circ}$  for 7 days. Eucalyptus trees, which are native to Australia and are not resistant to long periods of freezing temperatures, had been planted by the thousands in the early 1900's along the Oakland-Berkeley hills. By mid-February 1973, the foliage of these trees began to turn yellow. Ground examination revealed that the cambial cells of these now mature trees, which had boles averaging 61 cm (24 inches) in diameter and were 24 to 37 m (80 to 120 ft) tall, had been killed. The vast number of dead trees with highly flammable foliage represented a very dangerous fire situation for residents in the Oakland-Berkeley area.

At this time, the PSW Remote Sensing Research Work Unit was asked to photograph the affected area over the cities of Oakland and Berkeley and the East Bay Regional Park District, and we did so on February 15, 1973, at a scale of 1:12,000.

In some areas along the ridges, the killed eucalyptus stands were as large as 1 by 4 km (0.62 by 2.5 miles); the entire area of killed trees, although not of pure type (*fig. 28*), was about 3 by 30 km (1.87 by 18.7 miles).

In the San Francisco Bay Area, native grassy vegetation changes dramatically from its green winter-time appearance to its yellow and brown appearance in late spring and summer. The change occurs because of a cessation of winter rains. In late spring, the dying eucalyptus foliage appeared very similar to the drying-out native grasses.

We received an ERTS image taken before eucalyptus foliage discoloration occurred (January 2, 1973, scene 1183-18175). The next good image we received was April 22, 1973, scene 1273-18183, taken while the trees were still yellow but the native grasses were still green.

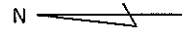
We found we could discriminate the dying timber quite accurately on an ERTS two-date combined image when the stands of timber were over 500 meters (1640 ft). A composite image (*fig. 28A*) from the above two time periods was created on our I<sup>2</sup>S viewer by using a blue filter on the January MSS-7 image and a green filter and red filter on the April MSS-5 and MSS-7 images, respectively.

On the portion of the imagery enlarged to 1:500,000 (*fig. 28B*) features around the Bay Area such as water bodies, bridges, and freeways are identifiable, as well as the extent of the eucalyptus killing. These affected stands of timber were located quite precisely from the 1:12,000 underflight color photography, but the dying eucalyptus were distinguishable from surrounding vegetation on this ERTS enlargement as a distinct reddish brown.

*Figure 28C* shows an enlargement (scale 1:50,000) of the two-date enhanced image of one large eucalyptus plantation about 1 by 4 km (0.62 X 2.5 miles); it is readily detectable at the smaller scale. An enhanced image such as the 1:500,000 enlargement (*fig. 28A*) would be useful for damage assessment in remote areas when catastrophes of this kind occur. In an urban area, however, where millions of dollars for tree removal and fire prevention are to be allocated, a sensor with better resolution, such as medium-scale color photography, is needed.

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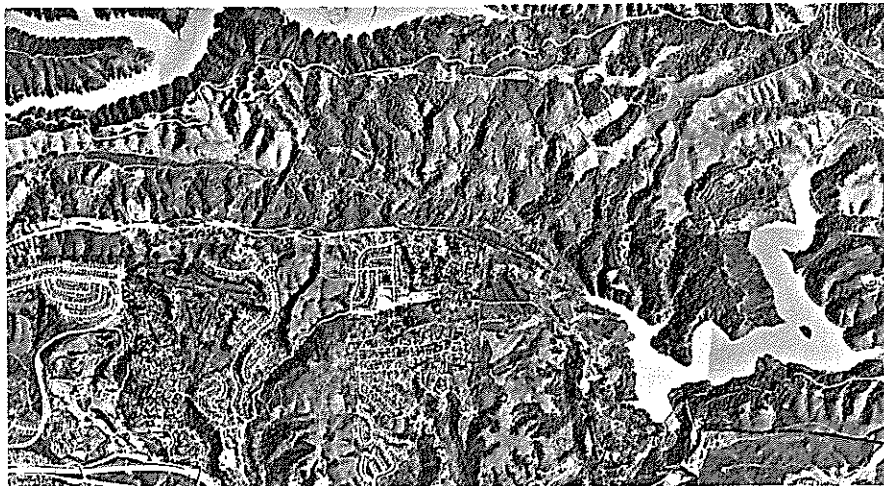
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A



B



C

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Figure 28—Eucalyptus trees killed by prolonged cold temperatures are shown here in two scales on ERTS color composites and on an aerial photograph in natural color. Data from parts of two ERTS scenes (January 23, 1973 and April 22, 1973) were combined to produce an enlarged (1:500,000) color composite (A). The white dashed lines outline the larger pure stands (more than 500 mm) of killed trees, which appear reddish brown on the enhanced print and are distinct from other objects. A further enlargement to approximately 1:50,000 (B) shows a eucalyptus stand near Lake Chabot, Oakland, about 1 by 4 km. A normal color print (C) reduced from an aerial mosaic (1:12,000) to match B shows the affected eucalyptus trees; they appear yellow as compared with the reddish-brown of the ERTS image. The difference in resolution between the ERTS image and the aerial photo is evident here.

## APPENDIX

### 1. Producing Color Composite Internegatives from ERTS Transparencies on an Additive Color Viewer

Richard J. Myhre

Robert W. Dana

A photographic technique was developed to produce standardized ERTS color composite negatives (8 by 10 inches) at a precise scale of 1:1,000,000, on the I<sup>2</sup>S additive color viewer.<sup>7</sup> The object was to control the enhancement and color saturation of the composites by careful monitoring of the light and filter levels within each ERTS band. Also, from large-format color negatives, enlarged color transparencies and prints could be made for the interpreters. The method described can be used by an investigator having access to a four-band additive color viewer (*fig. 29A*). Either two or three MSS bands are combined on the viewer to produce the most satisfactory normal color- or color infrared-appearing composite. Then, the illumination levels for each channel (and color filter combination), as well as total illumination for the composite, are recorded to determine proper film exposure and also for possible recombining of the image at a later time.

The illumination levels are taken with a portable photometer/radiometer built by Forest Service personnel (*fig. 29B*). This instrument consists of a radiometer box powered by batteries or line voltage and a beamsplitter input optics head with detector. The beamsplitter allows reflex viewing of the spot to be measured concurrent to the luminance measurement.

The low light levels being measured and loss in the beamsplitter required high sensitivity. Long-term stability and ease of calibration are also important. To accomplish this a diffused junction silicon diode detector is used, and its output is amplified with an integrated circuit operational amplifier in the current-to-voltage mode. Seven decades of amplification allow measurement ranges of  $10^4$  to  $10^{-2}$  foot-lamberts. The wavelength response curve of the standard observer (photopia) is accurately matched using Wratten 9 and Schott BG-38 filters. Repeated calibration using a standard lamp showed the instrument to be stable to within 1 percent over a period of 1 year.

Through a series of film test exposures, proper exposure time was determined according to the readings obtained with the photometer. A graph was prepared to show the relationship between the composite illumination reading and the required exposure time for the film (*fig. 30*). Assembly of a special timing device was required to handle the short exposure times (less than 1 second) required by the I<sup>2</sup>S illumination in conjunction with the internegative film (*fig. 29D*). A standard timer with 1/10-second increments (Lektra model TM-8, decade interval timer) was purchased and interfaced with a specially built relay system (25-amp relay) and switches that would handle the high amperage requirements of the I<sup>2</sup>S for extremely short intervals. Such a high amperage timer was not readily available on the market.

The I<sup>2</sup>S additive color viewer has a removable screen that can be replaced with an 8- by 10-inch-format film holder. Kodak Ektacolor Internegative film (type 6110) was determined to be best to obtain a color negative image of what appears on the screen. The film is then exposed according to the times computed from the photometer (*fig. 30*).

A special vacuum system for holding the film flat is required to eliminate misregistration because of variations in film flatness within the holder. The vacuum system (*fig. 29C*) consists of an 8- by 10-inch vacuum film holder specially modified to fit the I<sup>2</sup>S screen frame. An inexpensive vacuum source was provided by adapting a vacuum hose to the end of a portable vacuum-cleaner hose and connecting it to the film holder. Excess vacuum was bled off by drilling a series of small holes in the vacuum hose.

Once the internegative film was exposed it was processed in a modified C-22 chemical process consisting of a special internegative developer and normal C-22 chemicals. Several products can be produced from the color negative; color transparencies are made on Kodak Ektacolor Print film (type 4109) or color prints are made on Ektacolor paper. With proper color filtration techniques in the photo lab, color transparencies or prints can be produced that closely resemble the original color-combined image on the I<sup>2</sup>S screen.

<sup>7</sup>International Imaging Systems is now known as Stanford Technology Corporation.

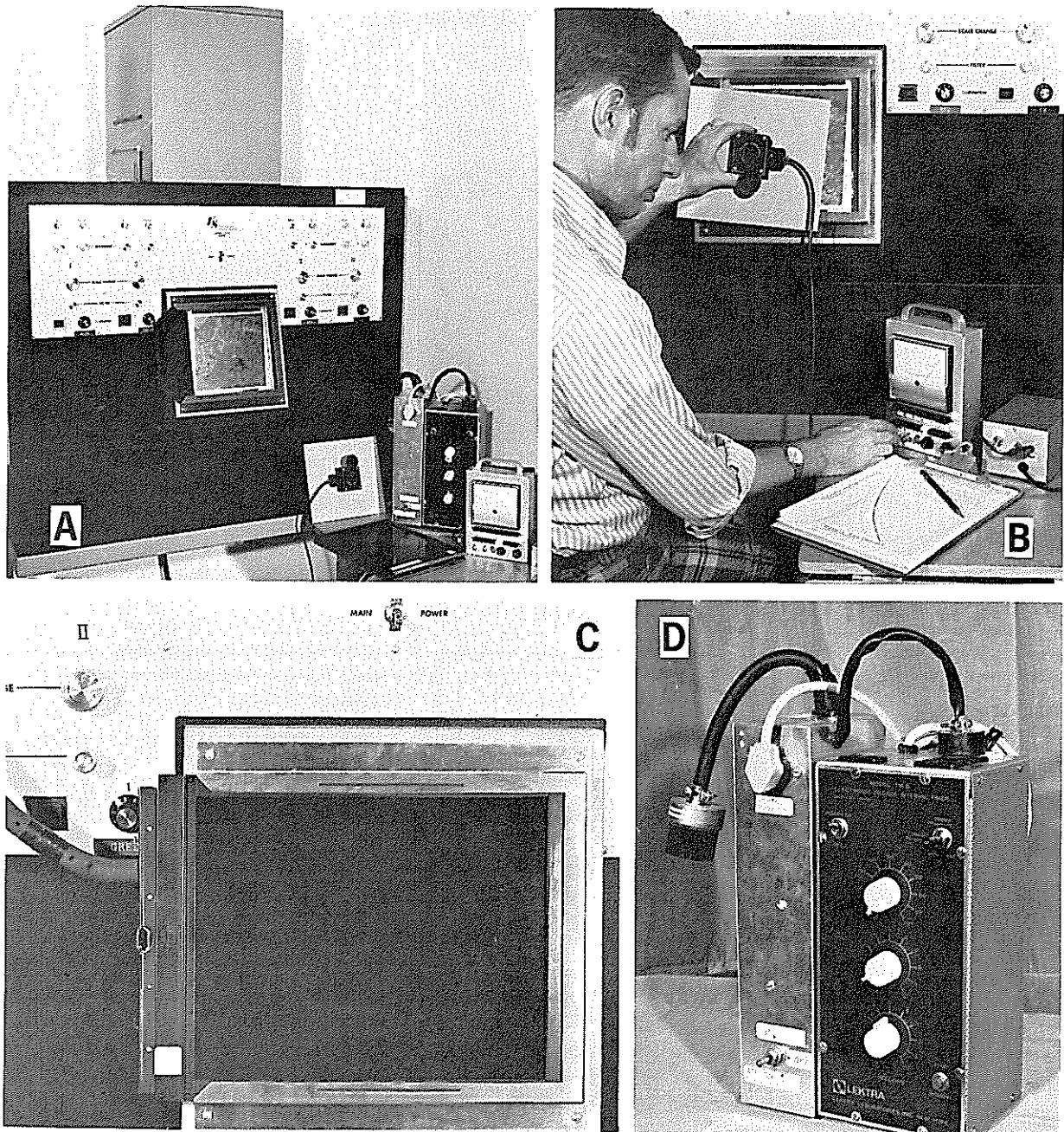


Figure 29—Equipment required to make color internegatives from ERTS 70-mm transparencies included (A)  $I^2S$  additive color viewer with photometer and high-speed timer, (B) Forest Service-designed photometer used to measure light intensity of each MSS band and of the color composite, (C) 8 by 10-inch vacuum film holder (vacuum hose, *left*), and (D) Lektra decade interval timer (*right*) with heavy-duty relay and switching circuit box (*left*).

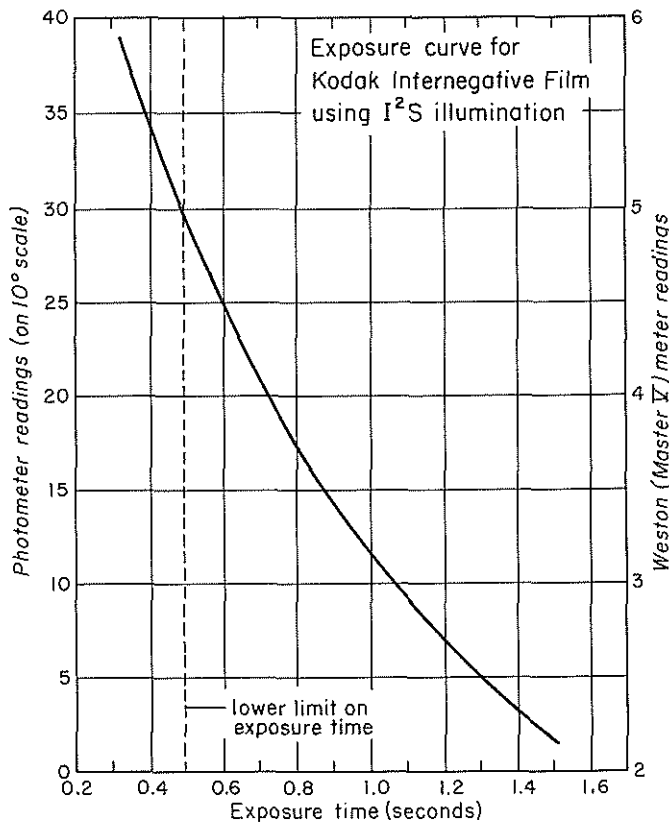


Figure 30—Exposure time is determined from the curve. Readings on the lefthand scale are from the Forest Service-designed photometer. Equivalent light intensity readings may be taken from a Weston Master V lightmeter (righthand scale).

## 2. Processing of ERTS Computer-Compatible Tapes

Nancy X. Norick

An automatic land-use recognition system, designed and implemented by the PSW Remote Sensing Work Unit was greatly expanded for the processing of ERTS computer-compatible tapes (bulk data). Considerable flexibility was built into the system so that the individual program components can be used in various combinations. The system programs run on a CDC 7600 at the University of California Lawrence Berkeley Laboratory, with input and output from a remote batch terminal at the PSW Forest and Range Experiment Station. The terminal consists of a Westinghouse 2500 with a line printer and other components. An Electronic Associates Inc. (EAI) model 430 off-line plotter is used with combinations of color pens to plot forest and land-use classification maps in the final classification process.

ERTS bulk CCT's are used as the first-step data input. Histograms and gray-scale maps are printed for each channel on a line printer so that study areas can be accurately located. If a study area falls on the

boundary between two tapes, the needed portion of the data on the second tape is rewritten onto one tape. An area surrounding and including the study area is plotted for one channel using a color-coded gray scale. The corners of the rectangular study area are then located precisely on this plot.

Three major corrections are applied to the bulk data:

1. Channel 4 is always corrected for its inherent 6th-line periodic distortion. This is done by taking the mean radiance values for all lines of similar sequence number mod 6 (mod is a standard FORTRAN function). These means are then subtracted from every pixel in each scan line of the corresponding sequence number mod 6. The grand mean for the channel is then added to each pixel. Before this correction is made the histogram for channel 4 is bimodal. After the correction, the histogram has a unimodal distribution similar to that of the other three channels. The correction also increases the

correlations between the scan line means for channel 4 and each of the other channels.

2. Next the gray-scale printouts are checked for missing scan lines for every channel. When a missing line is located, the radiance value for each pixel is constructed by averaging the values for the adjacent pixels from the lines just above and below the missing line.

3. The basic "ground truth" units we have been working with for ERTS are rectangular land-use maps of scales between 1:20,000 and 1:30,000 which have been constructed from medium- to small-scale aerial photos and ground checks. The average size of the areas covered is about 4 miles on a side or 12 to 15 inches on a map of this scale. After finding the corners of a rectangular study area on a gray-scale plot, a "rubber sheet-stretching" routine scales the corresponding nonrectangular ERTS area to the rectangular ground truth maps. This routine does a linear transformation of data array coordinates conforming to ground truth map coordinates. Nearest pixel data values are assigned to the new array elements. This is done in such a way that no data element is lost. Here and there an original data element will be used twice.

Upon completion of these corrections and calibrations a new tape is written, which becomes the data input to all subsequent programs.

The next step in the processing is to produce an EDMAP—empirical distribution map. The EDMAP is used to locate ground truth training samples and to visually screen the channels as potential contributors to the discrimination between land-use classes. Using information from the previously mentioned histograms, the range of radiance values for each channel is divided into any number of equal frequency intervals. Cartesian products of these intervals are formed for two or more selected channels. Data points falling into any product interval are assigned a mapping color and the EAI plotter is programmed to map. From the resulting sets of color-coded maps, with varying combinations of channels included or excluded, a subjective evaluation of the potential contribution of each channel for discerning each land-use

class can be made. We decided to use all four channels in our classification analyses.

The system has an option of three classification procedures. The first uses a boundary-finding algorithm to locate clusters of spectrally similar and adjacent pixels. A pixel is put into the same cluster as its neighbor if the distance between the two in the spectral space is less than some threshold value. Locations of all cluster elements are kept track of by a sequence of pointers. This storage technique allows the combining of clusters to be very efficient. The sums of radiance values and the sums of their cross-products are accumulated for each cluster during the process of cluster assignment. After all cluster assignments are made, the cluster mean vectors and covariance matrices are used for comparison with mean vectors and covariance matrices of samples of pixels of known land use, by means of the Bhattacharyya distance function (Fukunaga 1972). A cluster is assigned to the land use for which this distance is a minimum.

A weighting factor can be applied conforming to the expected frequencies in each land-use class or conforming to any loss function.

The second classification procedure compares the radiance vector for each pixel with the mean radiance vector for a sample of pixels from each land use. The land-use classification corresponding to the minimum Euclidean distance is assigned to the pixel. This classification can also use any set of weighting factors.

The third and last classification procedure available in our system is a linear discriminant analysis with maximum likelihood and Gaussian assumptions.

The final computer output consists of the listing of acreages of land assigned to each land-use class, confusion matrices for the training and test areas, and color-coded land-use maps. The maps are plotted in any desired scale and color code set on the EAI plotter. There is virtually no limitation upon the number of colors that can be used; however, the plotter can accommodate only eight pens at one time.

All programs are available and documented at PSW.



Heller, Robert C., *technical coordinator*

1975. Evaluation of ERTS-1 data for forest and rangeland surveys. USDA Forest Serv. Res. Paper PSW-112, 67 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Tests used data gathered by the first Earth Resources Technology Satellite. Results on sites in Georgia, Colorado, and South Dakota indicated that ERTS enlargements, preferably color, would be useful to forest managers of large ownerships for broad area planning. Forest land was distinguished from non-forest land with 90 to 95 percent accuracy, in both photointerpretation and computer-assisted analysis. Further breakdowns of cover types could not be made with acceptable accuracy by either method. Forest disturbances from natural causes or human activity could be detected with 90 percent accuracy when ERTS imagery was compared with 6-year-old aerial photos. Stress from mountain pine beetle could not be detected; ERTS wavebands are too broad to identify dying foliage.

*Oxford:* U629.19[+585+268+4]

*Retrieval Terms:* Earth Resources Technology Satellite; multi-spectral imagery; photointerpretation; remote sensors; forest stress; forest inventory; range inventory; plant communities; land classification; Atlanta, GA (Test Site); Black Hills, SD (Test Site); Manitou, CO (Test Site).

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