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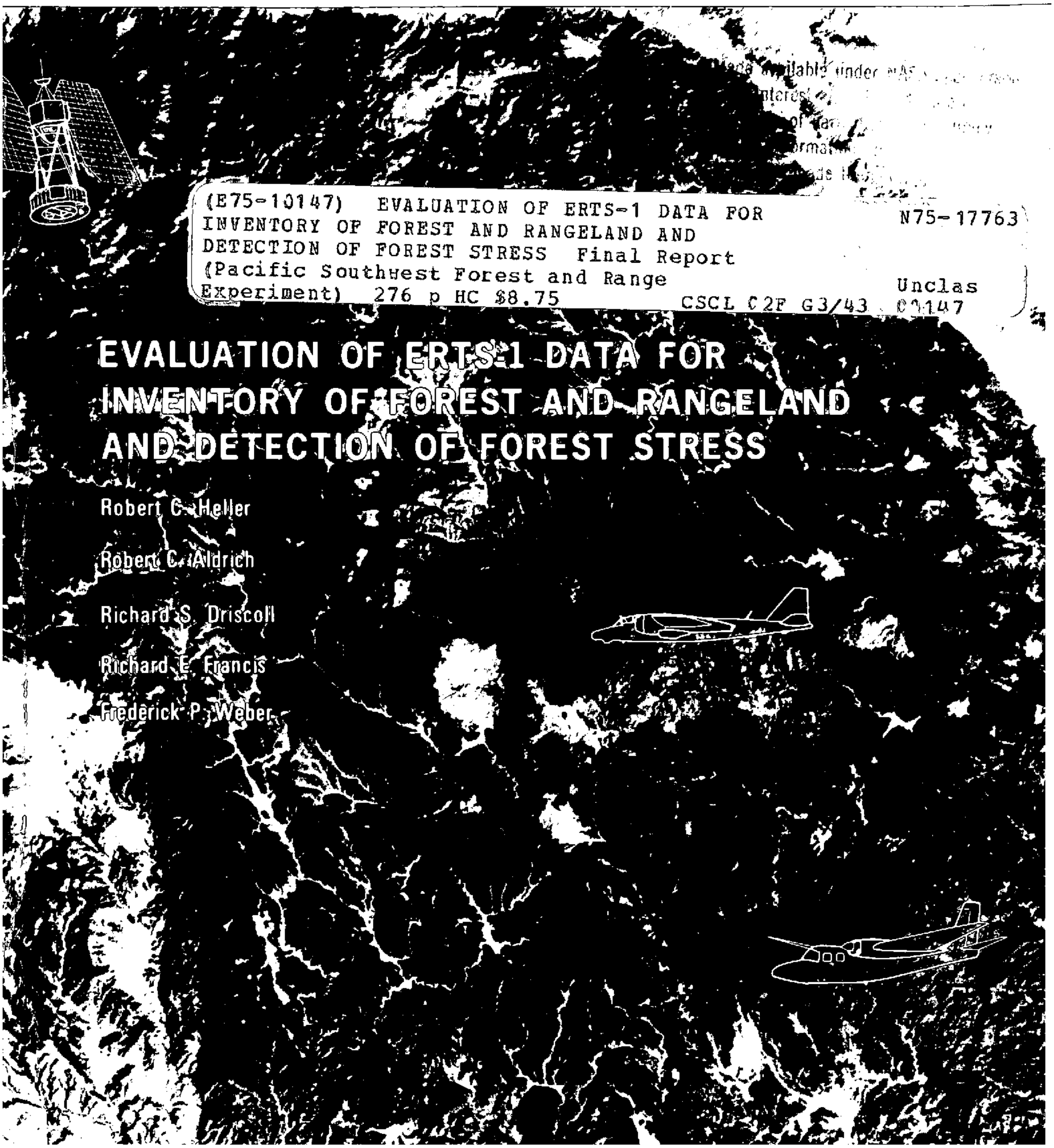

EVALUATION OF ERTS-1 DATA FOR INVENTORY OF FOREST AND RANGELAND AND DETECTION OF FOREST STRESS

Robert C. Heller

Robert C. Aldrich

Richard S. Driscoll

Richard E. Francis

Frederick P. Weber

Cover page: an enlarged portion (10X) of an Earth Resources Technology Satellite (ERTS) image of MSS band 7 (IR) obtained on January 11, 1973, over part of the Black Hills, South Dakota (ID 1172-17123). Snow is covering the ground but is not in the treetops. Scale is approximately 1:330,000.

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16. Abstract

Results of photo interpretation and computer analysis of three widely separated test sites in Georgia, Colorado, and South Dakota indicated that ERTS is a good classifier of forest and nonforest lands (90 to 95 percent accurate). Photo interpreters could make this separation as accurately as signature analysis of the computer compatible tapes. Further breakdowns of cover types at each site could not be accurately classified by photo interpreters (60 percent) or computer analysts (74 percent). Exceptions were water, wet meadow, and coniferous stands.

At no time could the large bark beetle infestations (many over 300 meters (1,000 feet) in size) be detected on ERTS images. The ERTS wavebands are too broad to distinguish the yellow, yellow-red, and red colors of the dying pine foliage from healthy green-yellow foliage.

Forest disturbances could be detected on ERTS color composites about 90 percent of the time when compared with six-year-old photo index mosaics.

ERTS enlargements (1:125,000 scale, preferably color prints) would be useful to forest managers of large ownerships (over 5,000 hectares (12,500 acres)) for broad area planning. Black-and-white enlargements can be used effectively as aerial navigation aids for precision aerial photography where maps are old or not available.

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EVALUATION OF ERTS-1 DATA FOR THE INVENTORY OF FOREST AND RANGELAND AND DETECTION OF FOREST STRESS

ABSTRACT

Three widely separated sites--near Atlanta, Georgia; Lead, South Dakota; and Manitou, Colorado--were selected as typical forest inventory, forest stress, and rangeland sites, respectively. At these locations we wished to learn whether low-resolution ERTS data could be used effectively with support aircraft photography and ground data to improve the collection and analysis of natural resource data for ongoing Forest Service, USDA, programs.

Color-combined ERTS images were viewed by photo interpreters under magnification with microscopes, projectors, and comparators to identify and classify the natural resource cover classes which applied to each discipline. Computer-assisted programs were also developed and compared with other computer analysis systems, the photo interpretations, and the ground data.

Results indicated that ERTS data is a good classifier of forest and nonforest lands and could be used as an accurate data base (90 to 95 percent accurate) for subsequent sampling by small- and medium-scale aerial photography. Photo interpreters could make this separation as accurately as signature analysis of the computer compatible tapes. Further breakdowns of cover types met with unacceptable accuracies; some classifications were excellent, such as water, wet meadow, and coniferous stands, but many of the cover types at each site could not be accurately classified by photo interpreters (60 percent) or computer analysts (74 percent).

At no time could the large bark beetle infestations (many over 300 meters (1,000 feet) in size) be detected on ERTS images. The ERTS

wavebands are too broad to distinguish the yellow, yellow-red, and red colors of the dying pine foliage from healthy green-yellow foliage. Large stands (over 500 meters (1,625 feet) in size) of dying Eucalyptus trees in the Oakland-Berkeley area were distinguishable on color-combined images from two dates.

Forest disturbances could be detected on ERTS color composites about 90 percent of the time when compared with six-year-old photo index mosaics. An operational exercise will be tried under controlled conditions to test the feasibility of this technique.

ERTS enlargements (1:125,000 scale, preferably color prints) would be useful to forest managers of large ownerships (over 5,000 hectares (12,500 acres)) for broad area planning. Black-and-white enlargements can be used effectively as aerial navigation aids for precision aerial photography where maps are old or not available.

PREFACE

The work described within the report is considered experimental, and the results should be construed as an investigation into the use of multi-spectral satellite data for inventorying forests and rangeland and detecting forest stress. Both the positive and negative aspects of the work are discussed and the authors point out what levels of success a forester or range specialist might expect at the present stage of development of image and computer processing techniques from satellite data.

Our Earth Resources Technology Satellite (ERTS) contract, S-70251-AG, has two identifiers which readers may find in information retrieval systems: (1) ID - AG 014 and (2) Proposal No. MMC 226. The contract funding became available to the investigators on May 1, 1972; the total contract period was extended from 19 to 26 months and is due to end October 9, 1974. The Forest Service, USDA, contributed scientists' salaries which represented about 1.8 times the cost of the National Aeronautics and Space Administration (NASA) contract. NASA-contributed funds were expended in computer time, subcontracts, travel, equipment purchase, and temporary salaries. NASA/Goddard Space Flight Center (GSFC) also contributed data products from ERTS in the form of transparencies, color composites, and computer compatible tapes. Also, the Lyndon B. Johnson Space Center (JSC)/Earth Resources Aircraft Program (ERAP) furnished color and color infrared transparencies and aircraft multispectral scanner data over all three test sites.

In connection with the NASA/ERTS contract, Robert C. Heller was identified as Principal Investigator and Robert C. Aldrich, Richard S. Driscoll, and Frederick P. Weber as Coinvestigators.

The following people were responsible for most of the study and the written portions of this paper:

1. R. C. Heller - organization of the paper, ABSTRACT, and SUMMARY.
2. R. C. Aldrich - FOREST INVENTORY section and APPENDIXES B AND C.
3. R. S. Driscoll and R. E. Francis - RANGE INVENTORY section.
4. F. P. Weber - FOREST STRESS section. Within this section T. H. Waite wrote the portion on "Photo Interpretation Prediction Model" and E. H. Roberts did the analysis and write-up of the "Data Collection System Postexperimental Evaluation."
5. R. J. Myhre and R. W. Dana - developing equipment and techniques and writing APPENDIX A, "PRODUCING STANDARD COLOR COMPOSITE INTERNEGATIVES FROM ERTS 70 mm TRANSPARENCIES."
6. N. X. Norick - APPENDIX D, "PSW COMPUTER PROCESSING OF ERTS BULK CCT's."

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PERSONNEL

Salaries of all professional and permanent full-time employees of both the Pacific Southwest (PSW) and Rocky Mountain (RM) Forest and Range Experiment Stations were contributed by the Forest Service. The employees assigned to or administering these studies were:

Carl C. Wilson, Assistant Director, PSW

Benjamin Spada, Assistant Director, PSW

Harold A. Paulson, Jr., Assistant Director, RM

Robert C. Heller, Supervisory Research Forester and Work Unit Leader, PSW

Richard S. Driscoll, Principal Plant Ecologist and Work Unit Leader, RM

Robert C. Aldrich, Principal Research Forester, PSW

Frederick P. Weber, Research Forester, PSW

Nancy X. Norick, Mathematical Statistician, PSW

Robert W. Dana, Physicist, PSW

Richard E. Francis, Associate Range Ecologist, RM

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Cooperating Forest Service employees from other locations include:

Wilmer F. Bailey, Aerial Survey Specialist, State and Private Forestry, U.S. Forest Service Region-2, Denver, CO

Robert Mattson, Forester, Black Hills National Forest, Deadwood, SD

ACKNOWLEDGMENTS AND COOPERATORS

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1. Richard P. Cook, David Hessee, Irving Case, Black Hills National Forest, R-2, Spearfish and Nemo Ranger Districts. Provided maps, vehicles, personnel, and use of property.

2. Homestake Mining Company, Forestry Department, Spearfish, South Dakota. Permitted use of property to conduct experiment.

3. Dr. James A. Smith, Associate Professor, Department of Earth Resources, College of Forestry and Natural Resources, Colorado State University (CSU), Fort Collins, Colorado. Provided computer and ADP expertise for processing ERTS computer compatible tapes at CSU.

4. Dr. Roger Hoffer, Professor, College of Forestry, and LARS, Purdue University, Lafayette, Indiana and Michael D. Fleming, LARS, and College of Forestry, Purdue University, Lafayette, Indiana. Consultation on computer processing and analysis of ERTS data by a separate subcontract.

5. Edward W. Crump, Technical Monitor, Code 430, NASA/GSFC, Greenbelt, Maryland. Provided assistance and advice throughout study and expedited the receipt of ERTS imagery and CCT's.

6. Vincent Dong, Editor, PSW. Provided editorial assistance in organization of paper and review.

ACRONYMS AND GLOSSARY

Band - a frequency bandwidth; for ERTS it is one of four wavelength bands of the multispectral scanner (MSS) Band 4 = 0.5 to 0.6 micrometers (μm), Band 5 = 0.6 to 0.7 μm, Band 6 = 0.7 to 0.8 μm, Band 7 = 0.8 to 1.1 μm.

Bulk ERTS data - or system corrected data. ERTS data which has only fair positional accuracy but excellent scene radiance and registration data. 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.

CCT's - computer compatible tapes (available in 7- or 9-track,556 and 800 BPI, respectively; all tapes used in this study were 7-track, 800 BPI).

Channel - there are six detectors for each waveband of the four-band MSS on ERTS. Thus, ERTS-1 is a 24-channel scanner.

CIR - color infrared photography, 0.5 to 0.88 μm.

DCP - data collection platform.

DCS - data collection system.

D-DAS - digital data acquisition system. Vidar 5403 system includes controller, clock, integrating digital volt meter, scanner, and 7-track magnetic tape recorder.

EAI - Electronic Associates Incorporated. Data plotter Model 430 used to plot classification signatures in color from CCT's at PSW.

GMT - Greenwich mean time. Mountain standard time (Black Hills) + 7 hours = GMT.

I^2S - International Imaging Systems - manufacturer of additive color viewer.

LARS - Laboratory for Applications of Remote Sensing, Purdue University.

NAR - Net allwave radiation.

μm - Micrometers, 1 μm = 10^{-6} meters.

NDPF - NASA data processing facility.

Pixel - a single picture element derived from a digital MSS CCT--and in form available for viewing. A pixel is considered to be approximately 56 meters horizontal and 79 meters vertical in size.

PSW - Pacific Southwest Forest and Range Experiment Station, Forest Service, USDA, Berkeley, CA.

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Precision ERTS data - or scene-corrected data has good positional accuracy at the expense of registered radiance data. Available as 9.5 inch black-and-white individual band transparencies, 9.5 inch color composites, or CCT's. Covers area 100 by 100 nautical miles.

RM - Rocky Mountain Forest and Range Experiment Station, Forest Service, USDA, Fort Collins, CO.

RSU - remote sensing unit - an RSU is a single digital data element which has been geometrically corrected, registered, and combined; it is used as the basic unit on which all statistics and signature analyses are performed. By adding an equal number of RSU's in the x, y directions, they can be expanded to any map scale. This is a definition originated by R. Hoffer, LARS, to describe a reformatted data CCT.

Scene - one ERTS photo covering an area approximately 100 nautucal miles square.

SR&T - supporting research and technology programs.

UTM - Universal Transverse Mercator map projection.

ZTS - Zoom Transfer Scope--a mapping projection and rectifying device manufactured by Bausch and Lomb Optical Company.

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EVALUATION OF ERTS-1 DATA FOR THE INVENTORY OF FOREST AND RANGELAND AND DETECTION OF FOREST STRESS

SUMMARY

BACKGROUND

This experiment was proposed to learn the applicability of low-resolution satellite data when used in concert with support aircraft and ground data to ongoing Forest Service, USDA, programs. We selected three widely separated sites (Figure 1) on which we already had a great deal of experience and firsthand knowledge about ground conditions from earlier remote sensing studies. The three sites represent locations where improvements in inventory techniques could be tested for wider scale application if the results showed promise.

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 (500 acres)) which results in a checkerboard pattern on aerial imagery. We believed such an area with many field and forest borders would present a challenge to the investigator to properly classify forest land use. Robert C. Aldrich, principal research forester, is the

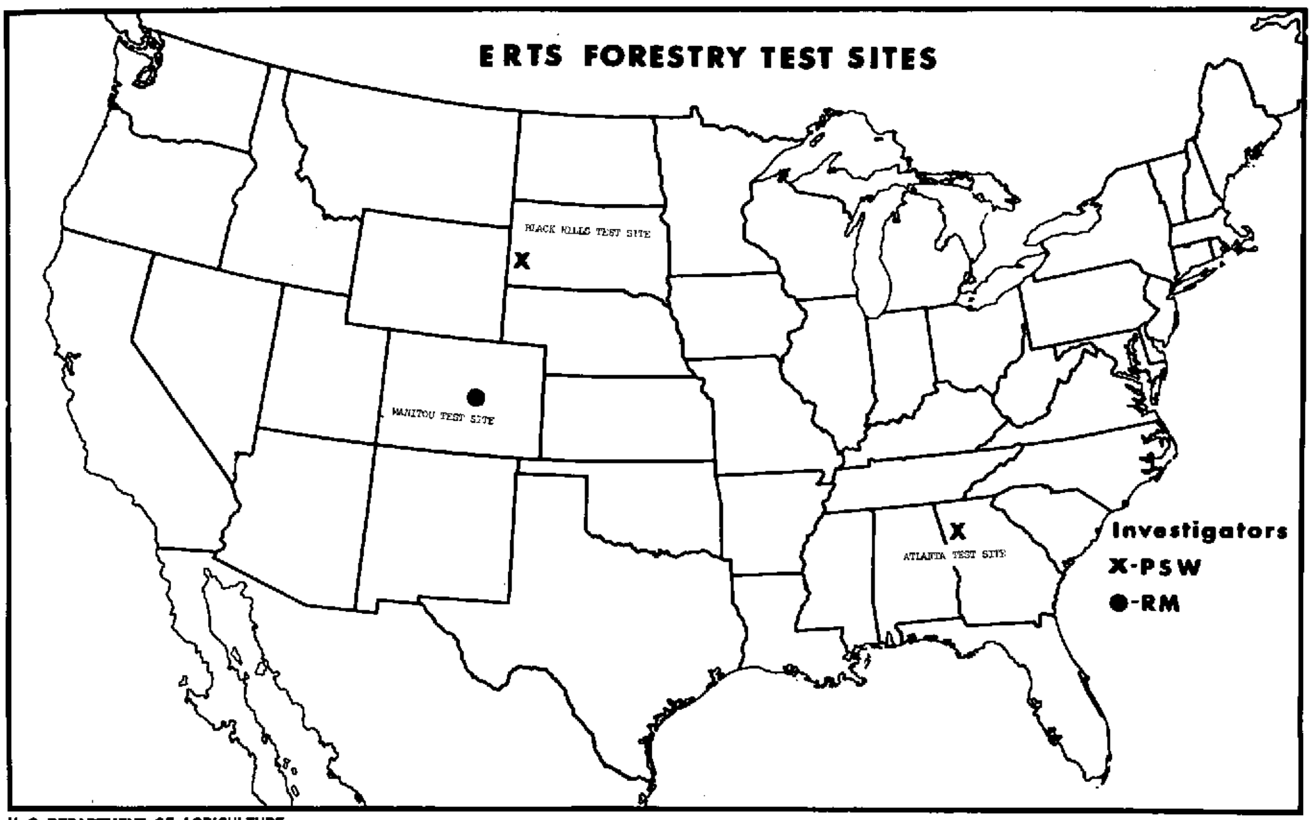

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Figure 1. The X's indicate the two sites near Atlanta, Georgia and Lead, South Dakota where Pacific Southwest Forest and Range Experiment Station scientists evaluated the usefulness of ERTS-1 data for forest inventory and forest stress, respectively. The black dot represents the range inventory site near Manitou, Colorado where studies were done by Rocky Mountain Forest and Range Experiment Station scientists.

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coinvestigator for this site and has considerable past experience and knowledge about the nationwide Forest Survey.[1] His detailed report follows this SUMMARY.

The second site is located in the Black Hills near Lead, South Dakota where a serious mountain pine beetle (*Dendroctonus ponderosae* Hopk.) outbreak has been responsible for killing several hundreds of thousands of 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 seriousness of the situation and in performing necessary 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 (CIR) 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 meters (10 to 20 feet) in size) with better than 90 percent accuracy. In this part of the experiment we set up the null hypothesis that ERTS-1 data could not detect insect infestations of any size and then attempted to disprove it. F. P. Weber, research forester, who is coinvestigator on this study, 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 punch cards and sent to PSW for analysis.

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[1] Forest Survey is a branch in the Division of Forest Economics and Marketing Research, Forest Service, U. S. Department of Agriculture, Washington, DC. The Forest Survey was authorized by the McSweeney-McNary Forest Research Act of May 22, 1928.

The range inventory site near Manitou, Colorado will be discussed by Richard S. Driscoll who is a principal plant ecologist. Rangelands are important national resources and need to be inventoried, protected, and managed. They are becoming more important as our food and fibre supplies diminish. An orderly system of classifying vegetation according to its relation to other plants and animals and its potential for vegetative development has been devised by Forest Service ecologists.[2] This hierarchical system forms the basis of determining at what level ERTS-1 data can accurately assess range vegetation types.

OBJECTIVES

The objectives of the experiment, as outlined in our proposal, were:

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.

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[2] ECOCLASS--a method for classifying ecosystems. 1973. A task force analysis by nine western forest and range ecologists. Task force cochairmen, Robert D. Pfister and John C. Corliss, January 18, 1973.

PROBLEMS ENCOUNTERED

An experiment involving a new remote sensing system, such as collecting earth resources data from a satellite, presents problems which are difficult to forecast even in carefully thought-out study plans. It was not until the investigators actually received and began working with ERTS images, and the programmers the CCT's, that the problems in conducting the experiment as proposed became evident. Listed below are some of the major difficulties we experienced in using ERTS data, which required us to change procedures and develop new techniques:

1. Inadequate number of suitable ERTS images when needed. For example, we did not receive a cloud-free image during the growing season over our Black Hills site until 13 months (August 1973) after the ERTS launch. At the other two sites, only three images covered each site completely for use on temporal and seasonal comparisons. While these numbers are adequate for analysis, it delayed the progress the investigator could make. It also caused delays in issuing a subcontract to an outside agency for computer processing of the CCT's.

2. Delays in receiving color composites from GSFC of adequate quality slowed down photo interpretation analysis.

3. Inadequate lead time to build and test field sensors for installation with DCP's before the ERTS-1 launch.

4. Delays experienced in setting up image combining equipment, in aligning optics, and in developing suitable photographic copying equipment for standardizing our color composites for photo interpretation analysis (see Appendix A).

5. Need to change analysis methods. We outlined five image analysis methods of ERTS and aircraft data in our proposal:

a. Human photo interpretation.

b. Optical combining, enhancement, and analysis.

c. Digital analysis from microdensitometer outputs of ERTS images.

d. Digital analysis from precision-processed digital tapes.

e. Analog and digital analysis from bulk ERTS tapes.

Items c and d were deleted from the analysis after we became more familiar with the imagery and CCT's. For example, scanning a precision-processed color composite on our microdensitometer was not practical because of poor spectral registration and a general degradation of the data. Signature analysis from precision CCT's was also found to be less useful than using bulk CCT's.

6. 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. However, Driscoll used part of the range inventory site to develop a multistage inventory with several stages of small- and large-scale aerial photos coupled with ground samples.

7. Low geometric accuracy caused us to change the experimental design. When the geometric accuracy of the ERTS products was found to exceed 200 meters (650 feet), we had to abandon our original experimental design of using map-located Universal Transverse Mercator (UTM's) projections for training and test samples. In most cases, the training examples of land-use classes located on maps did not correspond well enough to ERTS UTM's and would have resulted in invalid comparisons of the land-use classes (see <u>FOREST INVENTORY</u> section).

8. 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 (ADP versus photo interpretation, etc.). Therefore, no iso-cost and iso-error curves were developed.

DEVELOPMENT OF USABLE PROCEDURES

Slightly different photo interpretation instruments and techniques were used at each of the three test sites. For example, 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 insufficient cloud-free imagery was available during the growing season and prevented our getting a large number of training and test replicates. All three coinvestigators used Bausch and Lomb Zoom 70 microscopes to examine and classify their cover types on NDPF- and PSW-produced color composites. However, a VARISCAN rear-projection viewer was also used to advantage with the Black Hills imagery. An overhead projector was used with the bulk color composites for examining all sites when making comparisons 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.

For the computer-assisted processing of the bulk CCT's, three separate methods were used. For the first, a subcontract was let to the Laboratory for Applications of Remote Sensing (LARS), Purdue University, to determine the efficacy of their computer processing techniques to correctly classify and map cover types from bulk CCT's for all sites. For the second method, our statistician and programmers at PSW developed our own signature analysis and mapping routines from the bulk CCT's. They compared our accuracies with LARS'and the ground truth for the Atlanta and Black Hills sites only (Appendix D). For the third method, a computer program was tested at Colorado State University with the bulk CCT's to determine the effects of steep slopes and cloud shadows on cover-type classifications.

Evaluation of the computer classification accuracies for both the LARS and PSW map outputs required tedious checking procedures. We felt these checks were necessary to insure that accuracies of classification represented unknown areas which fell outside the areas on which the computer was trained. In other words, one should not use the original training classification algorithm to check the accuracy of that algorithm. Both area estimates of each cover type classification were checked against known ground areas and also a point-by-point check of replicated map cover types was made at each site.

RESULTS AND CONCLUSIONS

At all three sites, the coinvestigators found that ERTS-1 data could be used as an excellent tool for classifying forest from nonforest (Level I) either with photo interpretation methods or by computer signature analysis. Beyond the Level I classification, results varied considerably and will be summarized briefly below for each site. Detailed results for each site are available in the remainder of this report.

Forest Inventory

Photo Interpretation

1. Photo interpreters using 1:1,000,000 color composites could consistently classify forest from nonforest about 96 percent of the time regardless of the season the imagery was collected.

2. Photo interpreters could not classify Level II cover-type classes to acceptable accuracies. For example, pine was identified only 60 to 65 percent of the time--hardwoods only 50 percent. Other land-use classifications ranged from 7 to 85 percent. Grassland (80 percent), urban (74 percent), and water (100 percent) classes were separated more accurately than cropland (10 percent), bare soil (50 percent), and wild vegetation (20 percent).

3. Forest disturbances were detected 90 percent of the time when comparing ERTS color composites with 1:64,000 photo index sheets (1966). The disturbances were properly identified as to type of disturbance almost 80 percent of the time.

a. Spring ERTS imagery was best for detecting disturbances. Late fall and winter images are second choice and are better than summer images.

b. Clearcutting patches could be identified in the South up to 8 years after harvesting if the patches were over 1 hectare (2 to 3 acres) in size.

c. No time limit exists for discerning permanent changes from forest to nonforest if the area is over 1 hectare (2 to 3 acres) in size.

d. Nonforest to forest classes require a minimum of 3 years to detect a change on ERTS color composites.

4. Photo interpreters could seldom identify single-lane highways, secondary roads, power lines, or streams if they were less than 100 meters (328 feet) wide unless they coincided with an MSS scan line.

Computer Classification

1. Both the LARS and PSW computer analysis systems classified forest from nonforest 94 to 96 percent of the time--almost exactly the same as the photo interpreters.

2. The classification of pine and hardwood cover types by either the LARS or PSW system was better than the performance of the photo interpreters. However, other land-use types were classified by the computer systems with about the same accuracy as the photo interpreters--not too well.

3. For evaluating the computer accuracy on a point-by-point basis with ground truth maps for Level II cover-type identifications, we found that the LARS system was about 20 percent more accurate than the PSW system. However, the best average Level II classification for 1 block was only 74 percent--the other 2 blocks had lower accuracies. These accuracy levels are not good enough for forest inventory purposes.

4. The results in using seasonal CCT data to improve the land-use classifications in Georgia were not successful. More work is needed to isolate seasonal variations and combine seasonal data to improve computer classifications.

In general, ERTS-1 data appears useful to provide an up-to-date area sampling base to measure forest area by county within a specified accuracy. Our experiment in the Atlanta area shows ERTS-1 data to be a good Level I forest classifier. Furthermore, ERTS data appears useful for the Forest Survey to detect forest and nonforest inventory plot changes or disturbances where there is a great deal of human activity. It should be tested on an operational program.

Forest Stress

The greatest disappointment in conducting this part of the study was that the trees dying from bark beetle attack in the Black Hills of South Dakota were not detectable at any time period or with any kind of processing technique. Some stands of discolored timber were over 300 meters (1,000 feet) in size. For this kind of stress detection, we concluded that the ERTS-1 wavebands are too broad and the resolution too coarse to detect the subtle differences in the green-yellows and yellow-reds which characterize the discolored coniferous foliage. A considerable improvement in ERTS resolution and the use of narrower wavebands would undoubtedly be needed to improve the detectability of similar bark beetle infestations.

Some of the same photo interpretation and computer processing techniques were used in classifying Black Hills cover types as were used in the Forest Inventory study. These results are briefly summarized below.

Photo Interpretation

1. ERTS-1 color composites reduced photo interpretation time 20 percent over the four individual black-and-white transparencies.

2. Photo interpretation was 100 percent correct for conifer sites, wet pastures, bare soil, and water. Most of the errors occurred with dry pastures and hardwood sites. Errors in separating dense pine stands (> 50 percent stocked) from open stands (< 50 percent stocked) were excessive--50 percent commission errors.

3. As mentioned above, none of the 10,000+ beetle infestations were detected regardless of size, season, or processing technique.

4. Forest disturbances were discernible on projected color composites by the local land managers. These included past fires, logging, and old tornado damage.

5. A team of interpreters consisting of local specialists from many disciplines in the Black Hills did a very creditable job in correctly classifying seven cover types. This kind of viewing of projected ERTS color composites appears useful for making land-use planning decisions.

6. Very large stands of Eucalyptus trees killed by freezing weather in the San Francisco Bay area in the winter of 1972-1973 could be delineated when: (a) the stands were over 500 meters (1,600 feet) in size and (b) two-date imagery was available for image combining--one date when the annual grasses and Eucalyptus foliage were both green and the second when the grasses were green and the foliage yellow. This technique may be useful in developing countries where easy access is limited.

Data Collection System

Despite problems in keeping our sensors and Data Collection Platforms operational, we did derive some useful spectral data from our PSW-built spectrometers (ERTS matched). We found that:

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 channel 5 less than MSS-4. In this case, ERTS-measured radiance is 40 percent more than ground-measured radiance.

3. MSS bands 6 and 7 have reduced radiance on ERTS imagery as compared with bands 4 and 5 and also ground measurements. A 17-percent reduction is revealed for MSS-6 and a 20-percent reduction for MSS-7 as compared with ground spectral measurements. For these longer wavelengths (MSS-6 and -7), absorption by the intervening atmosphere is the dominant factor operating on the radiance as measured from ERTS-1.

4. These corrections to radiance values should be applied to the radiance levels on the CCT's to learn if improvements can be made to the signature analysis programs. We were unable to attempt these corrections during this study but hope to make an analysis soon using corrected tapes of one ERTS scene.

Computer-Assisted Processing

1. Neither the LARS nor PSW computer processing system could accurately identify beetle-killed pine. The LARS presentation showed no infestations, while PSW results had 3 percent of the area in dead pine; unfortunately, there was no coincidence of the ground truth data with the computer output of dead pine.

2. Both the LARS and PSW systems were reasonably successful in classifying area estimates of broad cover types in sub blocks to Level II. Agreement with the ground truth was just acceptable at Level III. The PSW algorithm was better in classifying cover-type density of ponderosa pine than LARS.

3. In assessing the in-place accuracy (pixel-by-pixel comparison) of computer classifications with ground cover types, both PSW and LARS systems produced very similar results for both the Lead and Spearfish blocks at Level II classification.

	LARS	PSW
Spearfish	91 percent	90 percent
Lead	74 percent	72 percent

4. The main usefulness of ERTS-1 imagery in the Black Hills is limited to providing information for broad area planning. The cover-type

classifications were not sufficiently accurate to the land planner and forest manager for developing unit plans or impact statements.

Classification of Range Plant Communities--Manitou, Colorado

All techniques used in classifying plant communities, either by photo interpretation, computer, or microdensitometer, were related to the "ECO-CLASS" hierarchical system described earlier. In this classification system, the Regional level is roughly equivalent to Anderson's Level II (1972) and the Series level to his Level III.

Photo Interpretation

1. In the Rocky Mountain area of Colorado, photo interpreters could correctly classify (95 to 99 percent) and separate conifers from grassland on June to September ERTS imagery and high-flight aerial photographs. However, interpreters had great difficulty in separating deciduous trees--mostly aspen--from conifers; accuracy was only 63 percent on ERTS imagery and 65 percent on high-flight photos when all dates (June, August, and September) were considered. August proved to be the best date to use ERTS images for all Regional classes; at this time, the interpreters were able to separate aspen correctly 92 percent of the time.

2. Photo interpretation of satellite imagery provided no acceptable results for classifying any of the forest classes to the Series level (Level III). For the high-flight aircraft photography, mid-September was the best date, and 1:50,000 was the best scale; CIR film was a little better than NC (normal color) film but not significantly so. Most of the errors of separating forest classes were made on north-facing slopes on both satellite and aircraft imagery.

3. Grassland classes were separated better than the forest classes at the Series level (Level III).

a. One experienced range ecologist was significantly better in classifying grasslands than the other two photo interpreters; his range of correct calls was from 83 to 100 percent.

b. The Shortgrass and Wet Meadow Series classes were identified correctly from 88 to 99 percent of the time on satellite imagery.

Unfortunately, Mountain Bunchgrass could not be identified better than 50 percent of the time--except for the photo interpreter mentioned above.

c. On high-altitude aircraft photos, stereo viewing, plus improved resolution, permitted the discrimination of the grasslands to be improved over viewing nonstereo satellite imagery.

Computer-Assisted Analysis

1. Training class performance for the LARS classifications was 90 percent or better at both the Regional and Series levels (Levels II and III). However, once an evaluation of the data outside the training area was made, overall performance for two units (Manitou and Eleven Mile) dropped to 77 percent at the Regional level (Level II) and to 48 percent at the Series level (Level III).

2. The effects of slope, aspect, and shadows were most pronounced on this mountainous site and caused many errors of misclassification to occur once we tried evaluating CCT data away from the training samples. Improvements in computer signature analysis need to be made before a resource manager could use computer-produced maps.

3. We found that for one forest series class (ponderosa pine) computer performance could be improved by adjusting spectral response to a

midslope response level. Other vegetation classes should improve similarly, but we had inadequate time to test this hypothesis.

Microdensitometric Interpretation

1. Analysis of bulk color composite image densities for the three primary Regional vegetation classes (deciduous forest, coniferous forest, and grassland) by a microdensitometer showed highly significant differences ($p = 0.99$) between all vegetation combinations at two dates (June and August). Thus, it appears possible to do automatic scanning of an ERTS color composite and relate density levels to Regional vegetation classes.

2. At the Series level (Level III), there was a great deal of overlapping of densities except for Aspen and Wet Meadow Series classes for the forest and grassland differentiations.

Discussion

1. For all sites, it appears that ERTS data can be used effectively to classify vegetation data to the Regional level (Level II) in Colorado, but only to Level I in Georgia and South Dakota. The classification can be done most effectively by computer processing, but photo interpretation does produce equally accurate results. The choice of computer or human interpreter would depend upon availability of trained people and equipment.

2. After working on our test sites for 2 years and introducing land managers to ERTS images, it became obvious to us that managers of large ownerships (4,000 hectares (10,000 acres) or more) would benefit by having enlargements of ERTS images for planning purposes. Color composite enlargements are preferable for vegetation analysis and can be most useful

at large scales (1:125,000 to 1:250,000). MSS-5 is the best waveband to use for vegetation analysis if only a black-and-white enlargement can be purchased.

3. Our remote sensing project has effectively used black-and-white ERTS enlargements (to scales of 1:125,000) for high-altitude aerial navigation. In remote areas, where maps are old and many changes have occurred, the pilot and aerial photographer can navigate more effectively from recent ERTS enlargements than from old maps. Mr. David Francis, with Hunting Aerial Surveys, Ltd., England, has also determined that ERTS enlargements were invaluable for aerial photography over parts of Africa where maps were unavailable.

FOREST INVENTORY

The forest inventory portion of our ERTS experiment concentrated on determining the accuracy of forest land classification. This choice of an experimental objective for ERTS data analysis was based upon the rationale that although forest land managers require more detailed in-place information with respect to volume, stand condition, and growth, the pre-launch specifications for ERTS data resolution did not encourage its use for these purposes. By the same rationale, land-use classification could be accurate enough and might enable us to obtain forest area statistics for small political units such as counties. While following this course we felt that we would learn what the true capabilities for ERTS-type data would be and at the same time develop techniques and new skills for handling these unusual kinds of data.

BACKGROUND INFORMATION

The site selected for this research was near Atlanta, Georgia (Figure 2). This is the same site used for the Apollo 9 inventory study in 1969 (Langley, Aldrich, Heller, 1969) and high-altitude aircraft studies sponsored by NASA's Earth Resources Survey Program between 1970 and 1972 (Aldrich and Greentree, 1971; Aldrich and Greentree, 1972). The area is typical of a large part of the Southern United States with its "checkerboard" land-use pattern. We felt that this complex pattern would be a rigorous test for any remote sensing system. Principal land uses in the area are forest, grassland (pasture), urban, and other. Agriculture is not a major use of land on this site but some scattered grain and soybean

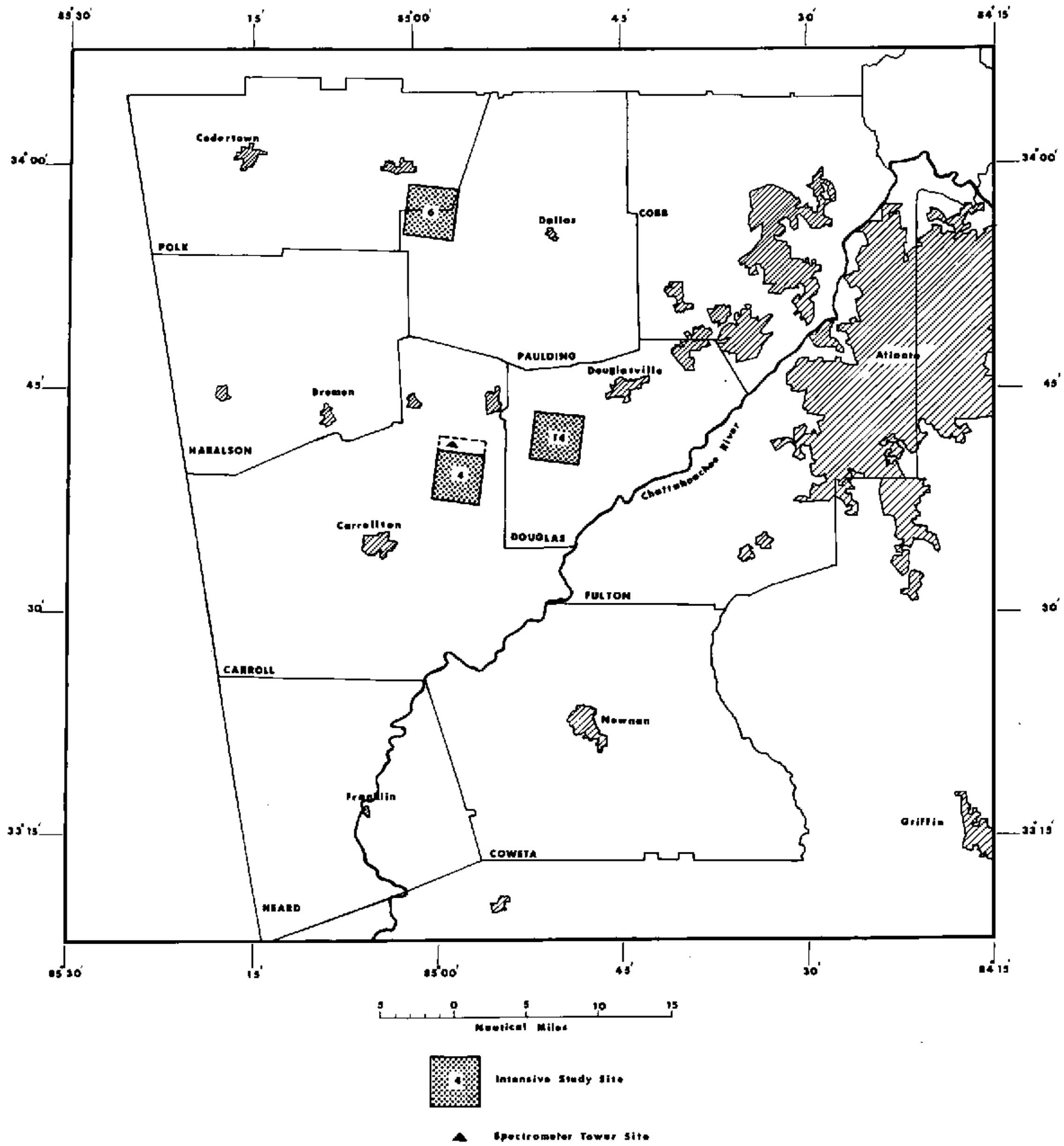

Figure 2. The Atlanta test site includes nine counties. Three intensive study sites were used in evaluating computer classification procedures.

crops are grown. The major forest types in the area are loblolly pine (Pinus taeda), oak-pine, oak-hickory, and oak-gum-cypress. Commercial forest land covers approximately 60 percent of the land area and is found primarily in small farm woodlots. Changes between forest and nonforest categories occur quite rapidly because of the influence of the pulp and paper industry and the expansion of metropolitan Atlanta.

Land-use data collected on the ground and on small- and large-scale aerial color photographs from previous studies were invaluable in the analysis. Since correlative seasonal data were needed to compare with ERTS imagery, we had to rely upon previous photography and ground inspections when aircraft support flights were cancelled.

ERTS DATA EVALUATION

The concept of an unmanned satellite collecting remotely sensed forest resource data at regular intervals is good because it almost guarantees the resource inventory specialist cloud-free coverage more than once each year over the same area. For instance, during the first 12 months of operation, ERTS passed over Atlanta 21 times. It was a particularly bad year weatherwise, yet there were three passes out of the 21 that were completely free of clouds and fulfilled the requirements of this study. The three scenes which were used in this analysis are listed below by their acquisition number and date.

Scene	Date
1084-15440	October 15, 1972
1264-15445	April 13, 1973
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 important because it permits an interpreter to make better discriminations of land use.

Two methods of data analysis of ERTS data were used in the Atlanta study. The first, conventional photo interpretation, made use of 9- x 9-inch false-color photo composites made on transparency film. The second method of data analysis was by computer classification using spectral data found in digital form on computer campatible tapes (CCT's). Two computer classification systems were tested. The first system was developed by the Laboratory for Applications of Remote Sensing (LARS) at Purdue University. The second system was developed by the Berkeley Remote Sensing Unit using "in-house" capabilities.

Image Quality

False-color photo composites of the ERTS bulk data used in this evaluation originated from two sources: (1) the ERTS Data Users Center at the Goddard Space Flight Center in Greenbelt, Maryland, and (2) the Forest Service Remote Sensing Research Unit facilities in Berkeley. The color composites were made by combining and enhancing two or three of the 70 mm black-and-white transparencies of the four spectral bands from the MSS. Goddard composites were made using band 4 (green, 0.4 to 0.5 μm), band 5 (red, 0.6 to 0.7 μm), and band 7 (infrared, 0.8 to 1.1 μm). Berkeley composites on the other hand were made by combining only band 5 and band 7 data. At Berkeley we felt that band 4 caused a "hazy" appearance in the composite and a general loss of information. It was also apparent that there was little information in band 4 that was not in band 5.

Originally we intended to use Goddard-produced false-color composites in the photo analysis. However, we soon found that without some degree of control over the image enhancements as well as the photo processing, it was not possible to make valid comparisons between seasons. This was evidenced by extreme variation in the film density and many incorrect interpretations made on Goddard color composites. To overcome this problem we combined, enhanced, and produced our own color composites using an International Imaging Systems (I^2S) Additive Color Viewer[3] and a specially designed copying system (Appendix A). This system enabled us to scale the ERTS scenes to match 1:1,000,000 map overlays. This scaling capability proved to be 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

Another factor that affects the value of ERTS data for forest inventory is the positional accuracy of points within the image. This is particularly important when precise locations of timber stands, sample plots, or particular areas of interest are concerned. For example, to locate the center of a perfectly square 4-hectare (10-acre) stand of timber, the positional accuracy must be at least ± 120 meters (390 feet). To relocate a circular 0.4-hectare (1-acre) sample plot requires a positional accuracy of ± 30 meters (100 feet). To be within a 100-meter-square sample, as called for in the original experimental design for this study, required a positional accuracy of only ± 50 meters (164 feet).

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

To check the geometric fidelity of both precision and bulk 9.5- x 9.5-inch data products, 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 1:20,000-scale color infrared (CIR) transparencies (dated October 2, 1972) to a copy of the original 1:250,000 Atlanta map sheet using a Zoom Transfer Scope (ZTS). 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-meter UTM grid intersections, and major natural and cultural features. The template was then matched to a bulk color-composite image (1102-15442-4, 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 were measured.

The results showed that the locational accuracy of this ERTS image was approximately 200 meters (656 feet). However, this error applies only when working 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 meters (656 feet) instead of 50 meters (164 feet) for conducting our experiment as originally designed.

DEFINITIONS

Any photo interpretation test begins with a list of classes, strata, or unknowns that must be delineated or recognized in some way on imagery. These classes must be real and definable on remotely sensed data, and they must be well-known by the interpreter.

Among government agencies today, the U. S. Geological Survey Circular 671, "A Land-use Classification System for Use with Remote-Sensor Data" has become the accepted source of Level I and Level II generalized land-use classes. Although the classes defined in Circular 671 cover most of the land-use variations that we feel are important to delineate forest land, there are some exceptions. It is because of these exceptions that we have developed our own hierarchy for the piedmont area of Georgia (Table 1). This hierarchy has been useful to evaluate remote sensing at three information levels. Levels I and II of our hierarchy conform quite well to Circular 671 Levels I and II. These include eight classes of resource data that are obtainable from ERTS. Level III of our hierarchy contains minor classifications definable from high-altitude aircraft photography or from some higher resolution satellite imagery. These more restricted classes are helpful to explain temporal differences found in the ERTS imagery. Furthermore, Level III classes are helpful to explain differences in interpretation by both human and machine classification systems.

The eight classes recognized on ERTS data for this study are defined in Appendix B. The definitions are based on Munsell Color notations[4]

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[4]Munsell Color Company. Munsell Book of Color. Ed. 1920-60. Baltimore. Munsell Color Co., Inc.

TABLE 1. A land classification hierarchy for remote sensing and ground information sources compatible with current nationwide Forest Survey objectives.

Remote Sensing Information		
Level I	Level II	Level III
Land Classification		
01 Forest Land	01 Conifer	01 Pine
		02 Pine-Hardwood
	02 Deciduous Hardwood	01 Upland Hardwood
		02 Bottomland Hardwood
02 Nonforest Land	01 Grassland	01 Undisturbed Grass
		02 Disturbed Grass
		03 Dead Grass (Annual)
		04 New Improved Grass
	02 Cropland	01 Immature Grain
		02 Immature Row Crop
		03 Mature Crop
		04 Harvested Crop
		05 Orchard
		06 Farm steads
	03 Bare Soil	01 Plowed Fields
		02 Errosion
		03 Urban (site preparations)
		04 Rock Outcrop
	04 Wild Vegetation	01 Idle Land
		02 Abandoned Land
		03 Transitional
		04 Kudzu
		05 Marshland
		06 Alder Swamp
	05 Urban	01 Transportation & Utilities
		02 Home Developments
		03 Commercial Developments
		04 Recreation
03 Water	01 Water	01 Clear Lakes & Ponds
		02 Turbid Lakes & Ponds
		03 Rivers & Streams

converted to ISCC-NBS color designations.[5] The definitions also include temporal variations found on the simulated color infrared composites for the three ERTS scenes used in this study.

PROCEDURES

The procedures and routines reported here were developed over a period of 2 years. These developments were fraught with many frustrations and discouragements because of equipment and material failures not to mention the lack of usable ERTS data when it was most needed. Through it all we prevailed and feel that the techniques reported here best accomplish the required tasks within time and manpower constraints and the limitations of the ERTS data delivery system.

Photo Interpretation

Land-use Classification

Preliminary studies showed that conventional photo interpretation of single-season ERTS data resulted in low classification accuracy (less than 40 percent). However, when temporal data for two scenes were viewed together, the accuracy increased to 67 percent. Using this background, the photo interpretation test reported here was made by viewing temporal data simultaneously. Prior to the photo interpretation test the interpreters were given special training that included looking at several examples of each resource class on high-altitude color infrared photography (1:120,000) and on the ERTS color composite coupled with ground truth. Then, two trained interpreters examined points and classified them into one of the eight forest and nonforest land-use classes defined previously. These

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[5]The ISCC-NBS Method of Designating Color and a Dictionary of Color Names. U. S. Department of Commerce, NBS, Circular 553. November 1, 1955.

points were scattered throughout the test site on an overlay as shown in Figure 3.

The overlay was attached to the April 1973 color composite of ERTS scene 1264-15445 and mounted in the center of a light table. The composite for the October 1972 ERTS scene 1084-15440 was mounted to the left of the April scene and the composite for the 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 (Figure 4). When this was completed, the stereoscope was moved to the right to view the April-June combination. The two independent interpretations of land-use classification were recorded for each interpreter and analyzed.

Interpretation results were summarized in two-way tables to show both the number and the percent of interpretations that were correct by class. These tables also show the number of points misclassified and the class they were assigned to.

An analysis of variance was made to determine whether there were significant differences between interpreters or between seasonal combinations. This analysis was based on a system of weights that varied from 1 to 5. A correct call received a weight of 1. Calling a forest point nonforest and calling a nonforest point forest were the most serious errors and received a weight of 5. This seemed to be an objective way of analyzing the results of our experimental objective in mind, i.e., how accurately can we estimate forest area?

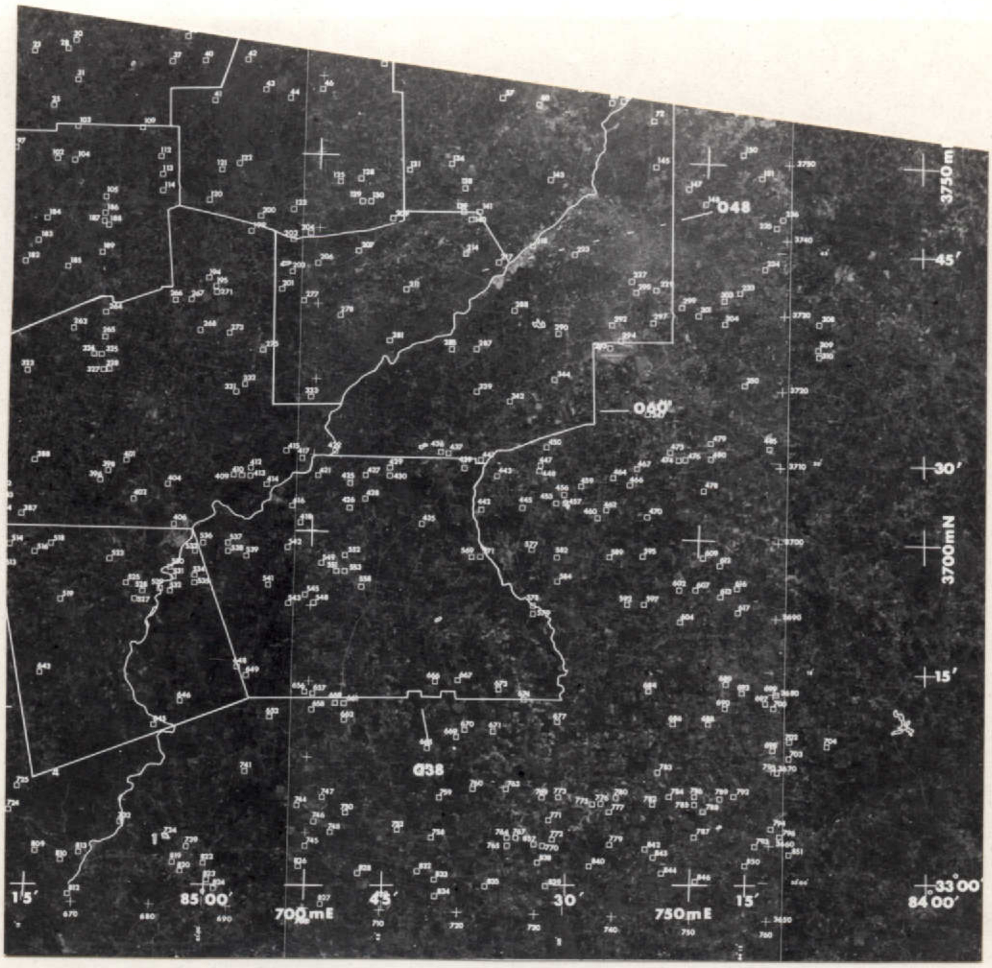

Figure 3. An overlay with 292 random sample points was attached to the April 13, 1973, color composite (1264-15445) for interpretation of eight land-use classes.

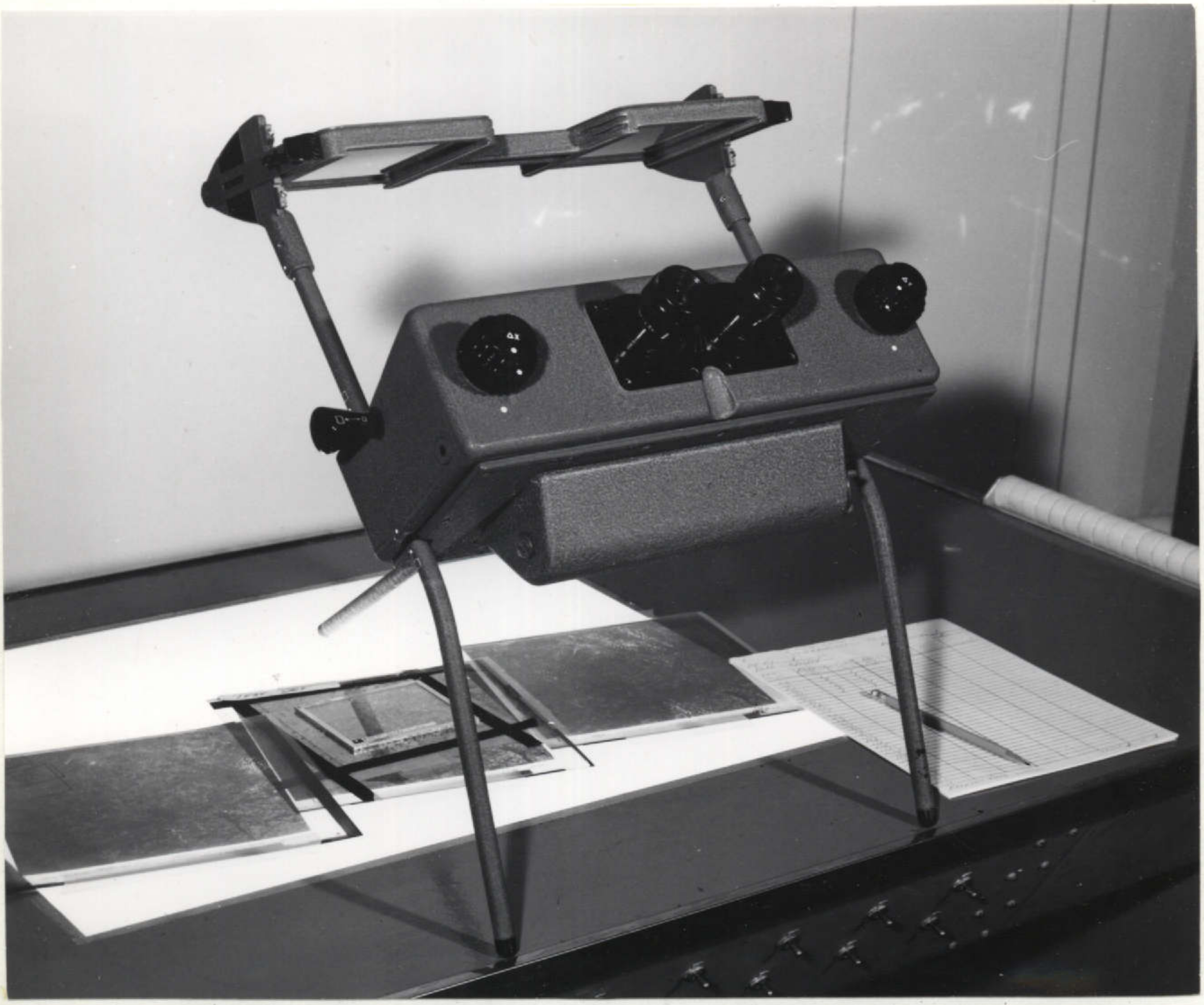

Figure 4. Each interpreter examined the center point of each sample with dual-season ERTS imagery using an Old Delft Stereoscope.

Forest Disturbances

It could be important at some time for a resource manager or a resource inventory analyst to know where and how much forest land has been disturbed by natural as well as manmade causes. ERTS would appear to be a proper and beneficial tool for monitoring these changes if the ground resolution were good enough, although its 18-day cycle is more frequent than required.

Carroll County, Georgia was selected as a site to test ERTS as a device for monitoring forest disturbances (Figure 5). Of concern were shifts in use between forest and nonforest classes, as well as timber harvesting, and natural disturbances such as fire, insects, disease, or flooding. Disturbance classes are defined in Appendix C.

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 detected a total of 209 disturbances. This detection was accomplished by viewing the two images simultaneously with a Bausch and Lomb Zoom Transfer Scope (ZTS) (Figure 6). The disturbed areas were circled on the photo index sheet, numbered, and the type of disturbance and number of acres recorded for each. Thirty-six additional points were circled where no disturbance had occurred.

An experienced photo interpreter was asked to examine 245 locations circled on the February 1966 photo index sheets for Carroll County, simultaneously with an April 13, 1973, ERTS color composite (scene 1264-15445). Before starting, the interpreter was given a short orientation in the identification of disturbances using photo aids (Figure 7) and an opportunity to practice using the ZTS. He was instructed to be as objective

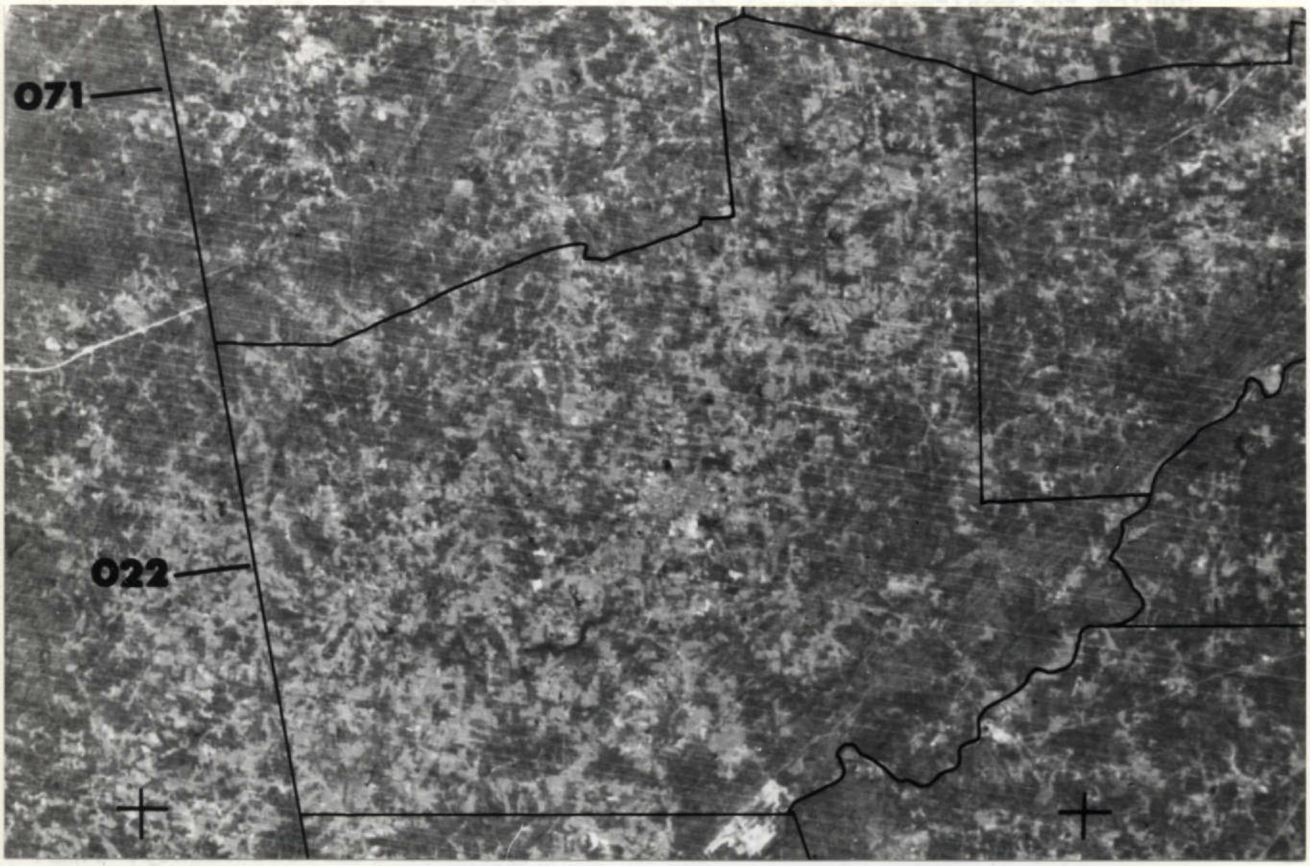

Figure 5. Carroll County, Georgia was used as a site to test ERTS as a device for monitoring forest disturbances. Carroll County was outlined on the ERTS color composite for scene 1264-15445 (April 13, 1973) with an overlay. The approximate scale of this reproduction is 1:500,000.

Figure 6. A Bausch and Lomb Zoom Transfer Scope was used to locate forest disturbances in Carroll County, Georgia. In the illustration, disturbances are being detected on ERTS scene 1264-15445 (April 1973) in conjunction with 1:63,360-scale photo index sheets for February 1966.

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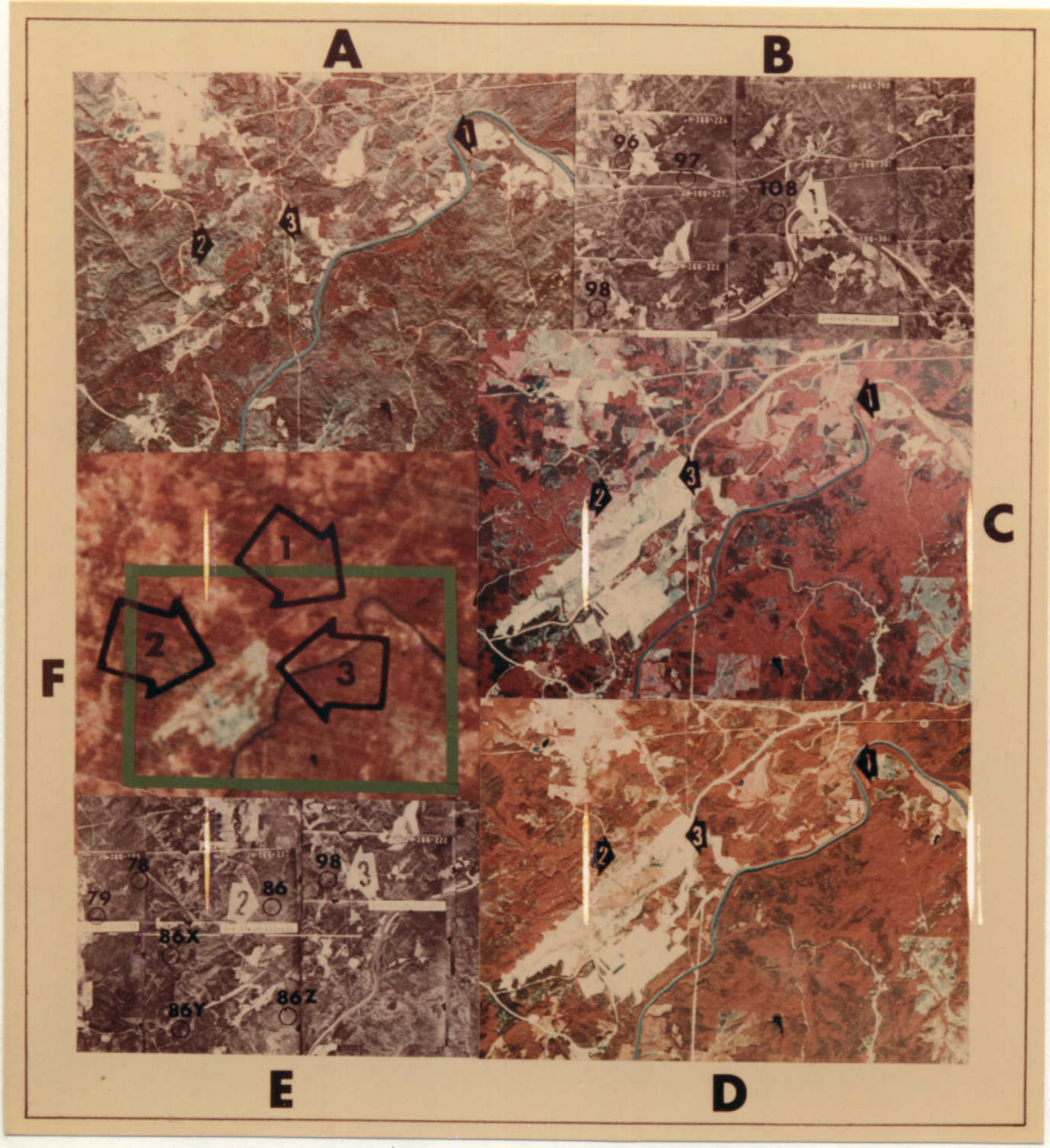


Figure 7. Forest disturbances are detected by comparing a current image with an image taken at an earlier date. For instance, land shown at B1 (108), E2 (86), and E3 (98), on February 1966 Department of Agriculture (ASCS) photo index sheets, appears disturbed on 1:120,000 CIR photos at C (June 1, 1972), and D (October 2, 1972). In November 1971 (A), when the deciduous trees were leafless, the disturbed areas were not as clearly separable. On the 1:200,000-scale enlargement of a portion of ERTS scene 1264-15445 (April 13, 1973) shown at F, all three disturbed areas are visible; points 1 and 2 were pulpwood cuttings and point 3 was cleared for a new power station.

as possible and was told that not all of the 245 points were real disturbances (only 209 were verified 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: (a) 0.4 to 2.0 hectares (1 to 5 acres), (b) 2.4 to 10.1 hectares (6 to 25 acres), (c) 10.5 to 20.2 hectares (26 to 50 acres), (d) 20.6 to 40.5 hectares (51 to 100 acres), (e) 40.9 to 202.3 hectares (101 to 500 acres), or (f) over 202.7 hectares (over 500 acres).

Ground Truth

Land-use Classification

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 photo interpretation 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 getting data to verify photo interpretation. Over 100 samples selected from 400 in a pre-ERTS photo training set were located on the ground. 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 a factor 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 the conditions that existed at the time.

Photo keys were prepared to illustrate the eight ERTS land-use categories (Figure 8). These keys were used to train interpreters to recognize the eight land-use classes on the three ERTS scenes used in the photo interpretation test.

Ground truth maps were drawn for three small test areas (Figure 9 and 10--in RESULTS). The maps were originally drawn to Level III land-use categories. However, these classes were later combined into the eight Level II ERTS classes to make comparisons with computer classification maps made from the ERTS CCT's.

Forest Disturbances

An additional 40 ground points in Carroll County were visited in January 1974 to verify forest disturbances detected on ERTS scene 1264-15445. Eighteen of these locations were regular Forest Survey plots on which some type of disturbance was recorded either during the reinventory of 1972 or by interpretation of current photography in 1973. Twenty-two additional locations were selected from a listing of 64 "off plot" disturbances that

Photo Key 6

Code	Classification
2	GRASSLAND
21	GRAZED

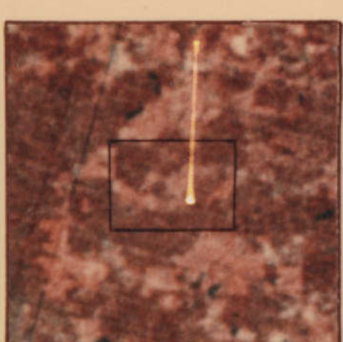
Description: A closely grazed pasture with vegetation consisting mainly of Bermuda grass (Cyndon sp.) and lespedeza (Lespedeaz sp.). Small blackberry patches and persimmon seedlings are scattered throughout this pasture.

Location: Coweta County, Georgia
Latitude 33°21'N
Longitude 84°38'E
Elevation 270.4 meters (900 ft.)

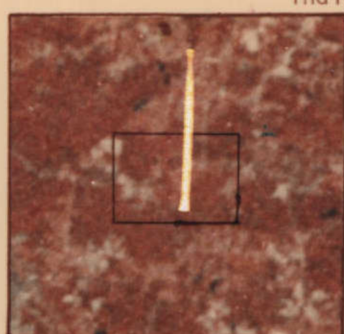
Date: October 7, 1972

N

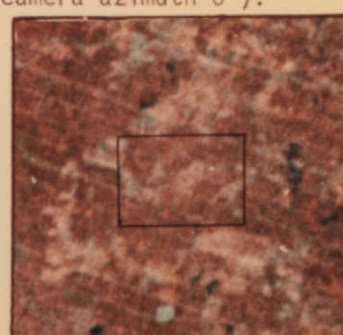
High-altitude color IR--Oct. 2, 1972
Ground photo angle is marked with an indicator (camera azimuth 6°).



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 8. A photo interpretation training aid to identify closely grazed grassland on high-altitude and ERTS photography. Seasonal changes are shown on the three ERTS photos.

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 would be correct in every case.

On each ground plot, the type of disturbance was observed and recorded. Also recorded were the condition 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.

Computer Processing by LARS (Purdue)

On March 22, 1974, the Forest Service made a contract with the Laboratory for Applications of Remote Sensing (LARS) facility at Purdue University to map three test blocks in the Atlanta site. The three blocks, each approximately 3,240 to 4,050 hectares (8,000 to 10,000 acres) in size, are shown by location in Figure 2. The CCT's for scenes 1084-15440 (October 1972) and scene 1264-15445 (April 1973) were furnished by NASA. All four spectral bands were included in the analysis.

Instructions on land-use classification categories to be used, area maps, and photographic aids were furnished by the PSW Remote Sensing Work Unit. Ground truth classification maps for two blocks (4 and 14) were also furnished as a source of computer training fields. However, no ground truth was furnished for block 6 since, by the terms of the contract, LARS was to test their procedures on block 6 by the extension of classification data from 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. It took at least 40 remote sensing units (RSU)[6] 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)).

In selecting RSU's for training fields, an element had to fall within at least two RSU's of a type-line to be used. By this criterion, all areas less than 5 acres were automatically eliminated from the selection process. By this process only 14 of 28 Level III land-use classes could be used because of an insufficient number of training fields (points) to select from. Four of these 14 classes had to be combined to provide enough points; cereal grain was combined with row crops and plowed fields were combined with borrow pits. This brought the total number of classes to be recognized down to 12. These were then finally reduced to nine classes after an initial performance test showed the combined class cereal grain and row crops, harvested crops, and urban, contributed significantly to classification errors in the other classes. Thus the final nine classes were identified as follows:

Level II Forest Service Class	LARS Class
01 Pine	01 Pine
02 Hardwood	02 Hardwood
03 Grassland	03 Grazed Grassland
	04 Undisturbed Grassland
04 Cropland	---
05 Bare Soil	05 Plowed Fields/Borrow Pits
06 Wild Vegetation	06 Idle

[6]Remote sensing unit (RSU) - term generated by R. Hoffer, LARS, which refers to reformatted, combined, and geometrically corrected ERTS digital elements. An RSU may be enlarged to fit any desired scale.

Level II Forest Service Class (cont.)	LARS Class (cont.)
	07 Abandoned
	08 Transitional
07 Urban	
08 Water	09 Water

As many training fields as possible were selected in each of the nine classes. In this way the number of training RSU's per class was roughly proportional to the class size. However a serious drawback to this procedure turned out to be that it left too few areas that met the requirements for a test set. Thus, to measure classification accuracy it was necessary for LARS to use training field performance. They justified this for several reasons:

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. Some subclasses had no area remaining to draw test fields from.

Development of PSW Computer Processing

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

Basically the classification system consists of groups of computer programs which allow for flexibility in handling an ERTS bulk computer compatible tape (CCT). There are five basic steps in the system between the raw digital data input and the final map product. Briefly, these steps are as follows:

1. Using the raw data for each channel, histograms and gray-scale computer maps are printed out on the line printer. These printouts are used to determine the range in radiance values and to locate corners of the study area.

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. Producing empirical distribution maps (EDMAP) to locate ground truth training samples and to screen the four channels of ERTS data as potential discriminators between land-use classes.

4. Selecting one of three classification procedures: (a) a boundary-finding algorithm to locate clusters of spectrally similar and adjacent pixels and assigning them to a land use, (b) a procedure that compares radiance of each digital element with the mean radiance of a sample from each land use, or (c) a linear discriminant analysis which uses maximum likelihood and Gaussian assumptions such as LARS (Purdue).

5. Making a final color-coded map on the off-line plotter and summarizing proportions of land area assigned to each land-use class.

These same procedures were used for the Black Hills test site. Additional details of the PSW computer classification system can be found in Appendix D.

Assessing Computer Classification Accuracy

After receiving copies of the LARS 1:24,000 computer classification maps, the PSW Remote Sensing Work Unit made two independent checks for accuracy. We justified these checks for the reason that the RSU's used in developing the original classification algorithm should not be used to check the accuracy of the algorithm. Instead, 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.

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, we should be able to locate the forested areas more than 90 percent of the time. Thus, the first accuracy check was based on the proportion of area classified in each land-use category. These proportions were converted to land area and compared with areas in each test block that had been derived from the ground truth maps. The second accuracy check looked at randomly selected pixels on a 1:24,000 overlay placed on the 1:24,000 LARS computer printout. Each point was examined and the LARS classification recorded. This classification was based on three independent observations: (1) the individual pixel at the point, (2) a subjective classification based on the nearest neighboring category, and (3) the greatest proportion of a matrix of 3 by 3 pixels surrounding the point. These then were compared with classifications taken from the ground truth maps at the same points. The ground truth at each point was determined by projecting the negative of the ground truth map onto the 1:24,000-scale random-point overlay with a Bausch and Lomb Transfer Scope.

These same procedures were followed to check the accuracy of the PSW classification procedure.

RESULTS

When comparing results of conventional photo interpretation (human) with results of the two computer classification systems reported here the reader should keep in mind differences in the two test designs. These differences in themselves bring out what are both advantages and disadvantages of computer classification. For example, the small physical dimensions of a 4,047-hectare (10,000-acre) area is no problem to a computer using digital data, but it does become a problem to 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, the only way to locate these specific areas is to print out portions of the digital tape on a computer gray-scale map representation. Specific resolution elements are then located by comparing the gray-scale map with details on aerial photographs. This rather mundane task is necessary because geometric errors within the ERTS data are too great for direct access by a coordinate system.

Photo Interpretation

Land-use Classification

Two photo interpreters correctly classified 98 percent of the 171 forest points on the October and April ERTS combination. Individually their scores were 99.4 and 96.5 percent, respectively (Table 2). The accuracy of nonforest land categories ranged from 25.0 percent for bare soil and 76.9 percent for urban. All four sample points falling in the water category were correctly classified by both interpreters; however, the small sample was not representative, and it is unlikely that small ponds

TABLE 2. Accuracy of Level I and II land-use classification by two photo interpreters on combined October and April ERTS data--7 classes.

Level I and II Land-Use Class	Code	Samples per class	Accuracy of classification			
			Interpreter I		Interpreter 2	
			Number Correct	Percent	Number Correct	Percent
Forest	1	171	170	99.4	165	96.5
Grassland	2	40	25	62.5	23	57.5
Cropland	3	15	5	33.3	4	26.7
Bare Soil	4	8	2	25.0	4	50.0
Wild Veg.	5	15	6	40.0	6	40.0
Urban	6	39	30	76.9	26	66.7
Water	7	4	4	100.0	4	100.0
ALL CLASSES	--	292	242	83.0	232	79.0

less than 0.4 hectares (1 acre) or streams less than 100 meters (328 feet) 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 meters wide or follow the same course taken by a scan line of the MSS. This factor becomes even more apparent when the computer classification outputs are examined.

The April-June ERTS combination showed very little difference in classification accuracy (Table 3). Most notable among the differences is a 20 percent increase in classifying grassland coupled with a similar decrease in the accuracy of classifying cropland. Almost 45 percent of the cropland samples were called grassland (Table 5). This seems to substantiate what was apparent to the interpreters at the time--that grassland and cropland cannot be easily separated on the June image because of the strong IR reflectance from the vegetative ground cover. When the separation was made correctly, it was usually based on the information in the April imagery. However, if grassland and cropland are combined as one class, 75 percent are correctly classified on the April-June combination; only 44 percent are correct on the October-April combination.

Misclassification errors combined for both interpreters and both seasonal combinations are shown in Tables 4 and 5. These data indicate the conflicts that exist between nonforest classes at the different seasons of the year. Of course some errors are caused by incorrect borderline decisions; this problem plagues photo interpreters even on larger scale aerial photography and is a primary source of error in area estimates

TABLE 3. Accuracy of Level I and II land-use classification by two photo interpreters on combined April and June ERTS data--7 classes

Level I and II Land-Use Class[1]	Code	Samples per Class	Accuracy of classification			
			Interpreter 1		Interpreter 2	
			Number Correct	Percent	Number Correct	Percent
Forest (I)	1	171	166	97.1	164	95.9
Grassland (II)	2	40	34	85.0	30	75.0
Cropland (II)	3	15	2	13.3	1	6.7
Bare soil (I)	4	8	4	50.0	4	50.0
Wild veg. (II)	5	15	1	20.0	1	20.0
Urban (II)	6	39	30	76.9	28	71.8
Water (I)	7	4	4	100.0	4	100.0
ALL CLASSES	--	292	241	82.5	232	79.5

[1] Numbers in parentheses refer to Level I or Level II classification.

TABLE 4. Land-use misclassification by two photo interpreters on combined October and April ERTS data--7 classes.

Level I and II Ground Class	Code	Forest 1	Grass-land 2	Crop-land 3	Bare Soil 4	Wild Veg. 5	Urban 6	Water 7	Total
Forest	1	--	2	0	0	3	2	0	7
Grass-land	2	1	--	11	1	13	6	0	32
Crop-land	3	2	7	--	2	8	2	0	21
Bare Soil	4	1	1	2	--	1	5	0	10
Wild Veg.	5	5	5	2	1	--	5	0	18
Urban	6	8	8	1	1	4	--	0	22
Water	7	0	0	0	0	0	0	--	0
TOTAL	--	17	23	16	5	29	20	0	110

TABLE 5. Land-use misclassification by two photo interpreters on combined April and June ERTS data--7 classes.

Level I and II Ground Class	Code	Forest 1	Grass-land 2	Crop-land 3	Bare Soil 4	Wild Veg. 5	Urban 6	Water 7	Total
Forest	1	--	1	1	0	2	6	0	10
Grass-land	2	1	--	4	2	6	5	0	18
Crop-land	3	2	12	--	9	1	3	0	27
Bare Soil	4	0	2	2	--	1	3	0	8
Wild Veg.	5	4	4	10	3	--	7	0	28
Urban	6	4	7	1	4	4	--	0	20
Water	7	0	0	0	0	0	0	--	0
TOTAL	--	11	26	18	18	14	24	0	111

based on interpreting a systematic sample of grid points. On ERTS imagery this type error is probably more common because of the low resolution and the "blooming" factor caused when one image (lighter color) bleeds into another. Despite this, it is interesting to note that 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 photo interpretation techniques.

The most serious forest classification errors were caused by identifying wild vegetation and urban land as forest. Wild vegetation in the form of abandoned agriculture and transitional agriculture 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 overall accuracy of classification for two interpreters is 96 percent (Table 6). This accuracy seems to hold true for both seasonal combinations which makes it very unlikely that there is 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

TABLE 6. Accuracy of Level I land-use classification on combined October-April ERTS color composites--two interpreters.

Level I land-use class	Samples per Class	Accuracy of classification	
		Number Correct	Percent
Forest	342	335	97.9
Nonforest	234	217	92.7
Water	8	8	100.0
ALL CLASSES	584	560	95.9

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.

Table 7 shows the accuracy obtained for Level II forest classification. 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. However, if the bottomland is combined with upland the overall classification 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 combinations. Interpreter 2 mistook cutover areas for hardwood type on the October-April combination.

An analysis of variance based on weighted interpretation errors showed that there were significant differences between interpreters and, as might be expected, highly significant differences between land-use classes (Table 8). There was no statistically significant difference between the two seasonal ERTS combinations used in the study. This was not unexpected since data summaries in Tables 2 and 3 indicated little difference in classification accuracy. Interpreter differences on the other hand are not so easily explained. However, the summary of mean weighted errors for six Level II classes by two interpreters (Table 9) indicates that there was apparently a difference in interpreter ability particularly for the agricultural

TABLE 7. Accuracy of Level II forest land classification by two photo interpreters on two seasonal ERTS data combinations--4 classes.

Level II Forest Class	Code	Ground Truth	Accuracy of Classification							
			October - April				April - June			
			Interp. 1		Interp. 2		Interp. 1		Interp. 2	
		Number	No.	%	No.	%	No.	%	No.	%
Pine	11	77	52	67.5	50	64.9	40	51.9	46	59.7
Bottomland hardwood	13	28	3	10.7	6	21.4	6	21.4	2	7.1
Upland hardwood	14	59	33	55.9	18	30.5	38	64.4	20	33.9
Cutover	15	7	7	100.0	1	14.3	7	100.0	7	100.0
ALL CLASSES	--	171	95	55.6	75	43.9	91	53.2	75	43.9

TABLE 8. An analysis of variance table for 6 land-use classes,[1] 2 interpreters, and 2 seasonal ERTS combinations.

Source of Variation	Sums of Squares	Degrees of freedom	Mean Squares	F Value	Probability Level of F
Interpreters (I)	.1756	1	.1756	7.1043	.9824*
Season (S)	.0179	1	.0179	.7249	.5921
I X S	.0189	1	.0189	.7642	.6042
Land Use	3.7966	5	.7593	30.7246	1.000**
Error	.3707	15	.0247	---	---
TOTAL	4.3797	23	---	---	---

* - significant

** - Highly significant

[1] See Level II land-use classes (six) listed in Table 9.

TABLE 9. Mean weighted land-use classification errors for two photo interpreters on the October-April ERTS data combination--all Level II classes.

Land-use class	Interpreter 1	Interpreter 2	Difference
	Mean Weighted Error[1]		
Pine	1.32	1.29	-0.03
Hardwood	1.44	1.65	+0.21
Grassland	1.80	2.00	+0.20
Agriculture	1.95	2.53	+0.58
Urban	1.74	2.15	+0.41
Water	1.00	1.00	0.00
TOTAL	9.25	10.62	+1.37

[1]A mean weighted error of 1.00 indicates 100 percent classification accuracy. The poorest possible classification accuracy would have a mean weighted error of 5.00.

and urban classes. Apparently when all nonforest classes are lumped together these errors are of little significance, lending more credence to the value of ERTS as a device for Level I land-use classification.

Forest Disturbances

There are three important conditions that must be met before recognition of disturbances in a forest environment is possible. First and foremost, it is necessary to have a base photograph taken at some earlier date to be able to detect changes (Figure 8). This photograph might be useful if it were taken 3 to 5 years prior to the proposed inventory. Second, it is necessary to have a picture of the same scene made by a remote sensor as close to "real time" as possible. This need is particularly acute in areas where changes are occurring most frequently. Third, it is necessary to have compatibility in photographic scale for both the base photograph and the current photograph. Wide variation in scales such as between the 1:64,000-scale photo index sheets and 1:1,000,000-scale ERTS imagery require specialized equipment such as the ZTS to view the imagery simultaneously.

Season of the year is a critical factor in interpretation of disturbed areas when viewing low-resolution (50 to 100 meters) imagery, such as ERTS. When high-altitude photography is used, seasonal differences do not seem to be quite as important because of the better resolution. A general rule for ERTS is to choose imagery during the period from early spring to late spring as a first choice and from the period late fall to late winter as a second choice. The reason for this difference is that during these periods the deciduous trees are either newly leafed out with high IR reflectant foliage in spring or leafless in winter, and the discrimination between deciduous trees and coniferous trees is much better at these times. On the other hand, summer and early fall ERTS images are oversaturated with IR reflectance and cutover and uncut hardwoods show little reflectance 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.

To test the possibilities of detecting change on ERTS, we first located and verified 209 forest disturbances on recent (1972) 1:120,000-scale CIR photography of Carroll County, Georgia. Then one photo interpreter, who was not involved with the study previously, detected and correctly classified 165 or 79 percent of the verified disturbances on an ERTS color composite for April 13, 1973 (Table 10). Another 23 disturbances, or 11 percent were misclassified. However, since detection is much more important than the correct identification, 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 omitted, i.e., not detected on ERTS, making for about a 10 percent error. Two-thirds of the omissions were less than 10.1 hectares (25 acres) and more than half of these were less than 2.0 hectares (5 acres). Although our data are limited, it would appear that most omissions fall in small land clearings and cutover forest areas. Commission errors are caused by calling something disturbed that was not disturbed. These errors are important because in application to a survey program it would mean for each interpretation error there would be one unnecessary field visit. At the approximate cost of $100.00 per visit, such errors could be expensive unless

TABLE 10. Number of forest disturbances detected by one photo interpreter on Earth Resources Technology Satellite color composite (1264-15445) by size class.

Disturbance Category	Number of Disturbances	Size Class Hectares (Acres) <2 (<5)	2-10 (5-25)	11-20 (26-50)	21-40 (51-100)	41-202 (101-500)	202 (500 +)	Total	Percent Correct
Harvested Forest Land	41	2	6	5	4	5	7	29	71
Land Clearing									
No Change	4	0	2	0	0	1	1	4	100
Forest to Agriculture	100	40	30	4	5	1	0	80	80
Forest to Urban	23	6	11	3	0	0	1	21	91
Forest to Water	18	9	5	1	0	0	0	15	83
Natural Cause	0	0	0	0	0	0	0	0	--
Regeneration to Forest	8	1	1	0	0	0	0	2	25
Other	15	0	10	1	0	3	0	14	93
TOTAL	209	58	65	14	9	10	9	165	--
	—	PCT	PCT	PCT	PCT	PCT	PCT	PCT	PCT
Correct		76	84	77	75	66	81	---	79

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 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 as artificial regeneration, (2) the inability to detect ground-fire damage after 1 year, (3) the inability to detect single-tree mortality, and (4) the inability to detect selective logging or stand improvement cuttings after 2 years.

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

Computer Classification

LARS System

Areas of land use estimated by LARS show surprisingly close agreements with areas derived from ground truth maps. This is particularly true of the Level II classes--pine, hardwood, and water. Table 11 shows the number of hectares and the proportion of the total land area 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 in 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.

When we move out of forest land, however, the accuracy of land-use classification was considerably reduced. 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 very unique 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. This error can be explained in part by the cutover hardwood stands that occur over large areas that LARS classed as wild vegetation.

TABLE 11. Areas of land use classified by LARS computer procedures compared with ground truth[1] for three test blocks; ERTS scene 1084-15440 October 15, 1972.

Level II Land Use	Block 4				Block 14				Block 6			
	Ground		Computer		Ground		Computer		Ground		Computer	
	Hectares	%	Hectares	%	Hectares	%	Hectares	%	Hectares	%	Hectares	%
Pine	1,093	30.9	921	26.0	1,476	37.2	1,400	35.3	764	19.7	698	18.0
Hardwood	620	17.5	747	21.1	1,166	29.4	1,131	28.5	2,465	63.6	2,205	56.9
Grassland	814	23.0	595	16.8	401	10.1	198	5.0	109	2.8	124	3.2
Cropland	103	2.9	---[3]	---	16	0.4	---	---	136	3.5	---	---
Bare Soil	64	1.8	170	4.8	44	1.1	246	6.2	19	0.5	97	2.5
Wild Veg.	393	11.1	1,061	30.0	436	11.0	968	24.4	132	3.4	729	18.8
Urban	393	11.1	---	---	412	10.4	---	---	236	6.1	---	---
Water	60	1.7	46	1.3	16	0.4	24	0.6	15	0.4	23	0.6
Total[2]	3,540	100.0	3,540	100.0	3,967	100.0	3,967	100.0	3,876	100.0	3,876	100.0
	(8,747)[4]		(8,747)		(9,803)		(9,803)		(9,578)		(9,578)	

[1]Areas were determined by dot count on ground truth maps at an intensity of 2 dots per acre.

[2]Total area was determined by the mean of three planimeter measurements on 1:62,500 USGS 15-minute quadrangle sheets.

[3]Dashes represent not classified by LARS.

[4]Numbers in parentheses are acres.

PSW System

The PSW computer classification system, with a different classification algorithm and much less sophisticated computer hardware, was reasonably successful in this test. For example, the areas of pine and hardwoods in Table 12 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 using a combination of the training sets from blocks 4 and 14.

Unlike the results of LARS, pine area was always overestimated and hardwood underestimated. This was true 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, wild vegetation in block 6 was badly overestimated because cutover hardwood stands had spectral signatures similar to abandoned and transitional agriculture land. Urban areas were underestimated as would be expected because of the resolution limitations of ERTS. Water was underestimated for the same reason. However, the estimates of water were fairly good considering the small area of water in these study blocks.

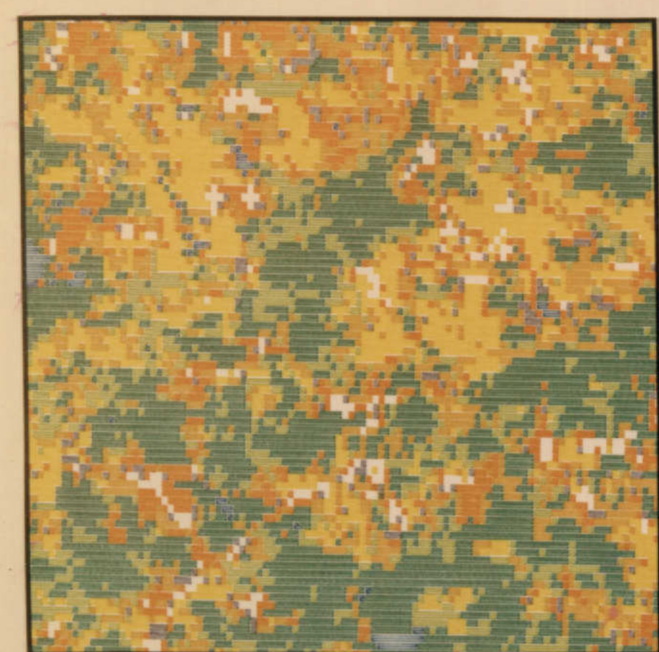
Comparison of LARS and PSW Computer Classification Systems

The displays of LARS and PSW classification maps in Figures 9 and 10 give the reader a visual comparison of the two systems with ground truth maps. Probably the first impression is a very good agreement. However, because the human eye and brain are not capable of scanning, assimilating, Atlanta, Georgia

Computer Map

Block 4

Produced by: Forest Service (PSW)



Scale

0 1 2 Mi.

0 1 2 3 Km.

Description

Data Source:
ERTS Scene 1084-15440, 10/15/72
System Corrected CCT'S

Spectral Bands:
4, 5, 6, 7

Classification Method:
Nearest neighbor procedure

Legend:

Pine	Cropland
Hardwood	Wild vegetation
Grassland	Urban
Bare soil	Water

Atlanta, Georgia

Ground Truth

Block 4

Produced by: Forest Service (PSW)

Scale

0 1 2 Mi.

0 1 2 3 Km.

Description

Data Source:
1:60000 color infrared photo by NASA ERAP Mission 214, 10/2/72

Classification Method:
Photo interpretation at 4X mag. and ground checks.

Legend:

Pine	Cropland
Hardwood	Wild vegetation
Grassland	Urban
Bare soil	Water

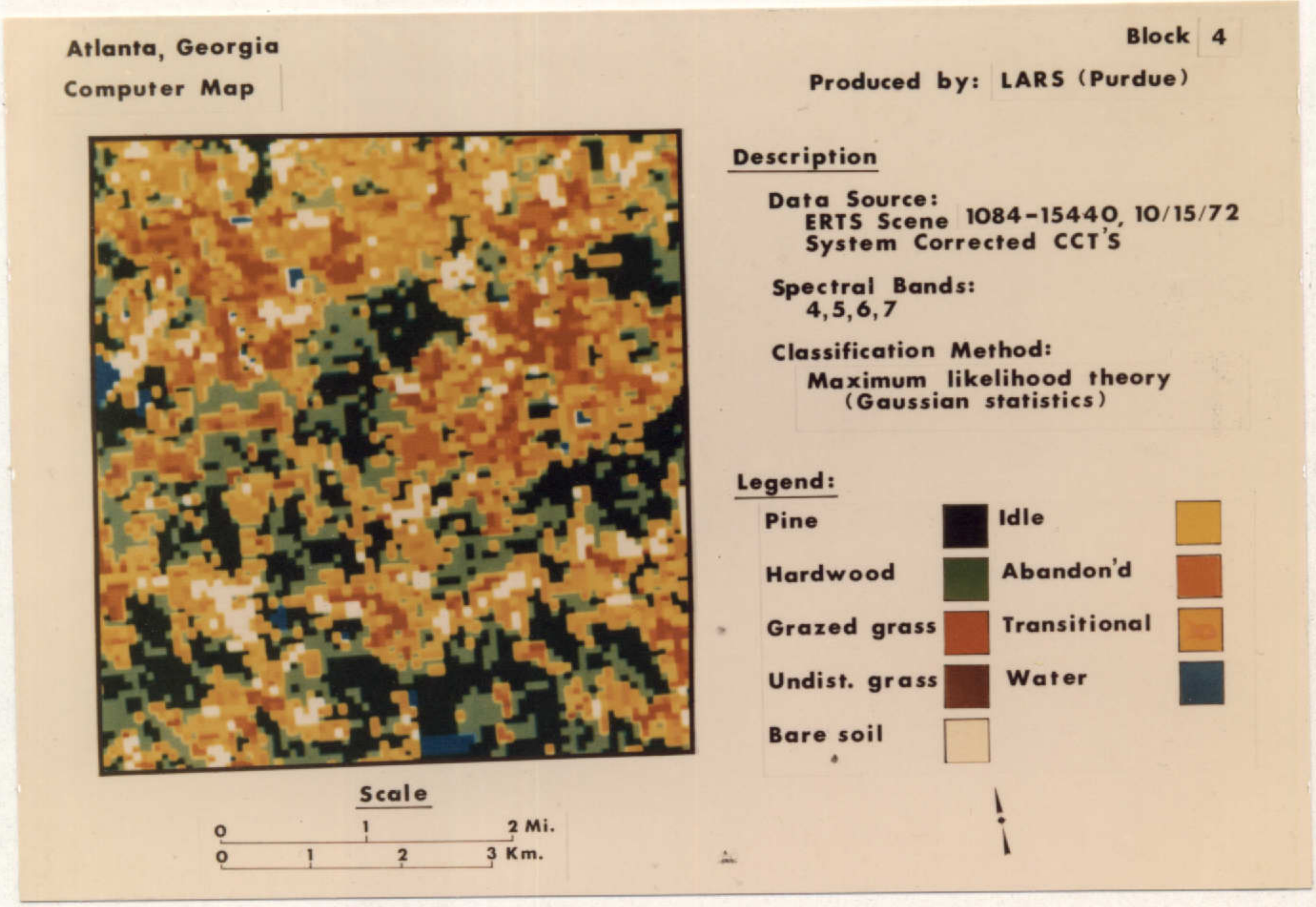


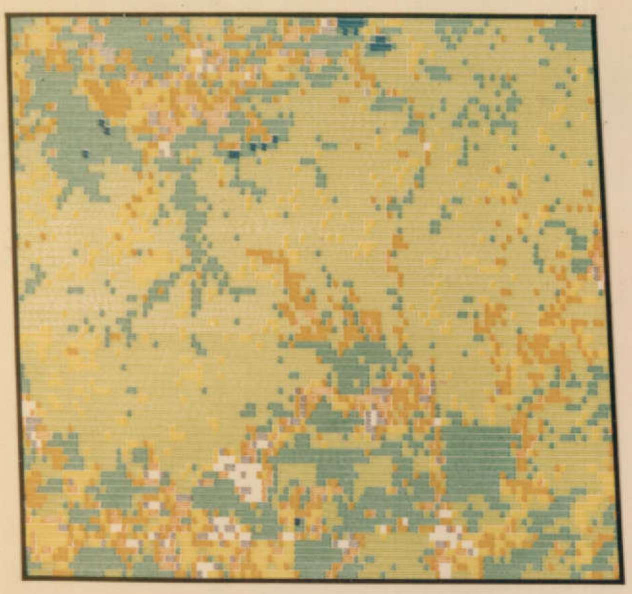
Figure 9. Two computer mapping systems are compared for block 4. In the upper half of the opposite page is the map produced by the PSW computer classification system using a CDC 7600 computer. The map itself was produced by an off-line tape-driven plotter (EAI) with 8 colored marking pens. On this page above is a map produced by the LARS (Purdue) system. The map was made photographically from a cathode ray tube (CRT) display using a filtering technique. Both computer maps were made using training sets selected from each land-use class within the mapped area. Print-by-print evaluations can be made by the reader using the ground truth map in the lower half of the opposite page.

Atlanta, Georgia

Computer Map

Block 6

Produced by: Forest Service (PSW)



Description

Data Source:
ERTS Scene 1084-15440, 10/15/72
System Corrected CCT'S

Spectral Bands:
4,5,6,7

Classification Method:
Nearest neighbor procedure

Legend:

Pine		Cropland	
Hardwood		Wild vegetation	
Grassland		Urban	
Bare soil		Water	

Scale

0 1 2 Mi.

0 1 2 3 Km.

Atlanta, Georgia

Ground Truth

Block 6

Produced by: Forest Service (PSW)

Description

Data Source:
1:60000 color infrared photo by NASA ERAP Mission 214, 10/2/72

Classification Method:
Photo interpretation at 4X mag. and ground checks.

Legend:

Pine		Cropland	
Hardwood		Wild vegetation	
Grassland		Urban	
Bare soil		Water	

Scale

0 1 2 Mi.

0 1 2 3 Km.

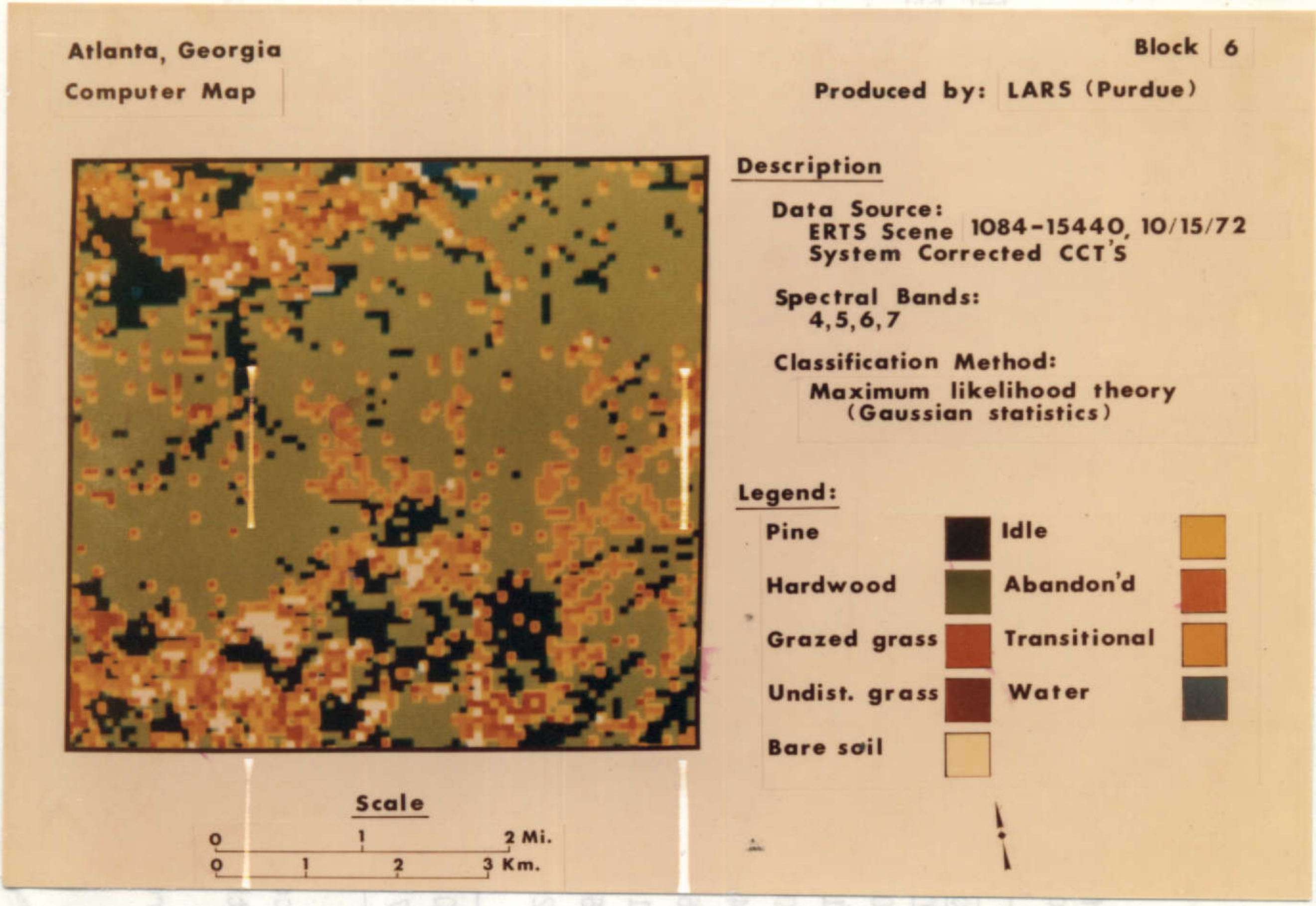


Figure 10. Two computer mapping systems are compared for block 6. In the upper half of the opposite page is the map produced by the PSW computer classification system using a CDC 7600 computer. The map itself was produced by an off-line tape-driven plotter (EAI) with 8 colored marking pens. On this page is a map produced by the LARS (Purdue) system. The map was made by photographing a cathode ray tube (CRT) display using color filters. Both maps were made using a combination of the training set data for block 4 and and 14. Point-by-point evaluations can be made by the reader using the ground truth map in the lower half of the opposite page.

TABLE 12. Areas of land use classified by PSW computer procedures compared with ground truth[1] for three test blocks; ERTS scene 1084-15440, October 15, 1972

Level II Land Use	Block 4				Block 14				Block 6			
	Ground		Computer		Ground		Computer		Ground		Computer	
	Hectares	%	Hectares	%	Hectares	%	Hectares	%	Hectares	%	Hectares	%
Pine	1,093	30.9	1,270	35.9	1,476	37.2	1,749	44.1	764	19.7	946	24.4
Hardwood	620	17.5	471	13.3	1,166	29.4	964	24.3	2,465	63.6	1,849	47.7
Grassland	814	23.0	570	16.1	401	10.1	460	11.6	109	2.8	391	10.1
Cropland	103	2.9	354	10.0	16	0.4	60	1.5	136	3.5	128	3.3
Bare Soil	64	1.8	96	2.7	44	1.1	119	3.0	19	0.5	54	1.4
Wild Veg.	393	11.1	641	18.1	436	11.0	452	11.4	132	3.4	419	10.8
Urban	393	11.1	106	3.0	412	10.4	155	3.9	236	6.1	74	1.9
Water	60	1.7	32	0.9	16	0.4	8	0.2	15	0.4	15	0.4
Total[2]	3,540	100.0	3,540	100.0	3,967	100.0	3,967	100.0	3,876	100.0	3,876	100.0
	(8,747)[3]		(8,747)		(9,803)		(9,803)		(9,578)		(9,578)	

[1]Areas were determined by dot count on ground truth maps using an intensity of 2 dots per acre.

[2]Total area was determined by the mean of three plainmeter measurements on 1:62,500 USGS 15-minute quadrangle sheets.

[3]Numbers in parentheses are acres.

and sorting all of the data in a glance, more objective techniques had to be used to evaluate the systems.

The individual discussions of system accuracies showed that both systems estimated forest land areas within reasonable limits. However, estimates of area by individual Level II classes were poor. This implies that ERTS-1 is really a Level I land-use sensor system. It is not surprising then, when Level I area estimates are compared by class with areas measured on ground truth maps, that very good agreement is seen (Table 13). For instance, forest area in both blocks 4 and 14 were within 2 percent of ground truth using either system. LARS underestimated forest and PSW overestimated forest. However, estimates of forest area in block 6, made with training sets from blocks 4 and 14, indicated 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. For instance, block 6 had a higher proportion of forest land, a higher proportion of hardwood type, 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 comptuer systems.

When the classified areas were combined by class for all three blocks (Table 13), the PSW estimate of forest land for a combined unit of 11,383 hectares (28,129 acres) is 7,250 hectares (17,916 acres). The ground truth is 7,589 hectares (18,725 acres). The difference, -327 hectares (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 with ground truth was -476 hectares (-1,176 acres) or 6 percent. Both

TABLE 13. Comparative accuracy of area estimates for two computer classification systems; ERTS scene 1084-15440, October 1972.

Level I Land Use	Study Block	Ground Truth		LARS System		PSW System	
		Hectares	%	Hectares	%	Hectares	%
Forest	4	1,710	48.3	1,667	47.1	1,742	49.2
	14	2,638	66.5	2,531	63.8	2,713	68.4
	6	3,229	83.3	2,903	74.9	2,795	72.1
All Blocks		7,577 (18,723)[1]	66.6	7,101 (17,547)	62.4	7,250 (17,915)	63.7
Nonforest	4	1,766	49.9	1,827	51.6	1,766	49.9
	14	1,313	33.1	1,412	35.6	1,246	31.4
	6	632	16.3	950	24.5	1,066	27.5
All Blocks		3,711 (9,170)	32.6	4,189 (10,351)	37.8	4,078 (10,077)	35.8
Water	4	64	1.8	46	1.3	32	0.9
	14	16	0.4	24	0.6	8	0.2
	6	15	0.4	23	0.6	15	0.4
All Blocks		95 (235)	0.8	93 (230)	0.8	55 (136)	0.5
All Classes	4	3,540	100.0	3,540	100.0	3,540	100.0
	14	3,967	100.0	3,967	100.0	3,967	100.0
	6	3,876	100.0	3,876	100.0	3,876	100.0
Grand Total		11,383 (28,128)	100.0	11,383 (28,128)	100.0	11,383 (28,128)	100.0

[1]Numbers in parentheses are acres.

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 land. The accuracy of water estimates are more important. However, water is not a major land use in the three study blocks. With just 94 hectares (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 hectare (1 acre) in size. With this in mind, it is remarkable that LARS measured 93 hectares (231 acres) of water --one less than the ground truth. Although the PSW system could only measure 55 hectares (137 acres) of water, it still seems pretty reasonable for a class that occupies only 0.8 percent of the total area.

Probably the most stringent test of either system is to locate a point on both the computer map and the ground truth map and then compare the classifications. 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. Classifications based on proportion of a 3- x 3-pixel matrix were almost as effective but required more time to make the evaluation.

The results of a point-by-point examination are given in Table 14. Generally speaking, LARS is correct more often than PSW--the totals for all classes reflect a 20 percent difference. If Level II land classification is maintained, the overall accuracy will probably 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,

TABLE 14. Comparison of percent accuracy at random sample locations on maps from two computer classification systems[1], ERTS scene 1084-15440, October 1972.

Level II land-use	Ground Truth			LARS Map			PSW Map		
	Block 4	Block 14	Block 6	Block 4	Block 14	Block 6	Block 4	Block 14	Block 6
	-Number of Points-			-Percent Correct-			-Percent Correct-		
Pine	48	69	20	63	80	55	58	59	42
Hardwood	30	59	124	62	70	81	23	53	61
Grassland	47	21	7	53	43	43	40	52	0
Bare soil	15	14	10	33	57	20	7[2]	50[2]	20[2]
Wild veg.	31	26	11	69	70	91	35[3]	27[3]	54[3]
Water	7	6	2	70	100	100	43	67	50
All Classes	178	195	174	59	71	74	38	52	54

[1]Classification for a single pixel at the point.

[2]Includes urban to compare with LARS.

[3]Includes cropland to compare with LARS.

the accuracy for forest land classification would be 90 percent by LARS and 80 percent by PSW. This is another good indicator that ERTS-1 is only a Level I sensing system.

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. Figure 11 shows the LARS and PSW computer maps for block 6 as a comparison.

Unfortunately LARS used the algorithms developed for October to classify April spectral data. The results show many areas to be misclassified. Most noteworthy 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, there appear to be problems involved in computer classification using seasonal data that are not straightforward. More work should be carried on to isolate seasonal variations and combine seasonal data to improve computer classifications.

Possible Applications

One Forest Service unit with the greatest chance of benefiting from ERTS data is the nationwide Forest Survey. 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

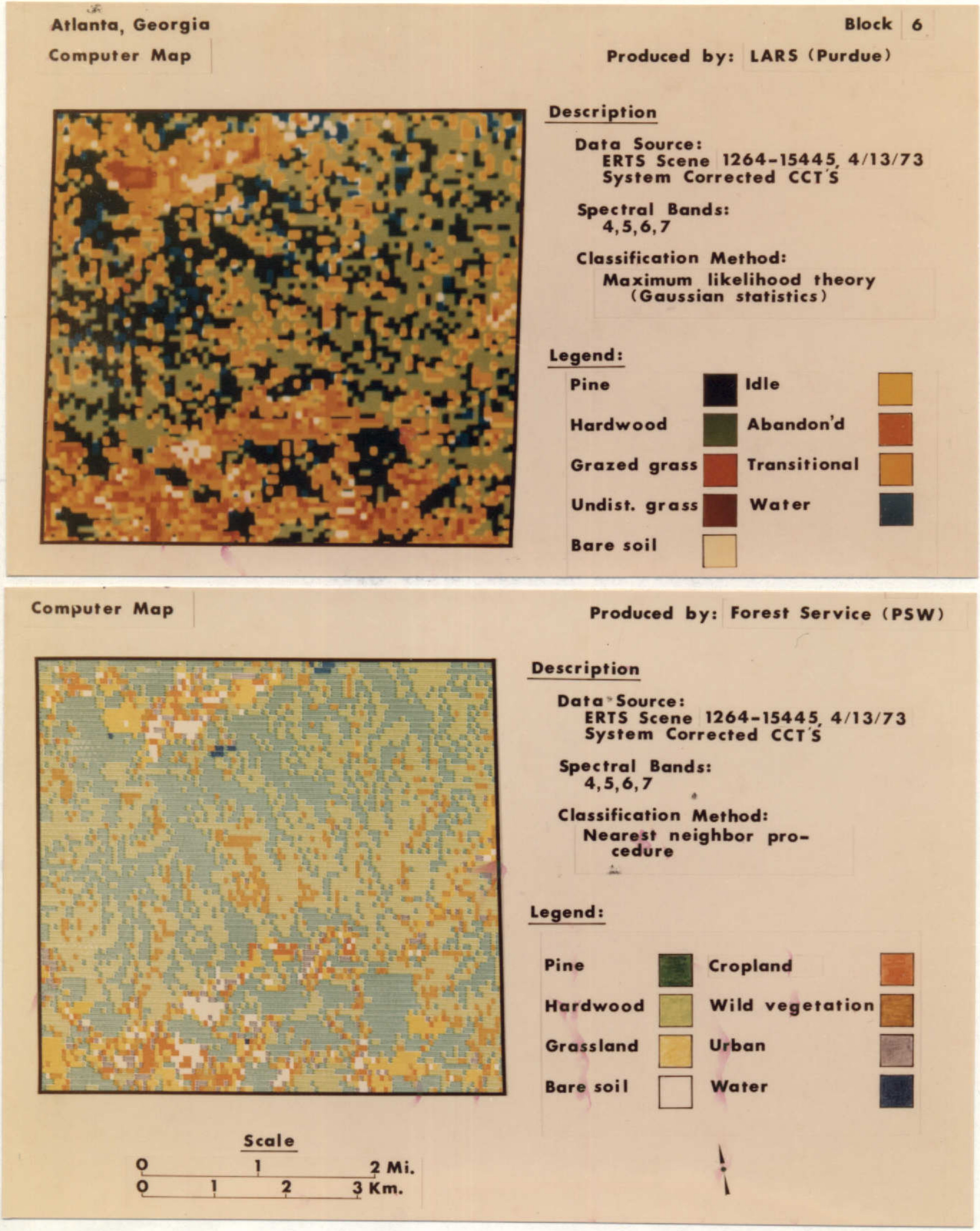


Figure 11. The two computer classification maps for block 6 were made using bulk CCT's for scene 1264-15445-4, 5, 6, 7 (April 13, 1973). The upper map was made by the LARS system using a combination of training sets for block 4 and 14 based on October data. The lower map was made by the PSW system using a combination of training sets for block 4 and 14 based on April data. By comparing these maps with those in Figures 9 and 10, the errors are quite obvious.

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of forest information--particularly in areas where there is a great deal c human activity. To be beneficial, however, ERTS must either provide information that will reduce present survey costs or provide information that is needed but cannot be obtained because of the high acquisition cost.

Forest areas estimated by computer classification reported here for relatively small areas were better than the accuracies now required by the Forest Survey for counties. Although this is very encouraging, there are several questions that 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 cents per hectare (0.005 cents per acre). It is difficult to establish a per-hectare cost based on the research reported here.

2. How can county lines be located within the ERTS data to obtain accurate county areas?

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?

At the present time a reinventory of the forest resources is made for each of the five Southeastern States approximately every 10 years. However, there are pressures in some areas of unusually heavy timber harvesting activity and land-use change to update the inventory every 3 to 5 years. In these areas, the present method is to use a light aircraft with an observer locating on existing aerial photos plots that have been disturbed. These plots are then reinventoried on the ground and the forest statistics for the county updated. This system is relatively slow, hazardous, and costly compared to using low-cost remote sensor data from space. ERTS-1 has been shown to provide a base for detecting disturbances over 1 hectare (2 acres) in size. The accuracy of detection can be as high as 80 percent. However, these research results must be duplicated under operational conditions to learn the true value of ERTS from a cost-benefit standpoint.

FOREST STRESS

Stress detection in our Nation's wildlands and forests is a large multiagency task for which several millions of dollars are spent each year conducting aerial and ground surveys. Stress detection in the National Forest System usually means the detection of insect or disease damage and the evaluation of impact in terms of counting the number of killed or damaged trees.

The purpose of the forest stress section of the ERTS proposal was to determine the potential usefulness of low-resolution satellite systems to detect and monitor forest stress. It was our belief that despite the rather poor spatial resolution specifications for the multispectral scanner subsystem, stress might be detected by (1) spectral separation of the resulting tree fading[7] and (2) by using the temporal capabilities of ERTS to detect change in the forest canopy which may permit us to compare imagery from successive 18-day cycles of the satellite. Therefore, we hypothesized that ERTS MSS imagery could not detect stress in forests and established a research investigation to disprove the hypothesis.

BACKGROUND INFORMATION

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.

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[7]The term "fading" is a colloquial expression for a dead or dying tree showing visible discoloration of the foliage.

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 et al., 1959). An epidemic outbreak of the mountain pine beetle in the northern Black Hills in 1963-64 gave rise to further involvement of the Forest Service Remote Sensing Research Unit. Aerial color photographs were taken at a scale of 1:7,920 over the northern Black Hills and 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 was established between NASA and the Department of Agriculture which launched the Remote Sensing Research Unit on a 7-year cooperative effort of stress detection research in the SR&T program.

Related SR&T Studies

Detailed studies on the Black Hills National Forest from 1965 to 1971 sought to establish guidelines for forest managers using aerial photography to assess host impact from damage caused by the mountain pine beetle. Simultaneous aerial and ground studies defined the usefulness of large- and small-scale photography in terms of cost effectiveness.

Large-scale (1:1,584) color aerial photography is 95 percent effective for counting individual dead and dying ponderosa pine in August, 1 year following initial attack by the mountain pine beetle. Neither color nor color infrared photography was successful for previsual detection of pine trees under stress, and only 60 percent of the dying trees were identified during May, 10 months after attack and initiation of stress. Color photography was preferred by entomologists and foresters for detecting dying trees and was just as accurate as color infrared film at a scale of 1:15,840. At smaller scales, CIR photography was preferred because of the superior haze penetration characteristics introduced by the use of the required minus blue filter. Optimum timing of aerial photography to detect faded trees is from August 20 to September 10. Photo interpretation of color infrared photography taken after September 10 will incur a high number of commission errors caused by interpretation of hardwoods in fall coloration as infestation spots. Normal color photography at a scale of 1:7,920 is optimum for entomologists who wish to count small infestations with high reliability, although little loss in accuracy is endured at an alternative scale of 1:15,840 where efficiency is greatly improved. Resource managers who require infestation trend data do well with color infrared photography at a scale of 1:31,680 (Heller and Wear, 1969). Only a few infestations of 10 or more trees are missed at this scale and the cost saving introduced by larger area coverage is considerable.

Biophysical studies were maintained on the ground for 3 years (1966-68) to determine the physiological impact of mountain pine beetle attack on host trees (Weber, 1969). Information necessary for the interpretation and utilization of airborne multispectral data for tree vigor evaluation was gained from sorting out the complex physiological and environmental relationship which exist on the ground. The continuous assessment of tree vigor in relation to the environment is essential for understanding successes and failures in the airborne detection phase of the research. Because of the nature of mountain pine beetle activity in the infested trees, and the associated destructive action of the blue stain fungi, most tree measurements had to do with water metabolism, leaf temperature, and energy exchange. Throughout the program and up to the beginning of the ERTS study in the Black Hills in 1972, a great deal was learned about how to measure biophysical responses, what the relevant measurements are for use with multispectral scanner imagery, and most important, what instruments are best for making the measurements required.

Throughout the SR&T program we followed closely the development of multispectral scanners and their application to resource problems. (Weber, 1972; Weber et al.,1973). The essence of our experience was that single line-of-sight scanners which provide data registration in all channels are required. It is of little concern whether the mission is detection and evaluation of forest stress or the classification and mapping of wildlands; the job is best performed with a multispectral scanner having a distribution of available data channels over a wide part of the electromagnetic spectrum. For the task most often performed by the Remote Sensing Research Unit, a 2-milliradian scanner system with the following spectral characteristics would be required:

spectral sensitivity -	spectral band
deep blue	0.38 to 0.44 μm
yellow green	0.52 to 0.58 μm
red	0.62 to 0.68 μm
near infrared	0.71 to 0.79 μm
near infrared	0.80 to 1.1 μm
mid infrared	2.0 to 2.6 μm
far infrared	10.1 to 12.5 μm

Our experience has been with both digital and analog scanners and processors. There have been advantages with both types of systems. Scanner data which can be formatted for hybrid processing in both analog and digital modes is most cost effective. Geometric rectification, scaling, and development of classification statistics are most efficiently performed in digital operations. However, switching to analog mode for detection and mapping over large land areas is preferred.

Area Description

The Black Hills test site (Figure 12) is a 10,200-square-kilometer (3,938 square mile) area in western South Dakota and eastern Wyoming. The focus of the ERTS-1 site 226A is the three-quarter million hectare (1.85 million acres) elliptically shaped, uplifted dome where ponderosa pine is the most important tree species and comprises more than 95 percent of the total commercial sawtimber volume. The Black Hills National Forest portion of the test site is, in geological terminology, an exposed crystaline core surrounded by sedimentary formations. The central formation is a region of highly dissected topography with an elevation between 1,200 and 1,700 meters (4,000 and 5,600 feet). A rather large amount of exposed soil and surface rock is present. Surrounding the central core are sedimentary formations of Paleozoic limestone. The topography here is gently rolling, especially in the northwestern Hills where the limestone forms a plateau generally above 1,800 meters (5,900 feet). The eastern part of the Black Hills contains the same formations but generally at lower elevations. In this area the radial-dendritic drainage pattern of the permanent east-flowing streams is pronounced on satellite imagery. The area immediately outside the periphery of the ponderosa pine zone, which encircles the Black Hills, is a valley formed from reddish colored Triassic and Permian soft shale and sandstone. The "red valley" as it is called locally, encircles the dome area and is highly visible on some ERTS-1 imagery.

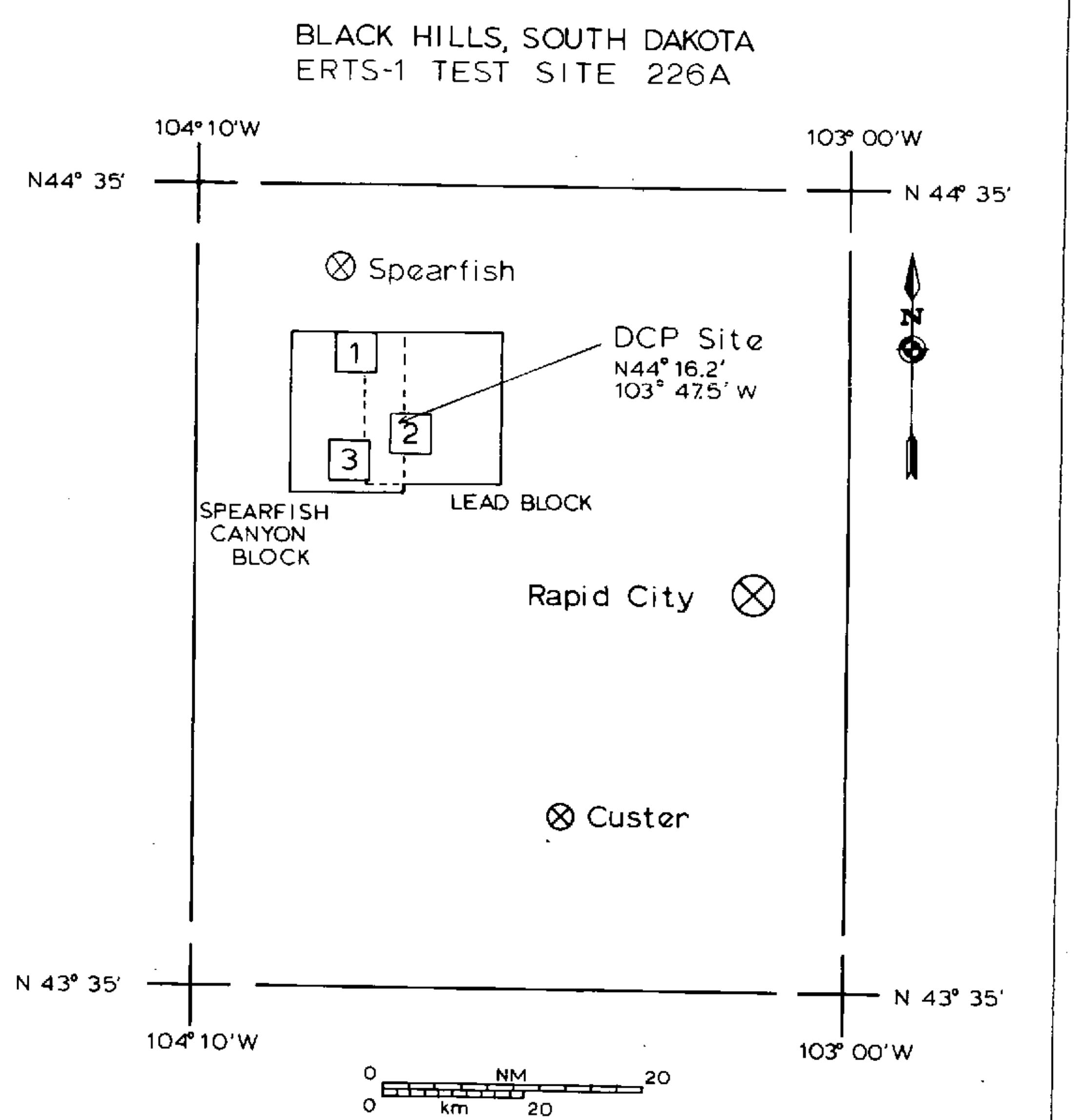

Figure 12. The Black Hills National Forest test site, 226A, is a 10,200-square-kilometer area located in western South Dakota and eastern Wyoming. The intensive investigation area covers 653 square kilometers surrounding the gold mining town of Lead. The area is composed of two study blocks and three smaller sub blocks. All biophysical instrumentation and the three DCP's were located within sub block 2--9.5 kilometers south of Lead.

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The intensive investigation area shown in Figure 12 covers 653 square kilometers (252 square miles) surrounding the gold mining town of Lead, South Dakota. The area is composed of two overlapping study blocks and three smaller sub blocks within the larger blocks. The Lead block is 41,293 hectares (102,036 acres) in size and contains 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 evidenced during endemic conditions. However, the Lead block is in an area first affected during an expanding bark beetle population and thus is a good barometer area for an impending epidemic outbreak. Sub block 2 within the Lead block is the location of ground instrumentation where biophysical data were sensed and transmitted through the ERTS-1 DCS system via three data collection platforms. The 35,648-hectare (88,087-acre) Spearfish Canyon block is located on the west side of the intensive study area. It is an area which traditionally 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 sporatic--showing up only during a widespread epidemic. Sub block 3 to the south is representative of the latter condition. Sub block 1, by contrast, contains the critical mass of the bark beetle population and is in an area of perpetual activity for the last 12 years. Beetle populations have remained constantly high in the area and it is thought to provide a source of beetles which aggravate the control problem in two surrounding national forest management areas. It is sub block 1 which contains the largest sized infestations which we hoped to detect and map on ERTS-1 imagery.

Status of Tree Mortality from Mountain Pine Beetle

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 aerial photography taken the end of August or early September by the Remote Sensing Research Unit. Other yearly surveys are conducted by the Forest Service, Region 2, Division of Timber Management and generally provide estimates of beetle damage for the entire Black Hills National Forest.[8]

Tree mortality counts within the three sub blocks for 1972 and 1973 are shown in Tables 15, 16, and 17. These data are presented because they encompass the period of the ERTS-1 experiment was conducted, However, it is only the 1972 mortality which applies to the analysis of the two ERTS scenes discussed later in this paper. Tree mortality counts for 1972 are the trees which faded the summer of 1972 and were counted on the CIR resource photography taken in early September. These trees were attacked by the bark beetles the previous summer. Therefore, trees which are counted as mortality for 1973 are actually trees which were infested during July and August of 1972.

Evidence of an expanding epidemic is shown by comparison of the totals in Tables 15, 16, and 17. Whereas sub block 1 had high mortality counts for both 1972 and 1973, there is evidence of threefold to fourfold increase in mortality in sub blocks 2 and 3 from 1972 to 1973. It is further recognized that the mortality counts in sub block 2 for 1973 are conservative due to the removal of many faded trees by salvage logging

[8]Internal office report of the Forest Service, Region 2, Division of Timber Management authored by Donn B. Cahill, Entomologist.

TABLE 15. The status of tree mortality caused by attack of the mountain pine beetle in sub block 1 is shown for 1972 and 1973.

Sub block 1, Savoy--Location: T.5N, R.2E, Sec. 15, 16, 17, 18, 19, 20, 21, 22, 27, 28, 29, 30, 31, 32, 33, and 34.

Area: 3,949.2 Hectares (9,758.6 acres)

FADERS[1]

Infestation[2] Size Code	1972	1973	Change
00	----	148	
01	2702	2653	
02	1198	1207	
03	1079	435	
04	715	845	
05	----	1050	
TOTAL	5694	6338	1.11 to 1

[1]Dead ponderosa pine which appear yellow to yellow-red in August and early September.

[2]Size of infestations in meters can be found in Table 21.

TABLE 16. The status of tree mortality caused by attack of the mountain pine beetle in sub block 2 is shown for 1972 and 1973.

Sub block 2, Englewood--Location: T.4N, R.3E, Sec. 15, 16, 17, 18, 19, 20, 21, 22, 27, 28, 29, 30, 31, 32, 33 and 34.

Area: 4,142.0 Hectares (10,235.1 acres)

FADERS[1]

Infestation[2] Size Code	1972	1973	Change
00	----	276	
01	2552	6811	
02	252	3060	
03	----	870	
04	----	325	
05	----	----	
TOTAL	2804	11342	4.04 to 1

[1]Dead ponderosa pine which appear yellow to yellow-red in August and early September.

[2]Size of infestations in meters can be found in Table 21.

TABLE 17. The status of tree mortality caused by attack of the mountain pine beetle in sub block 3 is shown for 1972 and 1973.

Sub block 3, Long Draw--Location: T.4N, R.2E, Sec. 31, 32, 33, 34, T.3N, R.2E, Sec. 3, 4, 5, 6, 7, 8, 9, 10, 15, 16, 17, and 18.

Area: 4,087.5 Hectares (10,100.4 acres)

FADERS[1]

Infestation Size Code[2]	1972	1973	Change
00	----	218	
01	1583	3682	
02	81	1003	
03	----	609	
04	----	110	
05	----	----	
TOTAL	1164	5622	3.38 to 1

1972 photo interpretation counts by E. H. Roberts
1973 photo interpretation counts by T. H. Waite

[1]Dead ponderosa pine which appear yellow to yellow-red in August and early September.

[2]Size of infestations in meters can be found in Table 21.

during July and August 1973, prior to the acquisition of the photography. More details are available in Appendix F regarding changes in mortality over time; a production model of actual mortality was made by T. H. Waite.

Data Acquisition System

Throughout the research program with multispectral scanners, a strong and continuing need for biophysical and environmental data has been established. Scene reflectance data are used to determine the timing of MSS missions and to establish baseline data for later interpretation of the imagery. For example, incident energy or irradiance data when ratioed to reflected target data are used to remove atmospheric effects when processing high-altitude aircraft MSS data. Our second line of reasoning for establishing a data acquisition system, and perhaps most important to the ERTS-1 experiment, is to provide on-site environmental conditions coincident with a satellite image pass when it cannot be monitored by persons on the ground. Furthermore, we established an on-site digital data acquisition system to collect biophysical data in parallel with ERTS-1 DCP's to check on the accuracy and reliability of the satellite data communication system. Table 18 presents three different applications of information recorded by the on-site data acquisition system. The first line of data was taken concurrently with a NASA C-130 multispectral scanner flight (Mission 247) on September 17, 1973. These data were used in preprocessing of Mission 247 imagery and will be discussed in a subsequent paper. The data for September 18, 1973, on the second line, substantiate that weather conditions were ideal at the time of proposed Skylab pass over the Black Hills test site and would have been used in processing S192 scanner data. Although the test site was not attended by research personnel later in September and October,

TABLE 18. Black Hills test site DCS/DCP transmitted biophysical data for coordinated ERTS-1, Skylab SL-3, and C-130 experiment during September 1973.

				Scene Radiance (MWatt/Ster·Cm^2)												
				(MSS-4)			(MSS-5)			(MSS-6)			(MSS-7)			
Date[1]	Time (GMT)	Mission	Total Solar Incident Energy (MWatt/Cm^2)	I[2]	H[2]	A[2]	I	H	A	I	H	A	I	H	A	Weather
73260	17002	C-130	67.3	23.77	.23	.02	3.35	.11	.13	3.27	.32	.24	7.04	1.00	.80	Clear Day
73261	17030	SL-3	72.5	26.22	.19	.03	3.76	.10	.11	3.82	.32	.32	8.35	1.00	.76	Clear Day
73263	17110	ERTS-1	35.4	12.59	.11	.02	1.86	.04	.06	1.79	.15	.18	3.92	0.48	.40	Cloudy Day
73281	17123	ERTS-1	39.7	13.98	.13	---	2.17	.06	---	2.07	.19	---	4.53	0.59	---	Cloudy Day

---

[1]Date is shown by last two digits of the year plus Julian day.

[2]I = Irradiance (MWatt/Cm^2)
H = Healthy Pine Radiance (MWatt/Ster·Cm^2)
A = Dead Pine Radiance (MWatt/Ster·Cm^2)

coincident data were gathered by the DCP's for two ERTS-1 image days as shown in the bottom two lines of Table 18.

ERTS-1 DATA EVALUATION

ERTS-1 images of the Black Hills test site were received for August 19, 1972, through August 16, 1973. An irony of the NDPF image screening system is that scene 1028-17121 (Figure 13), of August 20, 1972, was actually the first possible image to include the entire Black Hills test site, yet it was not available to us until nearly a year later. A full listing of all Black Hills scenes received by the Remote Sensing Work Unit is shown in Table 65 of Appendix E.

Ideally one scene covering the entire intensive study area should have been selected during the month of August or September 1972 and 1973. This approach would have allowed change detection as a feature of the interpretation effort. The realities of dealing with satellite imagery are that we received a scene for August 20, 1972, (which was relatively free of clouds) over the Lead block and to the east. The next logical scene would have been from a pass on September 7, 1972. On that day the entire test site area was covered by clouds. Therefore, we settled for coverage of the Spearfish Canyon block on scene 1047-17175 (Figure 14), although it partially truncated the block on the eastern edge of the image. We waited 1 full year before we learned that there were no August or September 1973 images obtained in clear weather. The best single scene received of the entire Black Hills test site was 1334-17124 taken on June 22, 1973. However, June is the worst possible time to detect stress resulting from mountain pine beetle attack in the Black Hills; attacks from the previous summer have just started visible fading and can only be

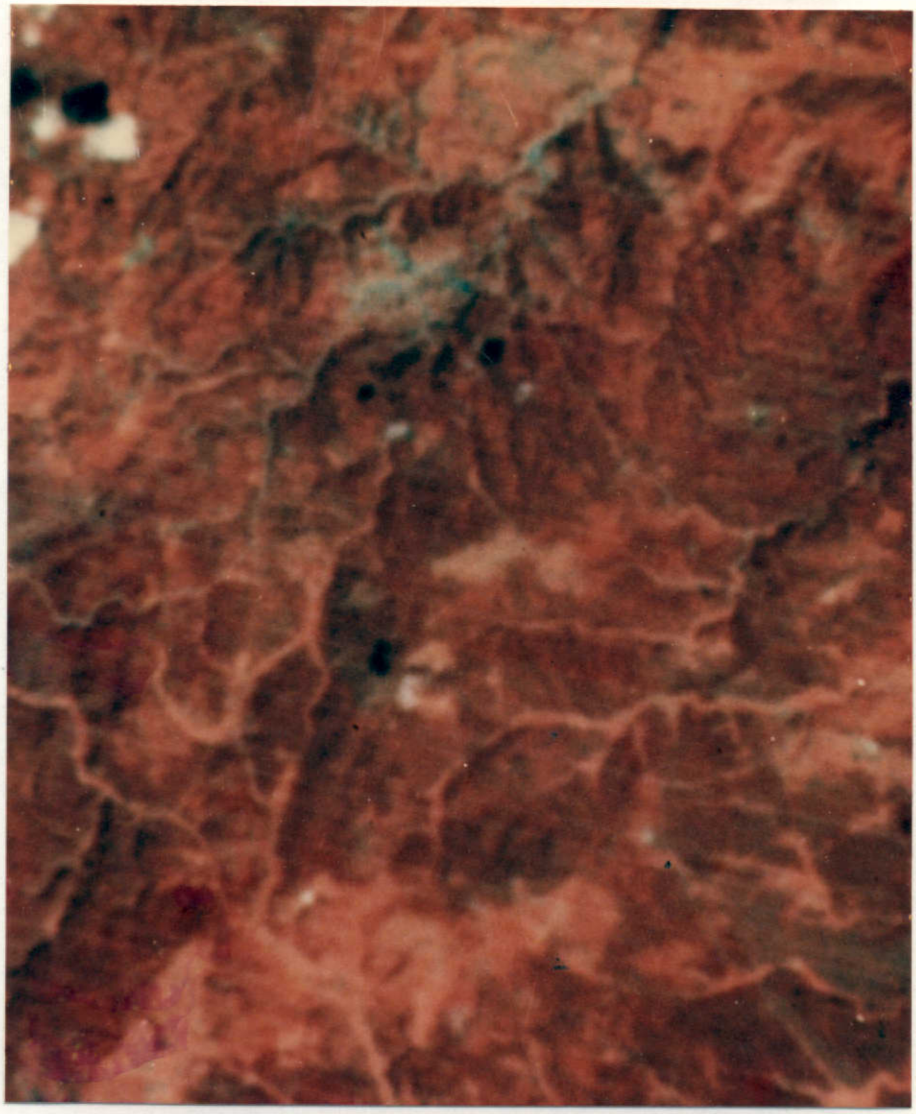

Figure 13. A three-channel false-color composite was created of ERTS-1 scene 1028-17121 taken on August 20, 1972. The Lead study block of the Black Hills test site is shown at a scale of 1:160,000. Scene 1028 of the 41,293-hectare Lead black was used by the Forest Service and LARS for the computer-assisted classification study of the Black Hills National Forest.

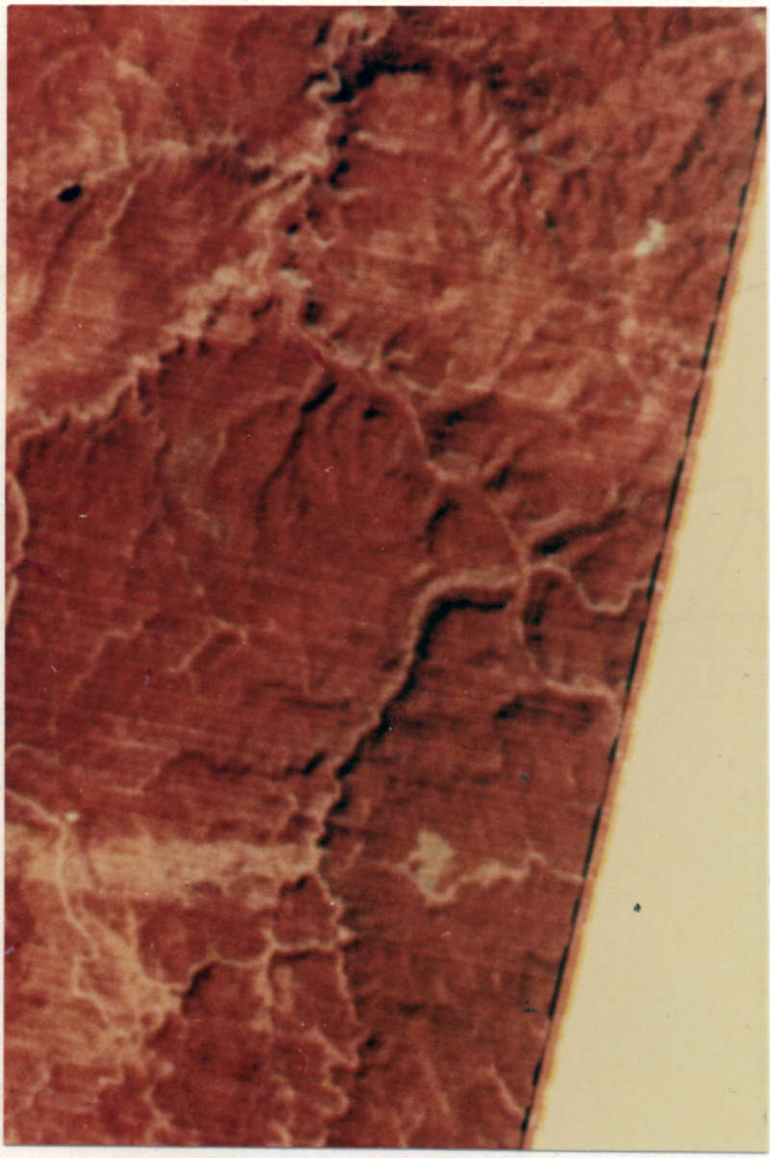

Figure 14. A three-channel false-color composite was created of ERTS-1 scene 1047-17175 taken on September 8, 1972. The Spearfish Canyon block of the Black Hills test site is shown at a scale of 1:160,000. The null area wedge of scene 1047 occupies 18 percent of the 35,648-hectare Spearfish Canyon block, and it was not considered in the computer-assisted classification study performed by the Forest Service and LARS.

detected on large-scale color photography. The old kills which faded during the summer of 1972 lose most of their red foliage by the following June and present very poor targets for satellite detection. The June 22 scene will not be discussed further in this paper and is being retained for comparison with Skylab scanner imagery obtained of the same area June 9, 1973.

PROCEDURES

Forest Classification

The key to interpretation of all Black Hills test site imagery, whether viewing color composites or analyzing computer classification maps, is the hierarchical classification of Black Hills ecosystem cover types. Early in the program we attempted to use an existing hierarchical system which classifies the Black Hills ecosystem into 13 habitat units.[9] Although it is very thorough and applies especially well for classifying wildlife habitat, it is not well suited for use with aircraft or satellite imagery. The classification hierarchy for the Black Hills National Forest (Table 19) was devised specifically for use with aircraft and satellite-acquired remote sensing imagery. The entire Black Hills test site can be classified without modifications or additions to this scheme. At Levels II and III, it differs from the remote sensing classification system developed by Anderson (1972) and the "ECOCLASS" system used by Driscoll in the RANGE INVENTORY section of this paper.

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[9]Personal communication from John F. Thilenius, Rocky Mountain Forest and Range Experiment Station, Rapid City, South Dakota.

TABLE 19. Black Hills National Forest classification hierarchy for aircraft and satellite remote sensing imagery.

LEVEL I		LEVEL II		LEVEL III	
01	Forest	01	Conifer	00	Dead ponderosa pine
				01	Pine, < 50% crown closure
				02	Pine, > 50% crown closure
				03	Spruce
		02	Deciduous	01	Pure hardwood
				02	Predominantly hardwood
02	Nonforest	02	Grassland	01	Wet pasture, on water course
				02	Dry pasture, well drained
		02	Bare Soil	01	Rock outcrop
				02	Gravel quarry
				03	Mine tailings
		03	Transition	01	Logging clearcut
				02	Burn area
				03	Soil, rock, sparse vegetation
				04	Infestation area
				05	Other disturbance
		04	Urban	01	Town
				02	Isolated building(s)
				03	Utilities
				04	Improved highway
				05	Forest road
03	Water	01	Water	01	Lakes and ponds
				02	Reservoir
				03	Streams and creeks

Preceding the development of the three-level hierarchical classification of the Black Hills was a guide which divided the cover types into nine strata (Table 20). These nine cover-type classes were used as a basis for type mapping the three sub blocks. Figure 15 illustrates the type map which was drawn for sub block 2 using the nine cover type classes established in Table 20. The type maps for the three sub blocks were first drawn on acetate overlays using the 1:32,000-scale CIR resource photographs. Typing was done to a minimum of 4 hectares (10 acres) except in the case of class 00 (infested beetlespots) which was classified by a separate standard discussed in the following section. Rectification of distortions in the first-iteration type map was done with a Bausch and Lomb Zoom Transfer Scope. The ZTS was used to superimpose a 1:110,000-scale color infrared transparency obtained from NASA Mission 211 onto the first type map, thus providing a rectified format for drawing a final type map with good geometric fidelity and positional accuracy.

Classification of Infestations

Prior to the beginning of the ERTS experiment in the Black Hills the Remote Sensing Research Unit classified infestations into strata based on the number of trees identified in an infestation spot on aerial photographs. The advent of microscale photography and satellite imagery required a shift in emphasis from infestation classification by numbers of trees to spot size as measured in meters. The relationship between the two classification methods is established in Table 21. For the purpose of typing the infestations in the sub blocks, only those spots which were greater than 50 meters (165 feet) in the longest dimension were typed.

TABLE 20. Black Hills National Forest cover type classes used for computer-assisted classification.

Cover Type Hierarchal Level	Cover Type Code	Cover Type Class
III	00	Dead ponderosa pine
III	01	Healthy ponderosa pine; 0 to 50 percent crown closure
III	02	Healthy ponderosa pine; 51 to 100 percent crown closure
III	03	Predominantly hardwood; up to 25 percent pine
III	04	Pasture, wet (cultivated or natural, usually on water course)
III	05	Pasture, dry (cultivated or natural, well drained)
II	06	Bare soil and rock outcroppings
II	07	Water
II	08	Transition: soil and rock with sparse vegetation including burned areas, logging areas, etc.

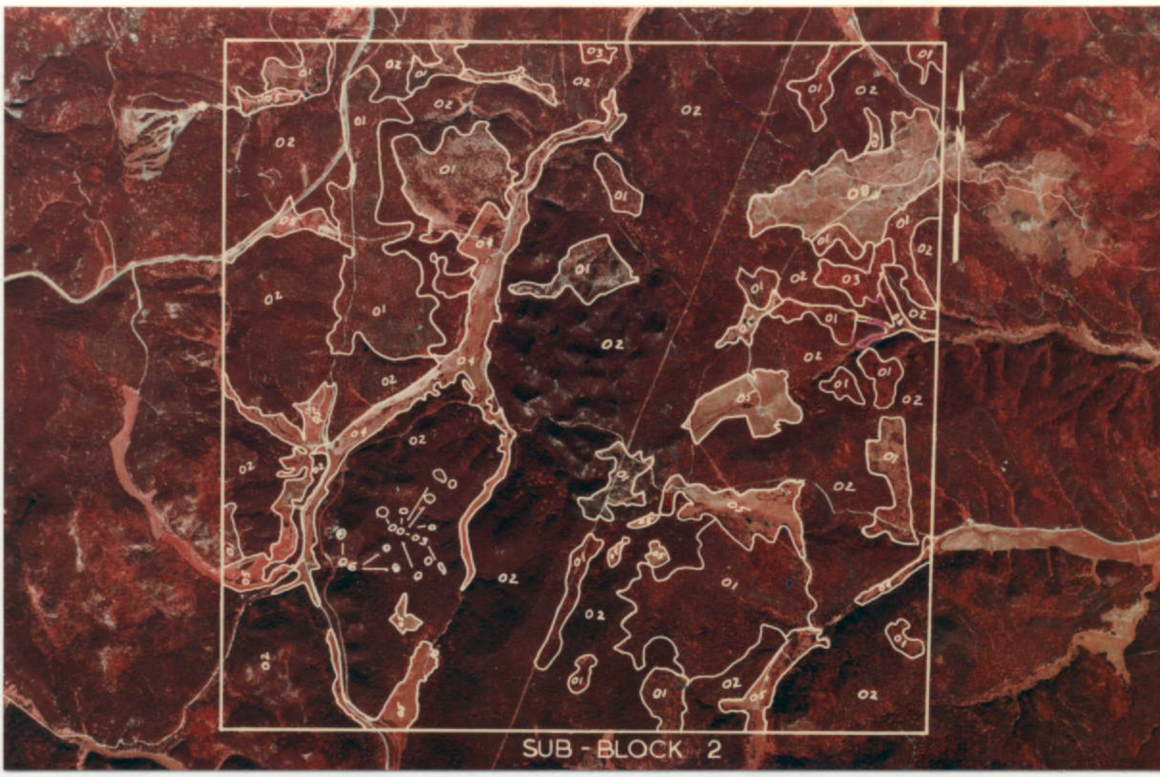

Figure 15. A cover type map for sub block 2 is shown at a scale of 1:70,000. The type map was drawn from 1:32,000-scale color infrared resource photographs taken by the Forest Service on September 8, 1972. Rectification of the original type map was done with the ZTS to superimpose on it a 1:110,000-scale color infrared transparency obtained from Nasa Mission 211, flown on September 14, 1972.

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TABLE 21. Mountain pine beetle infestation classification (cover type class 00) is given by average spot size in meters and average number of trees per infestation.

Infestation Size Code	Meters	Average Number of Trees
00	Less than 10	1 to 3
01	10 to 25	4 to 10
02	26 to 50	11 to 20
03	51 to 100	21 to 50
04	101 to 300	51 to 100
05	Greater than 300	100 +

As aforesaid, the nature of the mountain pine beetle infestations varied greatly between sub blocks. Figure 16 illustrates considerable aggregation of smaller prior infestations into several very large infestation centers. By contrast Figure 17 illustrates that most of the infestation spots in sub block 2, although considerable in number, were less than 50 meters (165 feet) 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 smaller spots with the effect of creating many infestations over 50 meters (165 feet) in size (refer back to Table 16).

Photo Interpretation

Interpretation of all ERTS photo products regardless of technique was done at a viewing scale of ∿ 1:83,000. This scale was selected by choosing a magnification factor common to all instruments used for human interpretation. We discovered early in the program that an optimum scale for interpreting ERTS 9½-inch photo products of the Black Hills was in the range of 1:50,000 to 1:100,000. Three separate visual interpretation approaches were used to analyze the ERTS-1 imagery. In the first, interpreters classified the cover types on 9½-inch color and black-and-white images (scale 1:1,000,000). For the second, only the bulk color composites were used to detect disturbances. For the third approach, an interactive team of foresters from the Black Hills National Forest viewed color composites and identified disturbances and ecological site classes; the color composites were enlarged by an overhead projector onto a wall screen.

Examples of each of the nine cover type classes shown in Table 20 were selected from the entire test site for the human interpretation test. Sites were selected subjectively based on availability, distribution throughout

Figure 16. Sub block 1 contains 14 infestation spots greater than 50 meters in the longest dimension which could be delineated on September 1972 resource photography. Two of the largest spots are shown in the 1:30,000-scale CIR photograph of the southwest corner of the sub block.

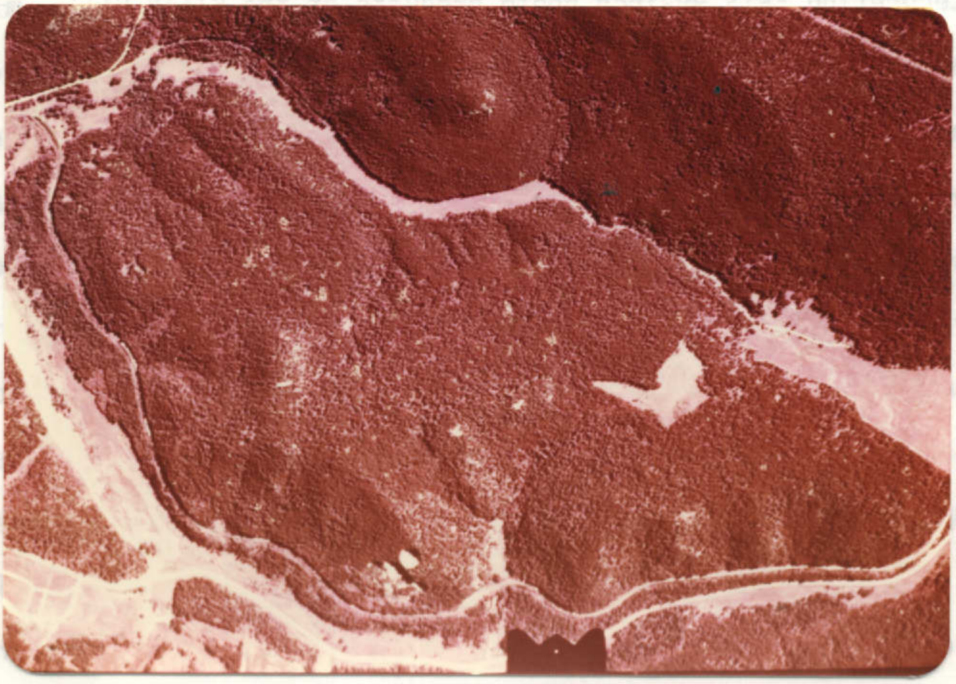


Figure 17. Sub block 2 contained 56 infestation spots identified on the September 1972 CIR resource photography. Most of the spots were less than 50 meters in size as can be seen in the 1:30,000-scale photograph of the southwest corner of sub block 2.

the study area, and distinctiveness with respect to the surrounding landscape. Neither of the two ERTS-1 scenes eventually selected for the Black Hills study covered the entire test site free of clouds. For the first interpretation approach, the sample points were identified, interpreted, and placed into one of the cover type classes if they could be located on an ERTS image. If a site was not covered on an image or was obscured by clouds it was not considered in the analysis.

A second interpretation approach was introduced after the two 9½-inch bulk data color composites were delivered from NDPF. Three interpreters (two District Rangers and the coinvestigator) scanned the entire image and annotated what they believed to be disturbances which fell within the test site area. Disturbances included bark beetle infestations. The disturbances were classed by interpreters at Level III within the Level II transition class. Interpreters relied mainly on deductive knowledge in classifying disturbances although some were no doubt classed because of knowledge of the location and existence of the disturbance.

The final approach to human interpretation, and perhaps the most productive of all, was to use a team approach to the interpretation of the imagery. The team was composed of two Forest Service researchers who are working in the Black Hills, two members of the Black Hills National Forest planning team, and the coinvestigator responsible for the stress portion of the ERTS study. All cases of classification differences among the team were resolved by reference to the 1:32,000- and 1:110,000-scale resource photography.

The first interpretative approach--locating and classifying ecological sites--was done on 9½-inch color and black-and-white transparencies of scenes 1028-17121 and 1047-17175 by the coinvestigator alone. The first of two methods for viewing the transparencies was with a Bausch and Lomb Zoom 70 Microscope mounted on a Richards light table. The viewing scale of ∿ 1:83,000 was accomplished by using 10X eyepieces and a 1.2:1 zoom ratio. Cover type classes were located by the interpreter by reference to an acetate overlay which had microdots locating the sites. The second viewing method was with a VARISCAN rear-projection viewer. The interpreter first scanned the image at a magnification ratio of 3:1 of ∿ 1:333,000 scale. As each microdot location was found the magnification ratio was changed to 12:1 giving the interpretation scale of ∿ 1:83,000.

The second interpretation approach was conducted by the coinvestigator and two District Rangers to derive a forest disturbance map. In addition to the first viewing method described above, the interpreters used a third method by annotating an acetate overlay on a color composite print.

The final interpretative approach--team interaction--was accomplished by viewing the image as projected on a screen with an overhead projector at a viewing scale of ∿ 1:83,000. The team was instructed to first identify the cover type sample points and then to proceed with a full interpretation of the scene. The only restrictions to the interpretation were that it had to be limited to the Black Hills National Forest and that whatever was being identified must be classed by the hierarchical system presented in Table 19.

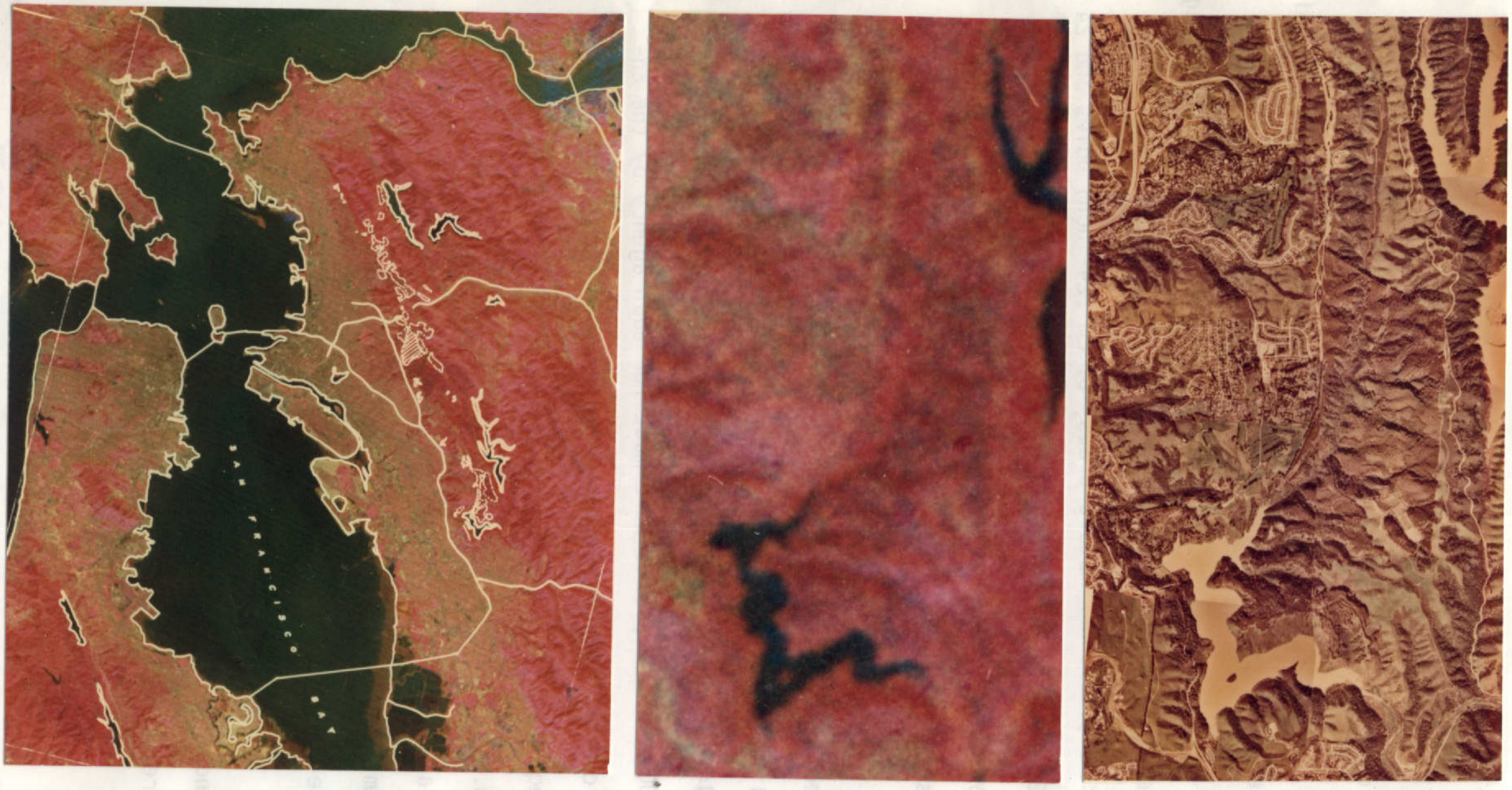
<u>Detection of Killed Eucalyptus Trees in the Oakland-Berkeley Hills</u>

While we were waiting for an acceptable cloud-free ERTS scene over the Black Hills site, we were presented with an opportunity (in February 1973) to detect a severely stressed forest site in the Berkeley hills. Very large targets of discolored Eucalyptus trees (4 km) were available for possible detection and mapping on ERTS-1 imagery. Through the help of our technical monitor, Edward Crump, we were furnished with six cloud-free ERTS images over the Bay Area for the period January to June 1973. In mid-December 1972, the San Francisco Bay Area was subjected to a period of extremely cold weather--an average of -8^{0} C 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 and ground examination revealed that the cambial cells of these now mature trees--61 cm (24-inch) boles and 24 to 37 m (80 to 120 feet) 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, our 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. We exposed color negative (Aerocolor Negative, type 2445) film of the affected area on February 15, 1973, at a scale of 1:12,000. Color prints were made for each agency by the Engineering Branch of the California Region of the Forest Service. Other prints were subsequently purchased by individual homeowners and insurance companies.

In some areas along the ridges, the killed Eucalyptus stands were as large as 1 by 4 km (.62 by 2.5 mi); the entire area of killed trees, although not of pure type (Figure 18a), was about 3 by 30 km (1.87 by 18.7 mi) in size.

In the San Francisco Bay Area, native grassy vegetation changes dramatically from its green wintertime appearance to its yellow and brown



a b c

Figure 18. (a) A portion of composite image (enlarged 1:500,000) was produced from two dates of ERTS images ID 1183-18175 (January 22, 1973) and ID 1273-18183 (April 22, 1973) which shows pure stands of Eucalyptus trees killed by prolonged cold temperatures in December 1972. The white dashed lines outline the larger stands (over 500 mm) which appear reddish-brown on the enhanced print and which are distinct from other objects. (b) A further enlargement (approximate scale 1:50,000) of Figure 18a to show Eucalyptus stand near Lake Chabot (Oakland, CA) which is about 1 by 4 km. in size. (c) A normal color (NC) print copied and reduced from an NC mosaic (1:12,000) to match Figure 18b. The affected Eucalyptus trees appear yellow as compared with the ERTS two-date image where the trees are reddish-brown. Note difference in resolution between ERTS and NC print.

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 one ERTS image taken before Eucalyptus foliage discoloration occurred (January 22, 1973, ID 1183-18175). The next good image we received was April 22, 1973, ID 1273-18183, which was taken at a time while the trees were still yellow but the native grasses 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 (1,640 feet) in size. A composite image (Figure 18a and b) from the above two time periods was created on our I^2S 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 image, respectively.

On Figure 18a, the reader can identify features around the Bay Area such as water bodies, bridges, and freeways on the image (outlined in white). Also, on this image the extent of the Eucalyptus killing is shown in white dashed lines. These affected stands of timber were located quite precisely from the 1:12,000 underflight color prints described above. However, the dying Eucalyptus appear on this 1:500,000-scale ERTS enlargement as a distinct reddish brown which can be separated from surrounding vegetation.

Figure 18b is an enlargement (scale $\sim$ 1:50,000) of the two-date enhanced image of one large Eucalyptus plantation about 1 by 4 km (.62 X 2.5 mi.) and which is readily detectable at the smaller scale. Compare Figure 18b with Figure 18c which was made from the 1:12,000 color prints assembled into a mosaic, photographed, and reduced to the same scale as Figure 18b.

An enhanced image such as the one shown in Figure 18a would be useful for damage assessment in remote areas when catastrophes of this kind occur. However, in an urban area, where millions of dollars for tree removal and fire prevention are involved, a sensor with better resolution such as medium-scale color photography is needed.

Field Instrumentation

In autumn 1971 an aerial and ground reconnaissance was conducted over the northern Black Hills for the purpose of selecting an instrumentation site for the forthcoming ERTS experiment. Three selection criteria were used to find an acceptable site: (1) the area was to be widely separated from the old infestation centers (sub block 1) which appear spectrally complex on microscale photography, (2) instruments should be located in an area on the fringe of the epidemic and in an area which was likely to become heavily infested during the ERTS experiment, and (3) the area had to be accessible enough so that our mobile research laboratory could be moved into the area with a four-wheel-drive vehicle.

The measurement of absolute target reflectance or scene radiance was regarded as most important of all the biophysical and environmental measurements in the ground instrumentation study. Five spectrometers (Figure 19) were built as reported by Weber, 1973, to make the scene radiance measurements. Each spectrometer simultaneously measured light energy in the four ERTS-1 MSS spectral bands. Four of the spectrometers were placed above subsite scenes to measure reflective energy; the fifth instrument measured downwelling incident energy from the top of a 21-meter (69-foot) tower.

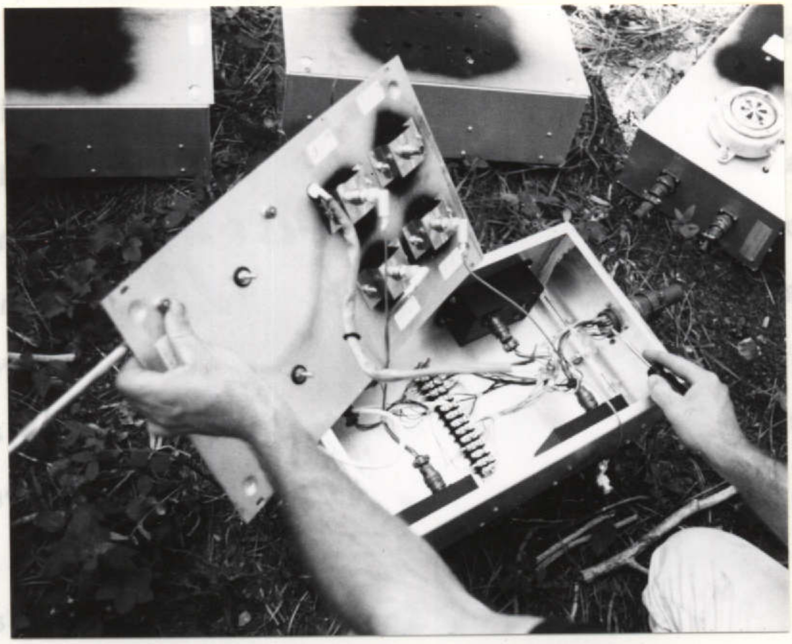


Figure 19. The interior of one of the five field spectrometers which operated at ERTS-1 test sites in Georgia and South Dakota is shown. The spectrometer used to measure downwelling energy is shown at the upper right.

Four instrumentation subsites were selected to provide a range of scene radiance data. Healthy and stressed ponderosa pine were selected as subsites of prime importance. Pasture and rock outcrop subsites were selected because they were thought to represent important variances in scene radiance from the ponderosa pine ecosystem.

1972 Data Collection System

The ground based data collection system, which went into operation the first week of September 1972, was designed around three ERTS data collection platforms. A three-level multiplexing system was built to accommodate the need for data packing within each DCP. Twenty-four instruments fed data continuously into a multiplexer/amplifier for each DCP. When the data collection system was fully implemented a total of 72 sensors measured biophysical and environmental variables. Table 66, 67, and 68 of Appendix E show the sensors and their respective multiplexer commutation levels which were fed into the three DCP's.

Data from the spectrometers suspended over the healthy and stressed pine subsites were fed to a central tower of a double tramway system, and then by underground cable 120 meters (394 feet) to the centrally located mobile laboratory. The pasture subsite which was instrumented with a spectrometer suspended on a boom arm 6.5 meters (21 feet) above the pasture was located 155 meters (508 feet) from the laboratory. Environmental measurements were also taken at the pasture subsite. Data from the rock outcrop subsite traveled 210 meters (689 feet) along cables suspended above the ground. The spectrometer at the rock subsite was suspended from a boom arm supported by a 6.5 meter (21-foot) tower.

Millivolt signals from field sensors went to the mobile laboratory where the amplifiers, multiplexers, and DCP's were located. The DCP signal output was sent via a special low-loss coaxial cable outside the laboratory and to the top of a 21-meter (69-foot) tower where the DCP antennas were located. The strategy proved correct as the loss of signal was greater when the antennas were on the ground with short antenna leads than when they were located above the dense forest canopy. On a typical pass directly over the Black Hills test site, DCP transmissions were acquired by the satellite as it passed N60° latitude over the Hudson Bay and lost at N28° latitude west of Baja, California.

Field sensor signals entering the multiplexer/amplifier system were split and recorded by a digital data acquisition system in parallel with the DCP's. In this way accuracy and reliability of the ERTS data collection system were determined.

1973 Data Collection System

Several problems encountered during the first year of operation were eliminated with redesign of the data system in 1973. Figure 20 shows the reconfigured data collection system which operated independently at each subsite. A DCP and an antenna were located at the top of a subsite tower along with a spectrometer and light-activated switch which controlled the battery power packs located at the base of each tower. No digital data acquisition system was used the second year of operation; thus, the operation of the data collection system was simplified as shown in Tables 69 and 70 of Appendix E. Data to one DCP still required multiplexing as there were only three transmitters to handle five subsites. Data from the pasture, rock outcrop, and incident-energy spectrometers were multiplexed through one DCP as shown in Table 71 of Appendix E.

Figure 20. Modification of the data transmission network during the ERTS-1 experiment resulted in each subsite becoming an independent unit. Shown at the top of the tower are the incident-energy spectrometer, multiplexer, DCP, antenna, and light-activated switch. The reflected energy spectrometer is at the end of the 4-meter (13-foot) boom arm and the alkaline battery power packs are at the base of the tower.

Nighttime data were not required in 1973, so light-activated switches were built to control power to the systems, thus limiting data collection and transmission to daylight hours.

Computer-Assisted Processing

Image processing with computer compatible tapes was perceived as one of the major approaches to analysis and display of Black Hills ERTS-1 imagery. Although mountain pine beetle infestation spots were small in relation to the resolution of the ERTS multispectral scanner, we hoped that computer classification techniques might work successfully to detect and map dead and dying pine trees. Computer-assisted processing provides many possibilities for statistical analysis of spectral characteristics, and the application of a powerful classifier can often yield results unavailable to an interpreter through image viewing alone.

Two scenes shown in Figures 13 and 14 were selected as the best available ERTS-1 data to meet the goals of the Black Hills study of forest stress. Neither scene showed the entire intensive investigation area, but they were taken on successive cycles in late August and early September 1972 and were the best data we had. Our approach was to use two different computer classification systems--our own and one from an outside contractor (LARS). The two groups worked independently toward the same classification goals and in the end their results were compared for classification accuracy and utility of the resulting classification maps.

General guidelines were offered to both groups, but they were not considered restrictive. The minimum classification suggested for the Black Hills was that shown in Table 20. However, the groups were encouraged to try to work with the hierarchical concept of classification while maintaining classification accuracy. A uniform color display of 1:32,000 scale was suggested, although in the end we settled on a scale of 1:24,000.

PSW Classification

The Forest Service Remote Sensing Research Unit developed a computer-assisted classification and mapping capability which is discussed in detail in Appendix D. Adaptations of the PSW routine were made for classification of the Black Hills ERTS-1 scenes. Input to the system was provided by detailed type maps of the three sub blocks. The computer coordinates for the corners of the blocks and the sub blocks were provided to the computer analyst by the Black Hills coinvestigator.

LARS Classification

The Laboratory for Applications of Remote Sensing, at Purdue University, was the successful bidding organization on a contract to process ERTS-1 multispectral scanner bulk data tapes. They were selected by a contract-selection panel from among five proposals which were submitted to the Forest Service.

The details of the procedures and the programs used at LARS for classification and mapping of Black Hills ERTS-1 tapes are given in the final contract report[10] and are not repeated here. However, a few highlights are discussed.

The ERTS tapes received from NDPF were converted to the LARS System (LARSYS) format with geometric corrections. In this process the data were deskewed, rotated, and scaled so that the line printer output had a scale of 1:24,000 with true north orientation. LARSYS is the entire processing and classification system at LARS, and it contains several processing functions which were used in the analysis and display of Black Hills data:

PICTUREPRINT prints a gray-scale image by channel on the line printer. Alphanumeric symbols are used to represent different gray tones.

IMAGEDISPLAY displays a 16 gray-level image of the data on a video screen The user can manipulate the data and select classification types with a light pen.

CLUSTER is an unsupervised classifier that groups data vectors into the number of classes specified by the analyst.

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[10] Analysis of Black Hills test site 226A, USDA Forest Service Contract 21-292 report by analyst Tina K. Cary, LARS.

STATISTICS calculates the mean vectors and covariance matrices for training classes. A coincident spectral plot is produced automatically. Histograms and correlation matrices can be requested.

SEPARABILITY uses data from the STATISTICS processor to measure the statistical distance (or separability) between classes of interest.

CLASSIFYPOINTS performs a maximum-likelihood classification on a point-by-point basis over an area specified by the analyst.

PRINTRESULTS produces a classification map, a training field, and class performance tables.

PHOTO displays classification results on a video screen. A color-coded photograph is produced.

Classification Performance Evaluation

A procedure was developed which permitted the careful evaluation of computer-assisted classification results for the Black Hills test site. The computer displays of both LARS and PSW were overlaid with a grid system which was based on computer-coordinate intersections. The starting point for the grid was critical and had to be a location which could positively be pinpointed for both blocks and on both computer displays. A starting point for each block was found to satisfy the requirement. The grid intersections were laid out at intervals of six lines and six columns. The intent was to create a cell focused at each grid intersection which contained 9 pixels. A buffer, 1 pixel wide, completely surrounded the sample cell 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 evaluation of the entire block. However, cells (9 pixels) were selected for the evaluation only if they were determined to occupy an area of pure cover type on the ground for the cell plus the buffer elements. This was determined by creating a carefully scaled reproduction of the computer grid which was placed over the 1:110,000-scale color infrared resource transparencies. Each of the 17,000$^+$ cells was interpreted on the photographs, and those cells which contained pure cover type were selected for the evaluation. The evaluation entailed the comparison of the cell classification determined from the photographs with the classification for the same cells on the LARS and PSW outputs. A cell was determined correctly classified if 5 or more pixels were correct. The cell was tallied incorrect if five or more elements were classified the same but incorrectly. The classification was called mixed and incorrect if there was no majority classification of pixels within the cell.

RESULTS

Photo Interpretation

Quantitatively speaking there were only minor differences in the interpretation results between ERTS black-and-white transparencies and the color composite transparencies. It mattered not which interpretative method was used nor which viewing instrument. The significant difference in the results was that the bulk color composite transparencies were much quicker to use, requiring only 20 percent of the interpretative time of the four individual black-and-white transparencies for the same scene. The reasons for using the black-and-white transparencies were (1) better resolution of the individual images as compared to the color composite and (2) the possibility that the mountain pine beetle infestations might be detected on the red band image whereas they might be masked in the creation of the color composite. In the latter case, the bark beetle infestations were not detected, regardless of image product or method of interpretation. For example, sub block 1 contained several infestations over 300 meters (984 feet) in its longest dimension (Figure 16) which were never detected.

Classifying 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. For the nine cover type sites listed in Table 20, wet pasture, bare soil, and water were interpreted 100 percent correct. Poorest results were in the classification of hardwood and dry pasture sites 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, a separation based on stand density (Level III) introduced 50 percent commission errors. That is, half of the total pine sites were classified into the wrong density class.

Based on the results of the first interpretative approach, one could expect to do a near-perfect job of classifying the Black Hills cover types on ERTS-1 color composites being satisfied with a stratification into conifer, grassland (including deciduous vegetation), bare soil and rock, water, and transition. The VARISCAN rear-projection viewer was preferred over the Zoom 70 Microscope as an interpreter choice, although the end results were the same.

Disturbance Detection

A total of 30 major disturbances were identified and their boundaries delineated on the first attempt by the study coinvestigator. Two District Rangers who are responsible for management of a major portion of the northern Black Hills also offered their interpretive expertise. Their experience and prior knowledge was obvious in the results achieved. In most cases they were able to identify the cause of the disturbance without reference to management records. The three interpreters independently identified the same 30 major disturbances and drew the same boundaries except for minor differences. In checking the Black Hills National Forest records, it was discovered that three of the disturbances which were correctly identified as caused by fire had occurred prior to 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.

The 30 disturbances which were clearly visible on ERTS imagery and which were 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. It was an unexpected surprise that the interpreters clearly delineated timber sale boundaries of active logging areas. These areas were not the result of clearcutting but were pine stands which were thinned from about 21.8 square meters (235 square feet) of basal area to about 7.4 square meters (80 square feet). The thinning areas had a distinct bluish gray tone (high response on MSS channel 4) on the simulated CIR composites. While this level of interpretation might consistently occur with persons experienced in the area, it is doubtful that others would identify active logging areas (other than clearcut areas) with any consistency.

Team Interpretation

The team approach to interpretation of ERTS-1 imagery seemed the most realistic procedure and would lend itself best to an operational program. This approach requires equipment for display of ERTS imagery so that the entire team may view it and react spontaneously as the interpretation develops. Either a rear-projection viewer with a large screen (like the VARISCAN) or an overhead projector could be used. We discovered that the definition lost in the image display by an overhead projector was more than compensated for by the team interaction.

The team results for Level II interpretation of the Black Hills study area were as follows:

conifer forest	- 100 percent	transition	- 83 percent
deciduous forest	- 20 percent	urban	- 50 percent
grassland	- 100 percent	water	- 100 percent
bare soil	- 100 percent		

It was difficult to objectively rate the balance of the team interpretive results. However, the team felt confident that most of the Level III units in the classification hierarchy could be identified throughout the forest. Notable exceptions were the uncertainty of identifying deciduous vegetation, although on-the-ground experience of one or more of the interpreters usually determined the accuracy of the classification. Interpreters felt that using a winter scene together with the summer images would have improved their results.

In assessing the team approach it was obvious that there were benefits in having multidisciplinary representation. For example, a forester and a geologist working together decided that the occurrence of 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.

Data Collection System

1972 Results

Many problems were encountered with the field data collection system during the operational period of September 1972 to January 1973. The original concept of monitoring field conditions continuously to insure baseline data for satellite imagery, which might or might not be forthcoming, does not now seem reasonable in light of our experience. The benefits derived from monitoring a large number of biophysical and environmental parameters with complex equipment from an unattended site do not seem to justify the effort required.

Although problems were encountered, a large volume of usable data was received from the DCP's via the ERTS data collection system and also from the on-site digital data acquisition system. September 8, 1972, and September 26, 1972, were two days selected for presentation of DCS data which coincided with ERTS overpasses. Biophysical data for these two days are presented in Tables 22 and 23 and provide information on the accuracy of the ERTS-1/DCS when compared to the results recorded by the on-site D-DAS. Considering the six times of coincident measurement of on-site parameters for the DCS and D-DAS for these two days, errors in the DCS were always less than 3 percent of energy balance data. The largest single difference was 10 percent, yet most of the values were within ± 2 percent.

The data for Tables 22 and 23 were received by the Remote Sensing Research Unit from NDPF within 5 days. We knew that the weather conditions in the general area of the test site were satisfactory for an ERTS-1 image on September 8, long before the image was received. We also determined that if an image for September 26 were received from NDPF it would be of marginal quality--and it was. This was derived from analysis of the energy balance data received via the DCS for 1717 (GMT), which coincided with the 17175 image time for both cycles 1047 and 1065.

Daily monitoring of radiometric instruments in the Black Hills has given a clearer picture of how energy relationships change in a ponderosa pine ecosystem. For example, Table 24 shows that the albedo of the rock outcrop subsite was unchanged from September 8 to 26, whereas the albedo of the pasture increased 3 percent.

TABLE 22. Energy balance data as monitored for a clear day on the Vidar 5403 digital data acquisition system (D-DAS) is shown for four ecosystem components on September 8, 1972. Comparable data transmitted through the ERTS-1 (DCS) from the Black Hills, South Dakota, test site are shown for three daytime transmissions.

ENERGY BALANCE (milliwatts/cm^2)

		Shortwave radiation (0.4 to 4.1 μm)			Net allwave radiation (0.4 to 15 μm)			
		Downwelling	Upwelling					
Time (GMT)	System		Healthy	Dead	Healthy Pine	Dead Pine	Pasture	Rock outcrop
1500	D-DAS	47.46	4.46	7.35	41.67	41.38	40.08	38.46
1533*	D-DAS	51.61	5.15	7.66	45.22	44.91	43.43	41.65
	DCS	51.47	5.41	7.65	45.22	44.78	43.41	41.90
1600	D-DAS	55.81	5.88	9.01	48.95	48.52	46.89	41.64
1700	D-DAS	67.96	7.48	10.20	57.02	59.13	57.09	54.79
1717*	D-DAS	71.67	7.88	10.75	62.89	62.29	59.96	57.73
	DCS	73.20	7.95	10.99	63.15	63.05	60.71	58.03
1800	D-DAS	77.85	8.58	11.70	68.25	67.53	65.21	62.69
1900*	D-DAS	80.35	8.84	12.06	70.40	67.79	67.39	64.79
	DCS	79.82	8.65	12.00	71.05	70.54	67.00	64.01
2000	D-DAS	78.14	8.60	11.74	68.51	67.74	65.58	62.98
2100	D-DAS	69.63	7.67	10.47	60.89	60.52	58.49	56.13
2200	D-DAS	53.47	5.44	8.10	46.93	46.60	45.00	43.18
2300	D-DAS	30.98	3.26	4.49	27.24	27.03	26.14	25.06

*Simultaneous recording from ground, D-DAS and ERTS-1, DCS.

TABLE 23. Energy balance data as monitored for a cloudy day on the Vidar 5403 digital data acquisition system (D-DAS) is shown for four ecosystem components on September 26, 1972. Comparable data transmitted through the ERTS-1 (DCS) from the Black Hills, South Dakota, test site are shown for three daytime transmissions.

ENERGY BALANCE (milliwatts/cm^2)

		Shortwave radiation (0.4 to 4.1 μm)			Net allwave radiation (0.4 to 15 μm)			
		Downwelling	Upwelling					
Time (GMT)	System		Healthy	Dead	Healthy pine	Dead pine	Pasture	Rock outcrop
1500	D-DAS	23.65	2.16	3.32	21.58	20.47	19.47	19.14
1534*	D-DAS	26.63	2.39	3.91	24.29	22.95	21.82	21.47
	DCS	26.65	2.67	3.85	24.52	22.18	21.56	21.10
1600	D-DAS	31.06	2.73	4.96	28.45	26.81	25.49	25.08
1700	D-DAS	40.46	2.94	6.48	36.78	34.91	33.20	32.66
1717*	D-DAS	46.59	4.58	7.46	42.33	40.00	38.17	37.52
	DCS	45.98	4.50	7.19	42.01	39.85	38.00	37.25
1800	D-DAS	48.92	4.99	7.84	44.40	42.12	40.02	39.34
1902*	D-DAS	69.17	6.85	11.24	62.90	59.60	56.67	55.76
	DCS	70.00	6.98	11.52	63.58	59.93	56.65	56.17
2000	D-DAS	51.59	5.11	8.26	46.91	44.48	42.26	41.61
2100	D-DAS	46.06	4.58	7.35	41.82	39.69	37.74	37.10
2200	D-DAS	35.51	3.19	5.32	32.27	30.66	29.15	28.65
2300	D-DAS	12.79	1.02	1.79	11.68	11.06	10.52	10.33

*Simultaneous recording from ground D-DAS and ERTS-1 DCS.

TABLE 24. The relationship between albedos is shown for four Black Hills, South Dakota, cover type components at the time of two ERTS-1 passes in September 1972.

Target	Percent Albedo[1]	
	September 8	September 26
Healthy pine	11	10
Beetle-killed pine	15	16
Pasture grass	19	22
Rock outcrop	24	24

[1]Albedo is the ratio of upwelling to downwelling shortwave radiation.

Early in the ERTS-1 program we wanted to know how the multispectral scanner radiance data compared with the field spectrometer data collected at the Black Hills test site. The only ERTS products available then were the 70 mm transparencies. Using the MSS transparencies for September 8 and September 26 we obtained scene radiance data from microdensitometer analysis of the bulk data film. Information presented in Tables 25 and 26 was obtained by scanning the bulk data 70 mm black-and-white transparencies on a Photometric Data Systems microdensitometer and converting the data to scene radiance by using the ERTS Handbook values assigned to the calibration wedge on each frame. It should be stressed that microdensity and resulting radiance values for beetle-killed pine were <u>not</u> obtained by actually "seeing" the dead pine, but rather by measurements obtained from areas where beetle-killed pine had been located on the ground.

The significance of scene radiance calculations from MSS imagery is illustrated clearly in Table 27. Scene radiance measurements of similar cover type targets were compared between satellite and ground-measured values transmitted by the DCS. Table 27 data were the first we received to show the potential effect of atmosphere on radiance values as measured on imagery when compared to that which existed near the ground. The greatest effect of atmosphere showed on MSS channel 4 where there was an overall 30 + percent increase in scene radiance on the satellite imagery. For the infrared channel 7 there was less than 10 percent overall difference in measured values, with the ground-measured radiance being the higher.

Post Experiment Evaluation

The three spectrometer units used in the Black Hills during 1973 were set up to monitor radiance reflected from healthy pine (RS-2M-1), dead

TABLE 25. Black Hills scene radiance data for September 8, 1972, are derived from microdensitometer analysis of black-and-white 70 mm bulk data positives for scene 1047-17175.

Target	Ecoclass/Level	Scene Radiance (milliwatts/cm²/sr) MSS Channel[1] 4	5	7
Healthy pine	02/III	0.333	0.188	0.847
Beetle-killed pine	00/III	0.344	0.229	0.983
Lake	01/III	0.339	0.200	0.675
Rock outcrop	01/III	0.418	0.270	1.218
Macadam road	04/III	0.394	0.194	0.953
Concrete highway	04/III	0.339	0.239	1.062
Mine tailings	03/III	0.354	0.239	1.062
New logging road	05/III	0.333	0.243	1.014
Tornado area	05/III[2]	0.414	0.300	1.206

[1]Imagery received for channel 6 was unusable because of the large number of data dropouts.

[2]Classed as transition at Level II and other disturbance at Level III.

TABLE 26. Black Hills, South Dakota, scene radiance data for September 26, 1972, are derived from microdensitometer analysis of black-and-white 70 mm bulk data positives for scene 1065-17175.

Target	Ecoclass/Level	Scene Radiance (milliwatts/cm²/sr) MSS Channel 4	5	6	7
Healthy pine	02/III	0.154	0.087	0.158	0.392
Beetle-killed pine	00/III	0.140	0.093	0.144	0.399
Pasture, wet	01/III	0.217	0.156	0.244	0.628
Pasture, dry	02/III	0.214	0.148	0.239	0.601
Macadam road	04/III	0.213	0.105	0.173	0.440
Rock outcrop	02/III	0.316	0.204	0.353	0.920
Open pit gold mine	03/III	0.250	0.170	0.311	0.805

TABLE 27. The relationship is shown between scene radiance data measured on ERTS-1 MSS imagery (scene 1065-17175) and that measured on the ground in the Black Hills by the field spectrometers on September 26, 1972.

Target	Scene Radiance (milliwatts/cm^2/sr) MSS Channel 4		5		6		7	
	ERTS	Ground	ERTS	Ground	ERTS	Ground	ERTS	Ground
Healthy pine	.154	.102	.087	.065	.158	.179	.392	.468
Beetle-killed pine	.140	.093	.093	.101	.144	.135	.399	.506
Pasture grass	.214	.141	.148	.149	.239	.280	.601	.646
Rock outcrop	.316	.219	.204	.199	.353	.358	.920	.999

pine (RS-2M-2) and irradiance incident on the scene (RS-2M-5). The spectrometers operated in four spectral regions matching the ERTS-1 multispectral scanner subsystem. The data from these spectrometers were relayed via the NASA Data Processing Facility (NDPF) and then to Berkeley. Data from the ground spectrometers is compared with radiance data from CCT's of areas within two scenes from ERTS: scene 1028-17121, August 1972, and scene 1047-17175, September 1972.

The environmental and atmospheric conditions within the study area at the time each of these scenes was imaged were stable and clear. The ground spectrometer data, although taken 1 year later can be compared with the radiance data from ERTS-1 because of comparable sun angles and atmospheric conditions.

The three spectrometer units were calibrated September 1, 1973, before being placed in the field in the Black Hills, and the calibration was checked April 1974 after the instruments were returned from the field. For several of the individual channels, the system calibration had changed very significantly (see Table 28) and makes the spectral data suspect if not used close to the time of calibration. Due to the lack of baseline data on many of the components, it is not possible to determine 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 edgesealed by the manufacturer to withstand the field environment.

Component degradation is assumed to have been a function of time in the field rather than a sudden change; however, since the specific factors

TABLE 28. Relative response of the ground based spectrometers as determined by calibration before being place in field use and after returning from field use.

SPECTROMETER		CHANNEL 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

causing a change in system response are not accurately known, only the first several weeks of data are used here.

Data from the field spectrometers and other biophysical instruments were received in Berkeley in the form of punch cards sent from NDPF. A computer program was developed to segregate the data by DCP identification number, day, time, and channel. It operates on the raw data with the appropriate instrument calibration factors, and prints out the data in a prescribed format under appropriate headings in user designated units, e.g., radiance in $mW \cdot cm^{-2} \cdot sr^{-1}$.

Because the field spectrometers were mounted just above the trees, radiance reflected from the forest and measured by these spectrometers is not affected by an intervening atmosphere. A comparison of the radiance measurements from the field spectrometers and from the ERTS-1 multispectral scanners shows the effects on the radiance of transmission through the atmosphere.

Scene Radiance Analysis

Radiance data measured at orbital altitude were taken from the ERTS-1 CCT's in raw-numbered count form and printed out in columns and rows. The resulting matrix of numbers, although not having absolute geometric fidelity with the ground, was used as a representation of ground points. With the aid of photographs and computer classification displays, sample areas were located on the "number map". The sample areas were representative of types used in mapping the study areas on aerial photography, and in point-by-point classification of the study areas by two different methods of spectral pattern recognition using computers. The mean and standard deviation of the values from each of three sample areas for each type were calculated for each of the MSS channels. These count values are shown in Table 29. The means from this table were pooled for each type and converted to radiance values using the equation $\overline{C}\ {}^{R}max/127$ = mW/cm^2/sr where $\overline{C}$ is the pooled mean count for the samples within each type for each MSS channel and R_{max} is 2.48 for MSS-4, 2.00 for MSS-5, and 1.76 for MSS-6. The equation for MSS-7 is $\overline{C}$ 4.60/63 = mW/cm^2/sr. According to NASA this straight line equation may not be absolutely accurate, but it is the only method that has been provided. The radiance values are shown in Table 30.

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 31), some effects of the atmosphere become apparent. For MSS channel 4 there is a 51 percent increase in the radiance when measured from ERTS-1 as compared to the ground. This is probably the result of backscattered 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 40 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 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.

TABLE 29. Multispectral scanner count values from CCT printout of ERTS-1 image 1028-17121. Mean and standard deviation are from nine data points for each of the samples.

Cover[1] Type Sample	MSS 4		MSS 5		MSS 6		MSS 7	
	Mean	Std.D.	Mean	Std.D.	Mean	Std.D.	Mean	Std.D.
01	22.6	1.1	15.9	1.8	37.3	1.9	20.7	0.9
01	19.6	1.9	14.6	2.4	34.8	3.3	20.6	2.7
01	20.0	2.5	14.2	2.3	34.7	2.1	20.0	1.5
02	16.9	0.8	11.2	1.1	23.7	1.4	13.4	1.0
02	16.3	0.5	11.3	0.5	24.8	1.0	13.9	0.9
02	17.1	0.3	11.2	0.7	24.1	2.1	13.4	1.7
03	22.8	1.6	15.4	2.7	47.9	1.4	30.0	1.7
03	17.8	0.4	12.0	0.7	40.2	3.6	24.1	2.3
03	21.3	0.7	13.9	0.6	48.9	1.2	30.0	0.7
04	23.4	1.0	15.2	1.6	50.8	2.4	31.8	2.3
04	24.1	0.6	15.2	0.7	53.0	2.6	33.1	1.8
04	22.1	1.1	15.4	1.5	45.4	2.9	28.0	1.7
05	29.4	1.9	28.8	2.0	49.0	2.2	29.6	1.5
05	27.7	2.4	23.3	3.0	49.3	3.7	28.6	2.0
05	25.8	0.7	19.6	1.2	52.0	3.1	31.4	2.0
06	56.0	3.4	66.0	5.7	71.3	3.2	34.0	1.6
06	32.5	1.5	40.8	3.0	42.1	2.4	16.5	1.2
08	24.7	2.1	20.0	2.9	41.7	1.5	23.4	1.6
08	27.2	1.2	22.6	1.0	40.4	1.5	21.9	0.9
08	24.1	0.8	18.8	1.9	42.9	2.5	25.1	2.0

[1]Cover type classes are described in Table 20.

TABLE 30. Radiance values ($mw/cm^2/sr$) from count averages shown in Table 29 for samples within the mapping types of scene 1028-17121.

Cover[1] Type Class	MSS 4	MSS 5	MSS 6	MSS 7
01	0.40	0.23	0.49	1.49
02	0.33	0.18	0.34	0.99
03	0.40	0.22	0.63	2.05
04	0.45	0.24	0.69	2.26
05	0.54	0.38	0.69	2.18
06	0.86	0.84	0.79	1.84
08	0.49	0.32	0.58	1.71

[1]Cover types are described in Table 20.

TABLE 31. Radiance reflected from healthy pine as measured by ground spectrometer for four clear days respresentative of the days and time of day when the ERTS-1 scenes used in this study were imaged. The radiance shown for each day is an average of five to nine separate measurements.

	Radiance mw/cm^2/sr			
Day	MSS 4	MSS 5	MSS 6	MSS 7
261	.2195	.1200	.3888	1.1935
265	.2195	.1321	.4206	1.2722
270	.2195	.1276	.4111	1.2128
272	.2151	.1350	.4206	1.2474
Mean	.2184	.1287	.4103	1.2315

For a feature such as closed-canopy pine forest, then, 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.

Computer-Assisted Processing

Results of the computer-assisted processing of ERTS-1 multispectral scanner tapes are discussed in terms of blocks and sub blocks. The sub blocks are of interest because they are the areas from which training samples and prototypes were drawn for developing classification parameters. Thus, the results of computer classification from the sub blocks should be good. In contrast, classification of the larger blocks was accomplished by extension of signatures developed within the sub blocks. And the classification results from the blocks would probably be less accurate.

Sub Blocks

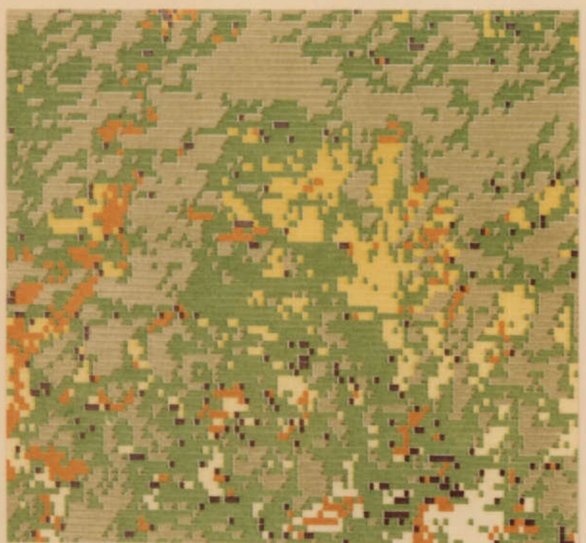
Composite Figure 21 shows the classification maps of LARS and PSW which are compared to the ground truth map for sub block 1. The major difference in the quality of the displays is that the PSW classification map is the product of a multicolor pen plotter whereas the LARS map comes directly from a photo printer display. While the LARS color photo display appears to have little promise as an accurate map, the actual results of the classification taken from the 1:24,000-scale rectified line printer output did not suffer the same inaccuracies.

In assessing the classification performance for sub block 1 (see Table 32) our focus is on the classification of dead beetle-killed pine (cover type 00). It is sub block 1 which contained the largest infestation and the highest number of dead trees in 1972 (Table 15). The LARS classification does not present results for dead pine. Although the PSW

BLACK HILLS, SOUTH DAKOTA ERTS-1 TEST SITE 226A

SUB BLOCK 1

COMPUTER MAP



Scale:

0 1 2 MILES

0 1 2 KILOMETERS

PRODUCED BY: U.S. FOREST SERVICE

DESCRIPTION

DATA SOURCE:

ERTS-1 Scene 1047-17175
September 8, 1972

System corrected CCT's

SPECTRAL BANDS: 4, 5, 6, 7

CLASSIFICATION METHOD:

Nearest neighbor

LEGEND

Pine, dead	Pasture, dry
Pine, <50%	Soil/rock
Pine, >50%	Water
Hardwood	Transition
Pasture, wet	

BLACK HILLS, SOUTH DAKOTA ERTS-1 TEST SITE 226A

SUB BLOCK 1

GROUND TRUTH

Scale:

0 1 2 MILES

0 1 2 KILOMETERS

PRODUCED BY: U.S. FOREST SERVICE

DESCRIPTION

DATA SOURCE:

1:32,000 scale color infrared photos
by USFS, September 8, 1972.

CLASSIFICATION METHOD:

Photo interpretation and ground checks

LEGEND

Pine, dead	Pasture, dry
Pine, <50%	Soil/rock
Pine, >50%	Water
Hardwood	Transition
Pasture, wet	

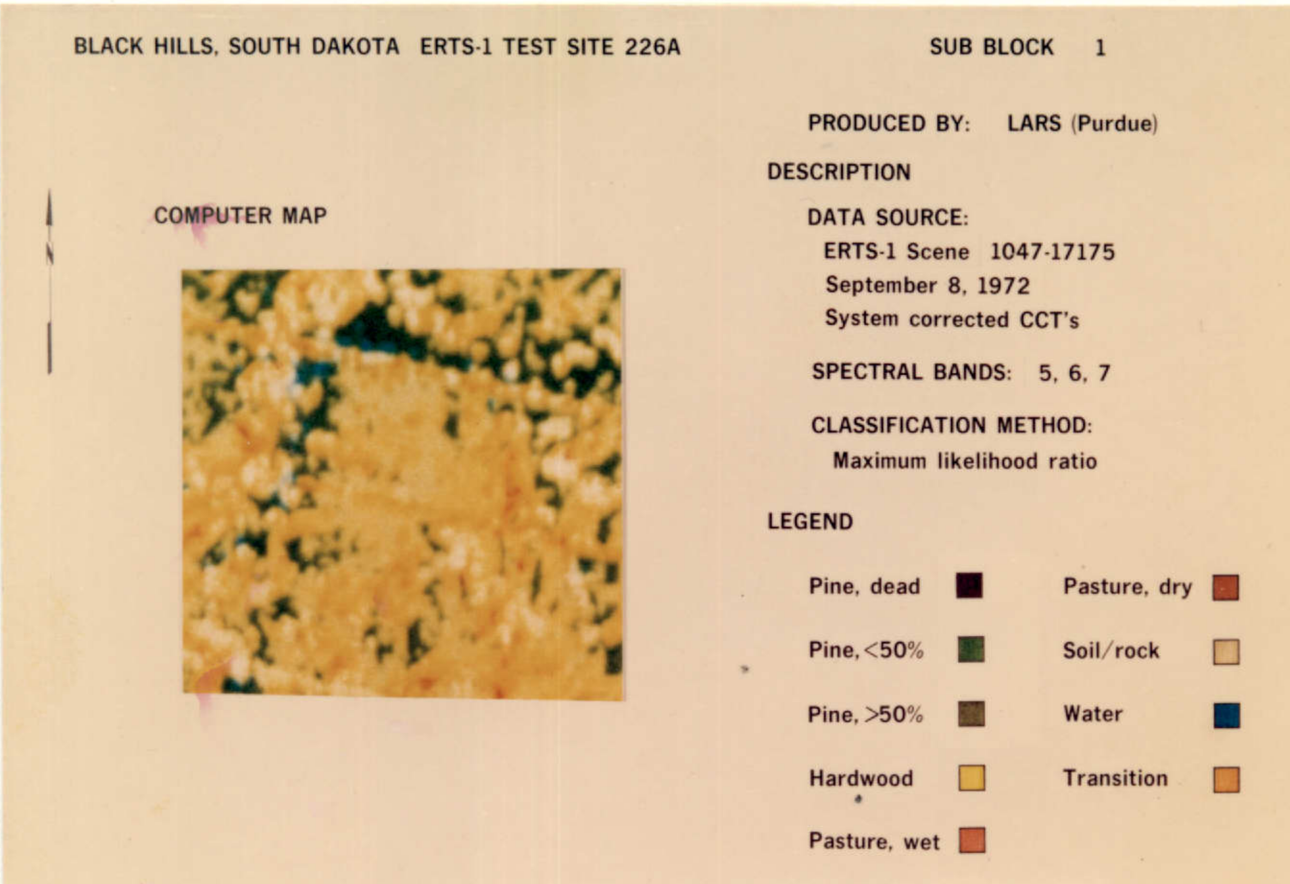


Figure 21. Computer-assisted classification displays are shown for the 3,949-hectare sub block 1. The ground truth map on the lower half of the facing page is a copy of the 1:24,000-scale rectified cover type map. Above on the facing page is a copy of the 1:24,000-scale Forest Service classification display similar to that used for the classification performance evaluation. The illustration above is a copy of the 1:32,000-scale LARS photograph from the digital display unit. The photograph was not used for the LARS classification performance evaluation; instead, the 1:24,000-scale line printer output shown in Figure 23 was used.

TABLE 32. Classification performance is given for sub block 1 which is an intensive study site within the Spearfish Canyon block of scene 1047-17175.

Level III Cover Type[1]	Ground Truth Percent	Ground Truth Hectares[2]	PSW Percent	PSW Hectares	LARS Percent	LARS Hectares
00	1.4	55.3	3.1	122.4	0	0
01	58.0	2,290.6	47.4	1,871.9	29.6	1,169.0
02	23.2	916.2	33.1	1,307.2	36.2	1,429.6
03	12.7	501.5	11.4	450.2	8.5	335.7
04	0.2	7.9	0	0	4.5	177.7
05	0.1	3.9	0	0	7.0	276.4
06	0.4	15.8	0	0	7.0	276.4
07	0	0	0	0	1.0	39.5
08	4.0	158.0	5.0	197.5	6.2	244.9
	100.0	3,949.2 (9,758.6)[3]	100.0	3,949.2 (9,758.6)	100.0	3,949.2 (9,758.6)

Level II Cover Type	Ground Truth Percent	Ground Truth Hectares	PSW Percent	PSW Hectares	LARS Percent	LARS Hectares
Conifer	82.6	3,262.1	83.6	3,301.5	65.8	2,598.5
Deciduous	12.7	501.5	11.4	450.2	9.5	335.7
Grassland	0.3	11.8	0	0	11.5	454.2
Bare Soil	0.4	15.8	0	0	7.0	276.4
Transition	4.0	158.0	5.0	197.5	6.2	244.9
Water	0	0	0	0	1.0	39.5
	100.0	3,949.2 (9,758.6)	100.0	3,949.2 (9,758.6)	100.0	3,949.2 (9,758.6)

[1] See Table 20 for explanations of cover type code.
[2] 1 hectare = 2.471044 acres
[3] Numbers in parentheses are acres.

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 report that computer-assisted processing of ERTS-1 multispectral scanner tapes is not successful in detecting stress in the Black Hills ponderosa pine ecosystem resulting from attack by mountain pine beetle.

Composite Figure 22 shows the comparison of computer-assisted classification maps for sub block 2 with the ground truth map. In contrast to sub block 1 which contained the large infestations, we did not anticipate detecting the small spots in sub block 2. The reader is directed back to Figure 15 for comparison to an aerial photograph of sub block 2, and to Figure 17 for location of the mountain pine beetle infestations. While we found considerable variation in the classification performance at Level III for sub block 2 (Table 33), 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 34), the PSW system appeared better for classifying cover type density of ponderosa pine (code 01 and 02).

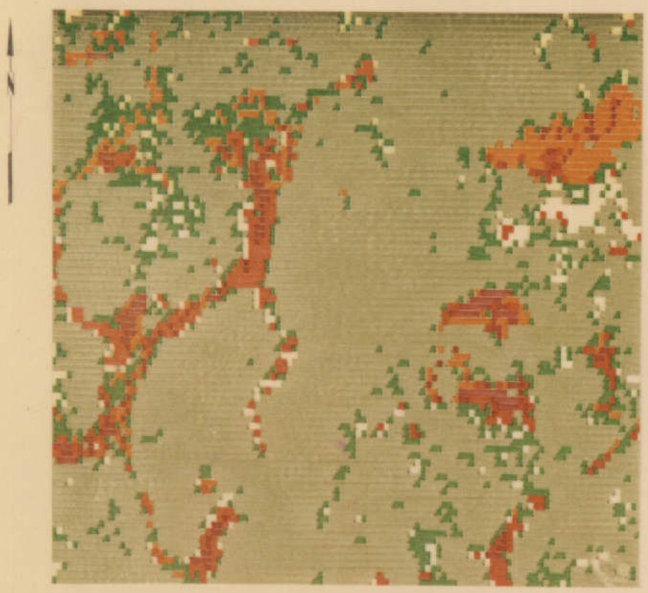
Blocks

The comparison of PSW and LARS computer-assisted classification for the Lead block is shown in Table 35. In reconciling the classifications to the ground truth one must remember that ground truth does not recognize the classes cloud or cloud shadow. This is because ground truth is derived from aerial photographs obtained with no clouds while the ERTS-1 imagery (see Figure 13) was obtained with several scattered clouds over the block.

BLACK HILLS, SOUTH DAKOTA ERTS-1 TEST SITE 226A

SUB BLOCK 2

COMPUTER MAP



Scale:

0 1 2 MILES

0 1 2 KILOMETERS

PRODUCED BY: U.S. FOREST SERVICE

DESCRIPTION

DATA SOURCE:

ERTS-1 Scene 1028-17121
August 20, 1972

System corrected CCT's

SPECTRAL BANDS: 4, 5, 6, 7

CLASSIFICATION METHOD:

Nearest neighbor

LEGEND

Pine, dead	Pasture, dry
Pine, <50%	Soil/rock
Pine, >50%	Water
Hardwood	Transition
Pasture, wet	

BLACK HILLS, SOUTH DAKOTA ERTS-1 TEST SITE 226A

SUB BLOCK 2

GROUND TRUTH

Scale:

0 1 2 MILES

0 1 2 KILOMETERS

PRODUCED BY: U.S. FOREST SERVICE

DESCRIPTION

DATA SOURCE:

1:32,000 scale color infrared photos
by USFS, September 8, 1972.

CLASSIFICATION METHOD:

Photo interpretation and ground checks

LEGEND

Pine, dead	Pasture, dry
Pine, <50%	Soil/rock
Pine, >50%	Water
Hardwood	Transition
Pasture, wet	

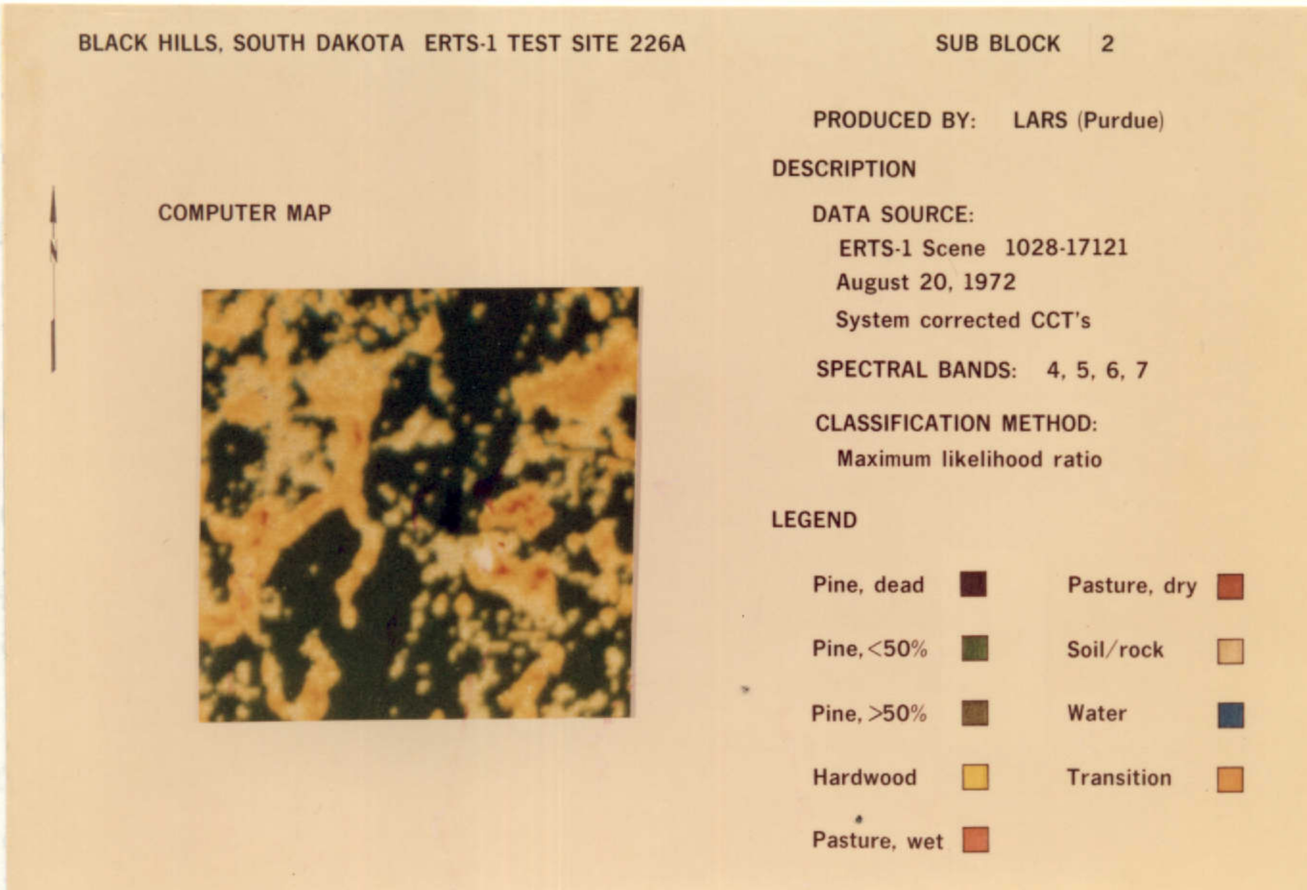


Figure 22. Computer-assisted classification displays are shown for the 4,142-hectare sub block 2. The ground truth map on the lower half of the facing page is a copy of the 1:24,000-scale rectified cover type map. Above on the facing page is a copy of the 1:24,000-scale Forest Service classification display similar to that used for the classification performance evaluation. The illustration above is a copy of the 1:32,000-scale LARS photograph from the digital display unit. The photograph was not used for the LARS classification performance evaluation; instead, a 1:24,000-scale line-printer output 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 in Figure 17.

TABLE 33. Classification performance is given for sub block 2 which is an intensive study site within the Lead block of scene 1028-17121.

Level III Cover Type[1]	Ground Truth Percent	Ground Truth Hectares[2]	PSW Percent	PSW Hectares	LARS Percent	LARS Hectares
00	0.2	8.3	0	0	0	0
01	16.1	666.9	12.7	526.0	26.0	1,114.2
02	70.6	2,924.3	72.9	3,019.5	62.8	2,601.3
03	0.7	29.0	3.7	153.3	1.0	41.4
04	3.6	149.1	4.1	169.8	3.6	149.1
05	6.0	248.5	2.8	116.0	1.8	74.6
06	0.1	4.1	0	----	0.1	4.1
08	2.7	111.8	3.8	157.4	3.4	140.8
(cloud)	--	-----	0	0	0.1	4.1
(shadow)	--	-----	0	0	0.3	12.4
	100.0	4,142.0 (10,235.1)[3]	100.0	4,142.0 (10,235,1)	100.0	4,142.0 (10,235.1)

Level II Cover Type	Ground Truth Percent	Ground Truth Hectares	PSW Percent	PSW Hectares	LARS Percent	LARS Hectares
Conifer	86.9	3,599.5	85.6	3,545.5	89.7	3,715.5
Deciduous	0.7	29.0	3.7	153.3	1.0	41.4
Grassland	9.6	397.6	6.9	285.8	5.4	223.7
Bare Soil	0.1	4.1	0	0	0.1	4.1
Transition	2.7	111.8	3.8	157.4	3.4	140.8
(cloud)	---	---	0	0	0.1	4.1
(shadow)	---	---	0	0	0.3	12.4
	100.0	4,142.0 (10,235.1)	100.0	4,142.0 (10,235.1)	100.0	4,142.0 (10,235.1)

[1]See Table 20 for explanation of cover type code.
[2]1 hectare = 2.471044 acres
[3]Numbers in parentheses are acres.

TABLE 34. Classification performance is given for sub block 3 which is an intensive study site within the Spearfish Canyon block of scene 1047-17175.

Level III Cover Type[1]	Ground Truth Percent	Ground Truth Hectares[2]	PSW Percent	PSW Hectares	LARS Percent	LARS Hectares
00	0.1	4.1	0	0	0	0
01	23.6	964.7	22.6	923.8	12.9	527.3
02	65.4	2,673.2	71.2	2,910.3	69.7	2,848.9
03	0.1	4.1	0	0	0.1	4.1
04	1.5	61.3	2.5	102.2	1.8	73.6
05	0.8	32.7	0	0	2.6	106.3
06	0	0	0	0	3.0	122.6
07	0	0	0	0	1.0	40.9
08	4.0	163.5	3.7	151.2	3.5	143.1
(null)[3]	4.5	183.9	0	0	5.4	220.7
	100.0	4,087.5 (10,100.4)[4]	100.0	4,087.5 (10,100.4)	100.0	4,087.5 (10,100.4)

Level II Cover Type	Ground Truth Percent	Ground Truth Hectares	PSW Percent	PSW Hectares	LARS Percent	LARS Hectares
Conifer	89.1	3,642.0	93.8	3,834.1	82.6	3,376.2
Deciduous	0.1	4.1	0	0	0.1	4.1
Grassland	2.3	94.0	2.5	102.2	4.4	179.9
Bare soil	0	0	0	0	3.0	122.6
Transition	4.0	163.5	3.7	151.2	3.5	143.1
Water	0	0	0	0	1.0	40.9
(null)	4.5	183.9	0	0	5.4	220.7
	100.0	4,087.5 (10,100.4)	100.0	4,087.5 (10,100.4)	100.0	4,087.5 (10,100.4)

[1]See Table 20 for explanation of cover type.
[2]1 hectare = 2.71044 acres
[3]Area excluded by the scene edge.
[4]Numbers in parentheses are acres.

TABLE 35. Results of computer assisted processing of scene 1028-17121 are compared to ground truth for the Lead block.

Level III [1]	Ground Truth		PSW		LARS	
Cover Type	Percent	Hectares[2]	Percent	Hectares	Percent	Hectares
00	0.5	206.5	0	0	0	0
01	32.5	13,420.1	12.7	5,244.2	32.1	13,255.0
02	54.6	22,545.8	66.7	27,542.2	53.3	22,009.0
03	4.5	1,858.2	6.6	2,725.3	2.1	867.1
04	1.8	743.3	7.3	3,014.4	4.8	1,982.0
05	2.3	949.7	2.4	991.0	2.6	1,073.6
06	0.1	41.3	0	0	0.1	41.3
07	0.1	41.3	0	0	0	0
08	3.6	1,486.5	4.3	1,775.6	3.9	1,610.4
(cloud)	---	---	0	0	0.6	247.8
(shadow)	---	---	0	0	0.5	206.5
	100.0	41,292.7	100.0	41,292.7	100.0	41,292.7
		(102,036.1)[3]		(10,036.1)		(10,036.1)

Level II	Ground Truth		PSW		LARS	
Cover Type	Percent	Hectares	Percent	Hectares	Percent	Hectares
Conifer	87.6	36,172.4	9.4	32,786.4	85.4	35,263.9
Deciduous	4.5	1,858.2	6.6	2,725.3	2.1	867.1
Grassland	4.1	1,693.0	9.7	4,005.4	7.4	3,055.7
Bare Soil	0.1	41.3	0	0	0.1	41.3
Transition	3.6	1,486.5	4.3	1,775.6	3.9	1,610.4
Water	0.1	41.3	0	0	0	0
(cloud)	---	---	0	0	0.6	247.8
(shadow)	---	---	0	0	0.5	206.5
	100.0	41,292.7	100.0	41,292.7	100.0	41,292.7
		(102,036.1)		(10,036.1)		(102,036.1

[1]See Table 20 for explanation of cover type.
[2]1 hectare = 2.471044 acres
[3]Numbers in parentheses are acres.

However, as the area involved is about 1 percent, it has small bearing on the classification.

The PSW classification of the Lead block suffered more overall in the signature extension than that performed by LARS. This is related to the representativeness of the prototypes or training blocks from the sub blocks when applied to the entire block for classification. 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. The problem remains that if deciduous and grassland cover type were considered one, the classification would be very good.

The area classification results for the Spearfish Canyon block (Table 36) is 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 combined deciduous and grassland into one class, the results would have looked good.

Classification performance was assessed for the blocks using nine-element computer cells of pure type as illustrated in Figure 23. Performance evaluation, in contrast to the simple comparison of area estimates, considers the pixel-by-pixel correctness of the classification. Although the overall area classification for the Lead block looked acceptable (Table 35), the performance evaluation (Table 37) showed that the LARS classification was 69.1 percent and the PSW 63.2 percent at Level III. For both classification systems the problem in the Lead block appeared to be with the transition cover type (08). A total of 10.4 percent of the total pixels

TABLE 36. Results of computer assisted processing of scene 1047-17175 are compared to ground truth data for the Spearfish Canyon block.

LEVEL III [1]	Ground Truth		PSW		LARS	
Cover Type	Percent	Hectares[2]	Percent	Hectares	Percent	Hectares
00	0.8	285.2	1.4	499.1	0	0
01	41.5	14,793.9	42.4	15,114.6	20.5	7,307.8
02	21.2	7,557.4	29.9	10,658.7	42.5	15,150.3
03	7.2	2,566.6	5.3	1,889.3	4.1	1,461.6
04	3.0	1,069.4	0	0	3.6	1,283.3
05	0.9	320.8	0	0	5.2	1,853.7
06	3.0	1,069.4	0	0	3.0	1,069.4
07	0.5	178.2	0	0	0.5	178.2
08	4.0	1,425.9	3.1	1,105.1	3.4	1,212.0
(null)[3]	17.9	6,380.9	17.9	6,380.9	17.2	6,131.4
	100.0	35,647.7	100.0	35,647.7	100.0	35,647.7
		(88,087.0)[4]		(88,087.0)		(88,087.0

LEVEL II	Ground Truth		PSW		LARS	
Cover Type	Percent	Hectares	Percent	Hectares	Percent	Hectares
Conifer	63.5	22,636.4	73.7	26,272.4	63.0	22,458.1
Deciduous	7.2	2,566.6	5.3	1,889.3	4.1	1,461.6
Grassland	3.9	1,390.3	0	0	8.8	3,137.0
Bare Soil	3.0	1,069.4	0	0	3.0	1,069.4
Transition	4.0	1,425.9	3.1	1,105.1	3.4	1,212.0
Water	0.5	178.2	0	0	0.5	178.2
(null)	17.9	6,380.9	17.9	6,380.9	17.2	6,131.4
	100.0	35,647.7	100.0	35,647.7	100.0	35,647.7
		(88,087.0)		(88,087.0)		(88,087.0

[1]See Table 20 for explanation of cover type.
[2]1 hectare = 2.471044 acres
[3]Area excluded by the scene edge.
[4]Numbers in parentheses are acres.

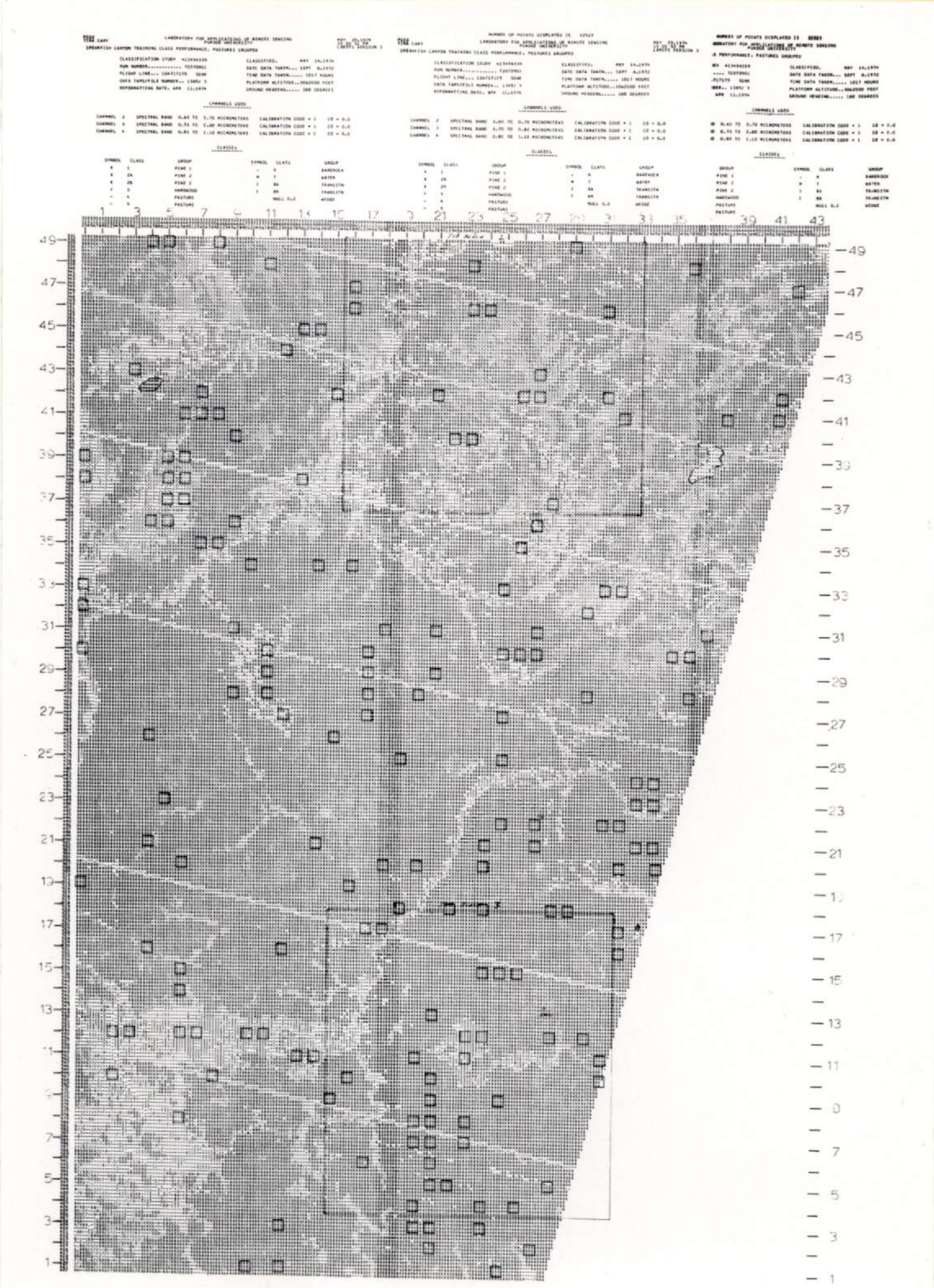


Figure 23. The LARS computer-assisted classification of the Spearfish Canyon block was for 29,268 hectares including sub block 1 and 96 percent of sub block 3 at a scale of 1:24,000. The small squares are the 186 nine-element cells selected from the aerial photographs as representing pure cover type and used to evaluate classification performance. Banding across the classification map is caused by scan line dropouts in MSS 5 and 6.

TABLE 37. Level III classification performance is shown for LARS and the Forest Service (PSW) for the Lead block of scene 1028-17121. Evaluation is based on examination of 10.4 percent of the total pixels.

LARS

Cover[1] Type	No. of Samples	PCT Correct	Cover Type 01	02	03	04	05	06	08	Mixed[2]
			Number							
01	35	71.4	25	10	0	0	0	0	0	0
02	117	97.4	2	114	0	0	0	0	0	1
03	12	66.7	0	0	8	1	0	0	0	3
04	6	83.3	0	0	0	5	0	0	1	0
05	9	66.7	0	0	0	2	6	0	0	1
06	2	50.0	0	0	0	0	0	1	0	1
08	72	20.8	26	3	3	7	2	0	15	16
	253		53	127	11	15	8	1	16	22

Overall Performance - $\frac{174}{253}$ = 68.8%

PSW

Cover[1] Type	No. of Samples	PCT Correct	Cover Type 01	02	03	04	05	06	08	Mixed[2]
			Number							
01	35	63.2	12	19	0	0	0	0	0	4
02	117	99.2	0	116	0	0	0	0	0	1
03	12	16.7	0	0	2	9	1	0	0	0
04	6	50.0	0	0	0	3	3	0	0	0
05	9	77.8	0	0	0	0	7	0	0	2
06	2	0	0	2	0	0	0	0	0	0
08	72	27.8	3	14	0	9	8	0	20	18
	253		15	151	2	21	19	0	20	25

Overall Performance - $\frac{160}{253}$ = 63.2%

[1]See Table 20 for explanation of cover type code.

[2]Mixed class is for the test cells which had no majority classification of the nine elements which made up the cell.

classified in the Lead block were used in the evaluation of classification performance.

We felt the Level III classification performance for the Spearfish Canyon block was much improved over that for the Lead block. Here a total of 8.2 percent of the total pixels classified was used in the performance evaluation. The 80.1 percent correct for LARS and 76.9 percent for PSW is good even though both systems suffered from commission errors in differentiating conifer cover type density (Table 38).

The Level II classification performance for both LARS and PSW improved (Table 39), although much more spectacularly for the Spearfish Canyon block than for the Lead block. While a performance of 90 percent or better is very good, it appears that the lack of a good classifier for transition cover type in scene 1028-17121 was a great handicap.

DISCUSSION

It appears from the results of the classification effort in the Black Hills 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. But we are uncertain of how far that use extends in providing quantitative information for developing unit plans or impact statements.

Stress detection in the Black Hills was an unequivocal failure with ERTS-1 imagery, in spite of our best efforts. We therefore accept our original hypothesis that ERTS MSS imagery cannot detect stress in forests.

TABLE 38. Level III classification performance is shown for LARS and the Forest Service (PSW) for the Spearfish Canyon block of scene 1047-17175. Evaluation is based on examination of 8.2 percent of the total pixels.

LARS

Cover Type[1]	No. of Samples	PCT Correct	Cover Type								Mixed[2]
			01	02	03	04	05	06	07	08	Mixed
			Number								
01	42	45.2	19	14	0	1	1	0	0	0	7
02	102	95.1	5	97	0	0	0	0	0	0	0
03	27	74.1	0	0	20	3	2	0	0	0	2
04	3	66.7	0	0	0	2	1	0	0	0	0
05	3	66.7	0	0	0	1	2	0	0	0	0
06	4	10.0	0	0	0	0	0	4	0	0	0
07	1	10.0	0	0	0	0	0	0	1	0	0
08	4	10.0	0	C	0	0	0	0	0	4	0
	186		24	111	20	7	6	4	1	4	9

Overall Performance - $\frac{149}{186}$ = 80.1%

PSW

Cover Type[1]	No. of Samples	PCT Correct	Cover Type								Mixed[2]
			01	02	03	04	05	06	07	08	Mixed
			Number								
01	42	76.2	32	10	0	0	0	0	0	0	0
02	102	83.3	16	85	0	0	0	0	0	0	1
03	27	81.5	2	0	22	0	0	0	0	0	3
04	3	0	0	0	1	0	0	0	0	2	0
05	3	0	0	0	2	0	0	0	0	1	0
06	4	0	3	0	0	0	0	0	0	1	0
07	1	0	0	0	0	0	0	0	0	0	1
08	4	10.0	0	0	0	0	0	0	0	4	0
	186		53	95	25	0	0	0	0	8	5

Overall Performance - $\frac{143}{186}$ = 76.9%

[1]See Table 20 for explanation of cover type code.

[2]Mixed class is for the test cells which had no majority classification of the nine elements which made up the cell.

TABLE 39. Level II classification performance is compared for the Lead block of scene 1028-17121 and the Spearfish Canyon block of scene 1047-17175. Evaluation is based on examination of 10.4 percent of the pixels in the Lead block and 8.2 percent of the pixels in the Spearfish Canyon block.

Correct Classification in the Lead Block				
	LARS		PSW	
Level II Ecoclass	Number	Percent	Number	Percent
Conifer	151	99.3	147	96.7
Deciduous	8	66.7	2	16.7
Grassland	13	86.7	13	86.7
Bare Soil	1	50.0	0	0
Transition	15	20.8	20	27.8

Level II performance (LARS) = $\frac{188}{253}$ = 74.3 percent

Level II performance (PSW) = $\frac{182}{253}$ = 71.9 percent

Correct Classification in the Spearfish Block				
	LARS		PSW	
Level II Ecoclass	Number	Percent	Number	Percent
Conifer	135	93.8	143	99.3
Deciduous	20	74.1	22	81.5
Grassland	6	100.0	0	0
Bare Soil	4	100.0	0	0
Transition	4	100.0	4	100.0
Water	1	100.0	0	0

Level II performance (LARS) = $\frac{170}{186}$ = 91.4 percent

Level II performance (PSW) = $\frac{169}{186}$ = 90.0 percent

CLASSIFICATION OF PLANT COMMUNITIES WITH ERTS-1 AND SUPPORTING AIRCRAFT DATA---MANITOU, COLORADO TEST SITE

INTRODUCTION

The Nation's forest-range resources are being continously sought by a demanding, ecologically aware public for various goods and services. These resources, included in natural ecosystems that produce or can produce herbaceous and shrubby vegetation, occur on approximately 63 percent of the land area of the 48 contiguous states (Forest-Range Task Force, 1972). Natural resource inventories and reinventories to assess cause and effects of change are required to meet multiple resource management decisions.

The initial requisite for forest-range inventory and monitoring is to determine what the resources are, where they are, and how much is present. What they are involves a hierarchy of plant community classification. Where they are involves geographic location. How much is present involves area measurement of the communities and quantification of their parameters. How ERTS-1 could fulfill this requisite formed the basis for the work subsequently discussed. Specifically, the primary objective of this work was to determine at what level in an accepted plant community classification hierarchy ERTS-1 multispectral scanner imagery could be successfully used in a central Colorado mountainous area. A coobjective was to establish the kind of aircraft support photography needed to extend the classifications.

THE STUDY AREA

The study area is located between 38° 30' and 39° 30' north latitude and 104° 40' and 106° 10' west longitude and includes approximately 14,000 sq. km. (5,400 sq. mi.) (Fig. 25). Included within the area was the NASA Manitou Test Site, No. 242, where, from 1969 to 1972, considerable work was done to ascertain aerial photo film/filter/scale/seasonal combinations to characterize and quantify plant community systems and components.

This nonurban, nonagricultural area in central Colorado is characterized by extreme diversity in plant community systems and extreme variations in topography. In general, the vegetation aligns itself to changes in 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 2,000 m (6,500 ft.) and 2,700 m (8,800 ft.), but extend below this zone to 1,800 m (5,900 ft.) and above the zone to 3,000 m (9,800 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. 26). The forests, ranging from approximately 1,900 m (6,232 ft.) above mean sea level to tree line at approximately 3,500 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 Engelmann spruce (Picea engelmanni Parry) and subalpine fir (Abies

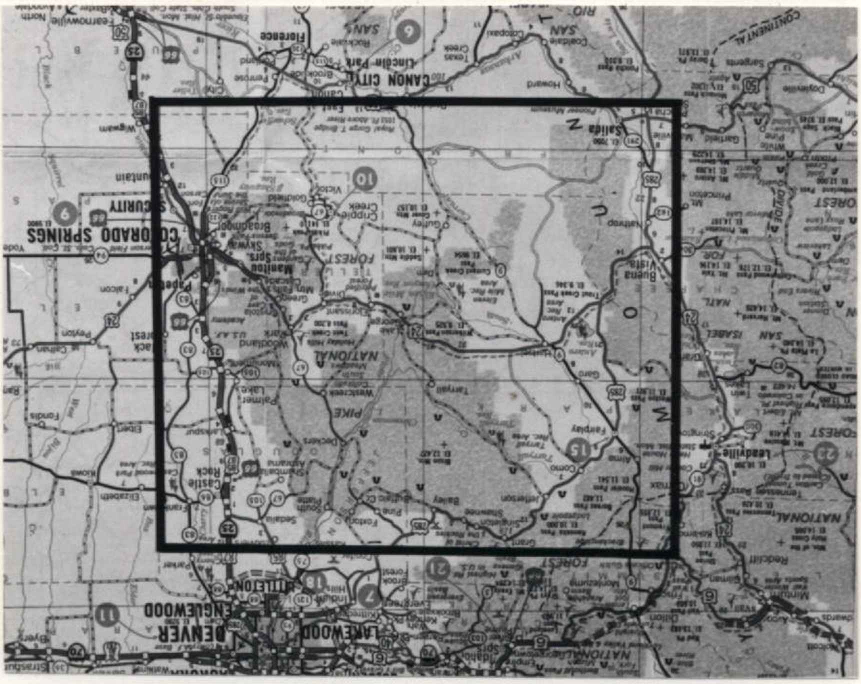


Figure 25. Map location of the central Colorado area. The area includes part of the Colorado Front Range on the east, a large high mountain park (South Park), and part of the Park Range on the west.

Figure 26. The vegetation of the Colorado Test Site is very complex, including pure stands of species types and intergrades among types. The dark tones are Coniferous Forests. The lighter tones are Deciduous (quaking aspen) Forests. Open areas are herbaceous vegetation. Note the dense mountain shadow in the left portion of the figure.

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 ecotones between forest types or as a result of plant succession due to man-caused disturbance. 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 parks, in which Arizona fescue (Festuca arizonica Vasey) and mountain muhly (Muhlenbergia montana (Nutt.) Hitchc.) were the dominant grasses, occur in the lower elevation areas and were principally associated with the ponderosa pine forests. 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.) at higher elevations. 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. 27).

Within the central part is South Park, a large, nearly treeless area. The vegetation of South Park is generally of low stature in which blue grama (Bouteloua gracilis (H.B.K.) Lag.) and slimstem muhley (Muhlenbergia filiculmis Vasey) are the most prominent. These and associated species provide the aspect of a shortgrass prairie. Around the fringes of the Park, and in some places within the Park where

Figure 27. The gradation between vegetation types is subtle, both among general classes (grassland vs forest) and within classes (forest vs forest).

ORIGINAL PAGE IS
OF POOR QUALITY

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 (Scripus 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.).

Topographically, the main portion of the study area varies from approximately 2,100 m (6,888 ft.) to 4,300 m (14,104 ft.) above mean sea level. Elevation variations are dramatic, as much as 400 m per km. (2,000 ft. per mi.) in many places. The average elevation of South Park is approximately 2,750 m (9,020 ft.) above mean sea level.

Geologically, the eastern portion of the study area is associated with the Pikes Peak and Kenosha batholiths, comprised 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, 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 geologically 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. However, many spur-fragments, as well as individual units within the major ranges, are oriented east-west. This presents a complex matrix of various slope-aspect relationships that influences vegetation patterns and adds to the complexity of processing and interpreting the remotely sensed data.

PROCEDURES

Vegetation Classification System

The hierarchical vegetation classification scheme used to evaluate the effectiveness of the ERTS-I and supporting aircraft data has been established according to ecological principals of polyclimax concepts (Daubenmire, 1952). This system, ECOCLASS, is in current use by the U.S. Forest Service to classify plant communities for land management planning. The system is in accord with that established by the International Biological Program for classifying terrestrial communities (Peterken, 1970). Five categories were defined, proceeding from the most general to the most specific. Descriptions of these categories are as follows:

Category	Definition
V - Formation	The most general class of vegetation characterized by general appearance: grassland, coniferous forest, deciduous forest, etc.

IV - Region	Groups of community systems with similar appearance and under regional climatic controls: montane grasslands, temperate mesophytic coniferous forests, alpine grasslands, etc.
III - Series	A group of vegetation systems, usually with single, common dominant climax species: ponderosa pine forests, fescue grasslands, herbaceous meadows, etc.
II - Habitat Type	The unit with relatively pure internal biotic and abiotic structure: ponderosa pine-Arizona fescue, Arizona fescue-mountain muhly, etc. <u>These are the elemental units of the classification scheme upon which primary management is based</u>. These units are frequently related to climax situations or situations held in a relatively stable state of high succession by proper management.
I - Community Type	Systems that appear 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.

Three Regional and eight Series categories within this framework were defined for this study. They were as follows:

<u>Category IV - Region</u>	<u>Category III - Series</u>
1. Coniferous Forest	1. Ponderosa Pine 2. Lodgepole Pine 3. Douglas-fir 4. Spruce/Fir
2. Deciduous Forest	1. Aspen

3. Grassland	1. Shortgrass 2. Mountain Bunchgrass 3. Wet Meadow

Data Acquisition

Three ERTS-1 color composite images, system corrected at a scale of approximately 1:1,000,000, that included most of the test site were selected for analysis. General characteristics of this imagery are provided in Table 40. The color composites, 24 cm (9.5 inch) format, were created by optically combining the black-and-white images from ERTS multispectral channels 4 (green waveband: 0.5 to 0.6 micron), 5 (red waveband: 0.6 to 0.7 micron), and 7 (near infrared waveband: 0.8 to 1.1 microns) with blue, green, and red filters, respectively. This produced a simulated color infrared photographic image of the scene. These scenes were selected because: (1) the 1972 scene was the first relatively 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 cloud free and represented a time when most vegetation was in either primary growth stages (June) or at peak growth (August) to determine if seasonal plant growth effects assisted classification. This material was used for visual interpretation and microdensitometric analyses according to procedures subsequently defined.

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

TABLE 40. General characteristics of the three ERTS-I images used for this study.

Date Exposed	Observation Identification	% of Test Site Included	% Cloud Cover Over Test Site
20 August 1972	1028-17135	95	10
22 June 1973	1334-17142	90	5
15 August 1973	1388-17134	90	2

portions of the August 1973 data were analyzed in cooperation with the Laboratory for Applications of Remote Sensing, Purdue University. Procedures for the analysis techniques used by both cooperators and the areas included are subsequently defined.

Also, 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. The purpose of this photography was to represent plant phenological conditions corresponding to the selected ERTS scenes. Aerial photo scales were approximately 1:50,000, 1:100,000, and 1:400,000. Also CIR photographs at scales of approximately 1:2,000, 1:10,000, 1:20,000, and 1:40,000 were flown by USFS aircraft to correspond to the August 1972 ERTS scene to further identify photo scales required for specific plant community systems.

Interpretative Technique

Within the total study area, five units, each approximately 576 km^2 (225 $mi.^2$), were selected for intensive investigation (Fig. 28). These units were not necessarily replications because the plant community classes in one unit were not completely represented in all other units. They were selected to include the variety of situations within the total test site.

Computer-Assisted Analysis

The first analysis method used to evaluate ERTS-1 data for classifying plant communities was machine processing of the computer-compatible magnetic tapes of the scene-corrected imagery. Two sets of imagery were used--

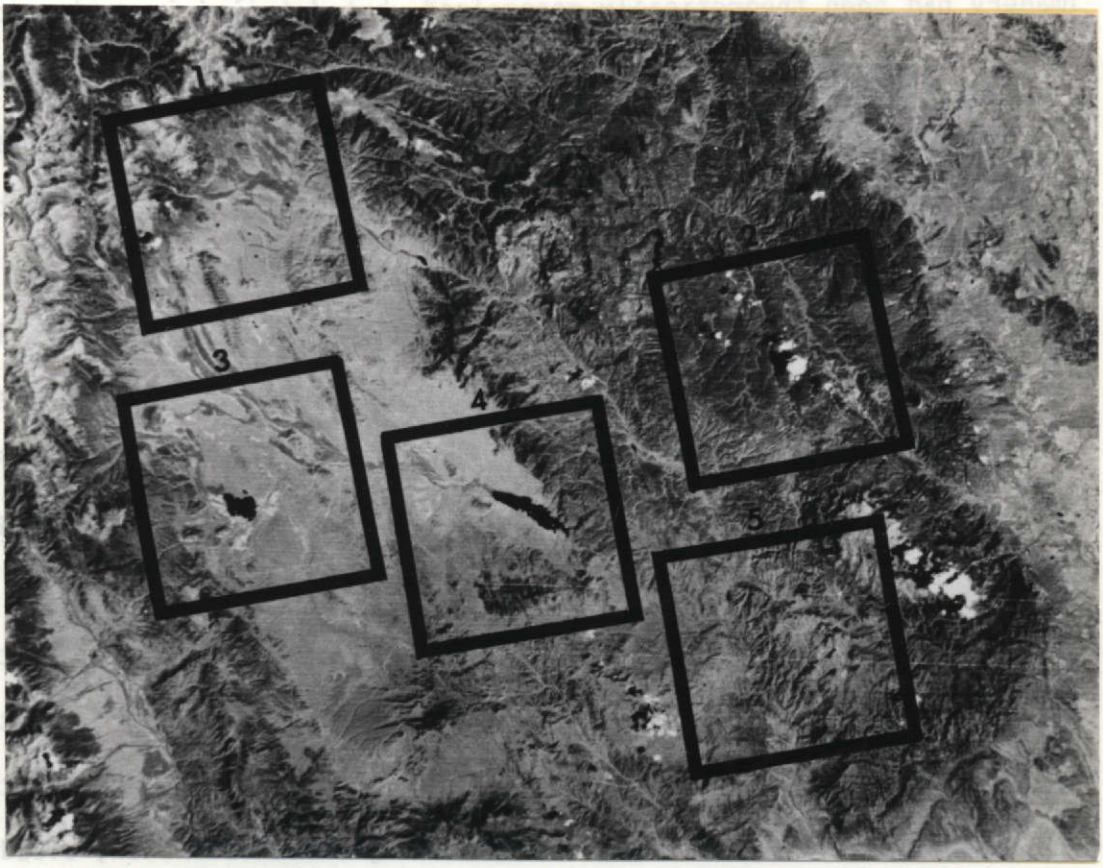


Figure 28. Location of the five units selected for intensive investigation within the Manitou Test Site. Pikes Peak occurs at the northeast corner of unit 5. The units outlined in this ERTS frame (1028-17135) are aligned in a true N-S orientation. The skewness in the ERTS imagery was due to the orbital path of the vehicle and earth rotation. Clouds in the scene represent one of the problems of interpreting fixed-orbit and fixed-time satellite imagery. Of 15 possible times when full site coverage with one ERTS frame with less than 10 percent cloud cover could have been obtained during the August-October 1972 and April-October 1973 period, only 3 were secured.

20 August 1972 and 15 August 1973. Analysis of the 1972 imagery was done 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 et al., 1973). The August 1973 imagery was processed in cooperation with Purdue University, Laboratory for Applications of Remote Sensing, to make an evaluation of the ERTS-1 imagery for classifying the plant communities to the Regional and Series levels.

To determine effects of topography on classification, a photolike image mosaic of these units at approximately 1:90,000 scale was generated from the computer compatible tapes using the microfilm capability of the CDC-6400 computer at Colorado State University. An initial classification of all classes was performed on selected portions of the data--unit 2 (Manitou) and unit 4 (Eleven Mile). Topographic maps, vegetation type maps, and 1:100,000-scale CIR aerial photographs were used to select and delineate on this mosaic representative computer training sets for the different vegetation classes. Also, training areas for water, clouds, and cloud shadows were selected. The size of these training sets varied due to the natural meandering of the vegetation class boundaries.

This processing was done to assist in locating selected portions of the Ponderosa Pine Series in the ERTS-1 computer compatible tapes for detailed investigations on effects of slope steepness on the apparent spectral signatures of the Series. Nine 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° to 15° (low), 15° to 30° (medium), and greater than 30° (high), as determined from topographic maps.

The initial classification was done using a supervised program RECOG, (Smith et al., 1972), a multiphase program patterned after the LARSYS approach (Purdue University, 1968). No thresholding was used in developing the recognition tables for the training sets; each apparent resolution element was forced into one of the plant community classes. The training sets for the slope classes of the Ponderosa Pine Series were then located with the aid of aerial photos on the resultant computer gray-scale maps. Standard statistical "t"- and "F"-tests were used to determine any significant relationships between spectral response and slope steepness.

Classification done at LARS-Purdue used a mixed supervised and unsupervised procedure following the general LARSYS approach (Purdue University, 1968). The basic analysis procedure involved five phases: (1) locating the area to be studied, (2) selecting training areas to be clustered, (3) clustering the areas, (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 apparent resolution element of ERTS-I data represented one recognition map symbol. The training areas were selected to provide representative samples of the classes to be classified. This information was used to "train" the computer for total classification. The evaluation of the final classifications 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 Regional level and one at the Series level. In addition to the vegetation classes at each level, classes for barren areas, water, cloud shadows, clouds, and "bad" data were introduced. Thus, the finished product resulted in all ERTS-I digital data cells being classified.

Sample cells used for evaluation consisted of a series of 2 X 2 apparent resolution element matrices with a two-element buffer on each side to minimize the effect of possible positional errors. Each sample cell matrix of the computer-assisted classification was recorded for each apparent resolution element within the matrix, and then compared to the information content of the same ground location interpreted from 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 cases, 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 occuring within the test site.

Microdensitometric Interpretation

A scanning microdensitometer (Fig. 29) 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.

Since the color composite ERTS-1 image was used, a red filter was inserted into the light-beam path to potentially enhance the color infrared vegetation signatures. An effective circular aperture covering an image area of 41,500 sq. microns was used. This area of the ERTS image was a circle with the diameter approximately equivalent to the side dimensions of the sample cells used for visual interpretation.

Figure 29. The microdensitometer (a General Aniline and Film Corp. (GAF) 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 prior to reading the apparent optical image density.

The same sample cells used for visual interpretation were measured by the microdensitometer. Point-sample 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 sample-cell 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.

Visual Photo Interpretation

Vegetation maps, topographic maps, the ERTS-support aerial photographs, and ground inspection were used to select sample cells for visual interpretation of both the ERTS-I 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^2 (1,640 $ft.^2$). The size of the data cell selected was determined by two factors: (1) the originally advertised resolution and geographic fidelity of the system corrected ERTS products and (2) expected positional errors in both the satellite and data collection systems and transferring sample cells from maps to the ERTS-I and supporting aircraft photographs. A 10 percent sample of those cells was field-verified using aerial photographs and ground search. Since only three of the field verified cells required reclassification, it was decided that the remaining classifications were acceptably accurate.

No fewer than 20 training and testing cells were selected for each vegetation class. A total of 660 cells were used for training and testing in the visual interpretation of the ERTS-1 imagery and supporting aircraft photographs.

Visual interpretation was conducted using the color composite ERTS-1 imagery. Transparent overlays were constructed showing cell locations for the total study area and each of five units (Fig. 30). 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 24 cm (9.5 inch) ERTS-1 format. The plotted cell size at this scale represented an area 900 m^2 (2,952 $ft.^2$) to minimize edge effect of cell-wall lines. In addition, 50 km. (31.07 mi.) UTM coordinates were plotted to assist in positional location on the ERTS frames.

These same cell locations were used to interpret the aircraft support photographs. Cell locations were transferred directly from the vegetation and topographic maps to the aerial photographs.

RESULTS AND DISCUSSION

The three interpretation and analysis procedures--(1) computer-assisted analysis, (2) microdensitometric interpretation, and (3) visual interpretation--of the ERTS-1 system-corrected imagery provided similar results. In general, plant community classification to the Regional level was acceptable (> 80 percent accuracy) for most classes. Classification to the Series level was not acceptable (< 80 percent accuracy). Classification should be improved 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. Also, the results of classification to either the Region or Series level by the visual microdensitometric techniques indicated no date-dependency between

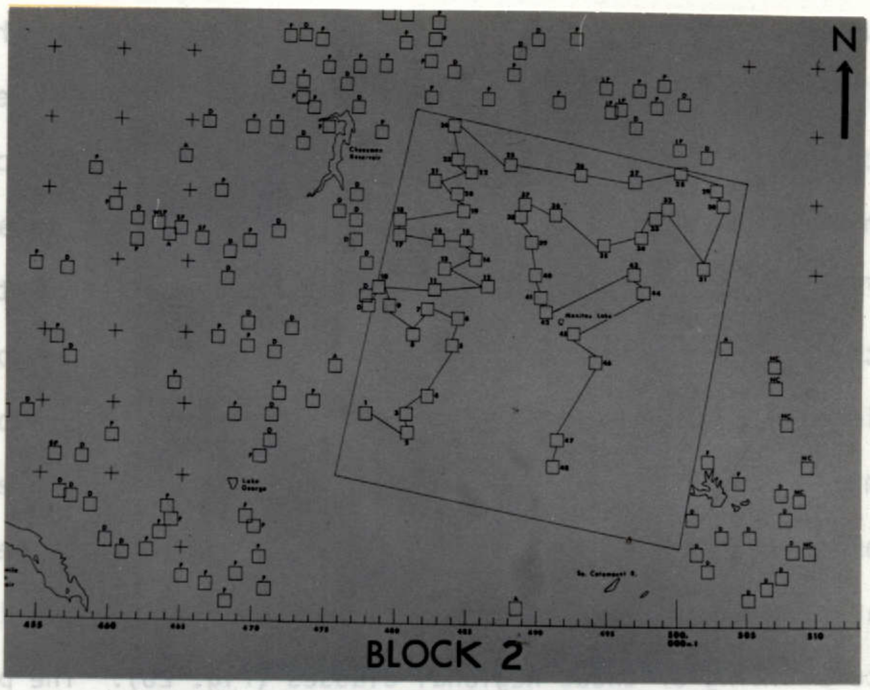


Figure 30. Graphic representation of training and testing sample cells used for visual interpretation of ERTS-I 24 cm (9.5 inch) color composites. Each small square represents an area approximately 900 m^2 (2,952 $ft.^2$) The interpreters concentrated on the 300 m^2 (984 $ft.^2$) center and named the class category they believed was represented by that signature.

late spring (June) and midsummer (August) ERTS-1 imagery. There were no variations in these results which are subsequently discussed.

Classification to the Regional level through visual interpretation of late spring (mid-June) and late summer (mid-September) aerial photos was not date- nor scale-dependent. Results of interpretation to the Series level were varied and are subsequently discussed.

Computer-Assisted Analysis

The training class performance of the computer-assisted analysis was very accurate at the Regional level of classisfication for both the Manitou (Table 41) and Eleven Nile (Table 42) units. 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 due to very 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 apparent resolution element, and as a result total signature was assigned to the Barren category. The confusion between the Coniferous and Deciduous classes was due to a mixing of these Regional classes (Fig. 26). The plant components, quaking aspen in this case, of the Deciduous class frequently occur in different amounts within the Coniferous class, and these mixes, or ecotones, apparently spectrally align themselves to one or the other of the primary classes. It is often difficult to determine on the ground to which class such ecotones belong without detailed ecological investigation.

TABLE 41. Computer-assisted training class performance for Regional vegetation classification--Manitou Unit[1]

Class category	Number of samples	Percent correct	Computer-assisted classification - category					
			GL	DF	CF	B	C	CS
Grassland	382	97.1	(371)	0	0	11	0	0
Deciduous Forest	78	98.7	0	(77)	1	0	0	0
Coniferous Forest	1294	97.6	1	30	(1263)	0	0	0
Barren	60	98.3	0	0	0	(59)	0	0
Cloud	384	99.2	0	0	0	0	(381)	0
Cloud Shadow	340	98.5	0	0	2	0	0	(335)
Total	2538	98.0[2]	372	107	1266	70	381	335

[1]Line totals may not add to sample size due to exclusion of "bad" data (0.3%) points from total sample.

[2]Overall performance = Number correctly classified/total number of samples.

TABLE 42. Computer-assisted training class performance for Regional vegetation classification--Eleven Mile Unit[1]

Class category	Number of samples	Percent correct	Computer-assisted classification - category				
			GL	DF	CF	W	B
Grassland	1193	97.7	(1166)	9	15	0	3
Deciduous Forest	173	97.7	4	(169)	0	0	0
Coniferous Forest	1137	99.2	8	1	(1128)	0	0
Water	1090	99.3	0	0	0	(1082)	0
Barren	41	100.0	0	0	0	0	(41)
Total	3634	98.7[2]	1178	179	1143	1082	44

[1]Line totals may not add to sample size due to exclusion of "bad" data (4%) and cloud shadow (0.01%) points from total sample.

[2]Overall performance = number correctly classified/total number of samples.

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The confusion in training class performance of the Eleven Mile unit was primarily between the Grassland and Coniferous classes and the Deciduous and Grassland classes. The errors, although not significant, between the Grassland and Coniferous classes were probably due to a mixing of the two categories at the boundaries (Fig. 27). 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-I sensors at the time the scene was exposed (August 1973).

Training class performance at the Series level also indicated high accuracy for all classes for both the Manitou (Table 43) and Eleven Mile (Table 44) 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" Series. The Mixed Conifer not only included high foliage cover ponderosa pine, but also Douglas-fir and some lodgepole pine. This was due to the fact that apparent spectral responses of those units were so similar that they could not be separated in the ERTS-I digital data analysis. Therefore, even on evaluation of training class performance, the ERTS-I 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.

TABLE 43. Computer-assisted training class performance for Series vegetation classification--Manitou Unit[1]

Class category	Number of samples	Percent correct	Computer-assisted classification - category								
			MB	WM	A	PP	MC[2]	LP	B	C	CS
Mountain Bunchgrass	268	97.0	(260)	0	0	0	0	0	8	0	0
Wet Meadow	114	97.4	0	(111)	0	0	0	0	3	0	0
Aspen	78	98.7	0	0	(77)	1	0	0	0	0	0
Ponderosa Pine	333	91.9	1	0	12	(306)	14	0	0	0	0
Mixed Conifer[2]	874	95.4	0	0	18	19	(834)	3	0	0	0
Lodgepole Pine	87	100.0	0	0	0	0	0	(87)	0	0	0
Barren	60	98.3	0	0	0	0	0	0	(59)	0	0
Cloud	384	99.2	0	0	0	0	0	0	0	(381)	0
Cloud Shadow	340	98.5	0	0	0	0	0	2	0	0	(335)
Total	2538	96.5[3]	261	111	107	326	848	92	70	381	335

[1]Line totals may not add to sample size due to exclusion of "bad" data (0.3%) points from total sample.

[2]The "Mixed Conifer" Series includes part of the Ponderosa Pine, all of the Douglas-fir and part of the Lodgepole Pine Series.

[3]Overall performance = number correctly classified/total number of samples.

TABLE 44. Computer-assisted training class performance for Series vegetation classification--Eleven Mile Unit[1]

Class category	Number of samples	Percent correct	Computer-assisted classification - category							
			MB	SG	WM	A	PP	MC[2]	B	W
Mountain Bunchgrass	136	91.9	125	0	11	0	0	0	0	0
Shortgrass	863	97.6	0	842	3	0	15	0	3	0
Wet Meadow	194	80.9	28	0	157	9	0	0	0	0
Aspen	173	97.7	0	0	4	169	0	0	0	0
Ponderosa Pine	672	99.3	0	3	1	1	667	0	0	0
Mixed Conifer[2]	465	99.1	0	0	4	0	0	461	0	0
Barren	41	100.0	0	0	0	0	0	0	41	0
Water	1090	99.3	0	0	0	0	0	0	0	1082
Total	3634	97.5[3]	153	845	180	179	682	461	44	1082

[1]Line totals may not add to sample size due to exclusion of "bad" data (4%) and cloud shadow (0.07%) points from total sample.

[2]The "Mixed Conifer" Series includes all the Spruce/Fir, Douglas-fir and Lodgepole Pine Series.

[3]Overall performance = number correctly classified/total number of samples.

The training field performance evaluation was indicative only of how well the training classes were selected and not necessarily of 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.

The Regional level classification of the Manitou unit using the computer-assisted techniques provided acceptable results for two categories, Grassland and Coniferous Forest (Table 45). The Decidous Forest and Water categories were not accurately classified. For the Water category, however, there was only one small (approximately 2 hectares or 5 acres) water body in the area, a sample size too small for adequate evaluation. The Deciduous Forest was classified where it was, but there were additional points classified as that category that were not in fact that category. These points were distributed throughout the area and were mostly associated with Grassland and Coniferous Forest class edges.

The Regional classification evaluation of the Eleven Mile unit showed that only the Grassland and Water categories were classified with sufficient accuracy to be acceptable (Table 46). The Deciduous Forest was confused with Grassland, primarily as a result of misclassification between the Deciduous Forest and Wet Meadow component of the Grassland Region. The reason for this will be subsequently discussed. The accuracy of the Coniferous Forest classification was only 66 percent. This was due to the decision on what to call a class when the apparent spectral response of Regional categories overlapped (Fig. 26).

In general, classification to the Regional level with ERTS-1 digital data is not accurate enought for total operational use. Ecotonal situations among Regional classes resulted in serious misclassifications,

TABLE 45. Total Regional classification evaluation, Manitou Unit

Class category	Number of samples	Percent correct	Computer-assisted classification - category			
			GL	DF	CF	W
Grassland	257	84.4	(217)	10	30	0
Deciduous Forest	21	23.8	8	(5)	8	0
Coniferous Forest	1239	86.1	146	26	(1067)	0
Water	3	66.7	0	0	1	(2)
Total	1520	84.9[1]	371	41	1106	2

[1]Overall performance = number correct/total number of samples.

TABLE 46. Total Regional classification evaluation--Eleven Mile Unit

Class category	Number of samples	Percent correct	Computer-assisted classification - category				
			GL	DF	CF	W	B
Grassland	433	80.1	(347)	7	74	0	5
Deciduous Forest	94	51.1	35	(48)	11	0	0
Coniferous Forest	739	66.0	76	175	(488)	0	0
Water	60	95.0	0	0	3	(57)	0
Barren	54	1.9	34	1	18	0	(1)
Total	1380	68.2[1]	492	231	594	57	6

[1]Overall performance = number correct/total number of samples.

especially between the Deciduous and Coniferous Forests. Also, frequent misclassification between the Deciduous Forest, Aspen in this case, 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 classifications by the computer-assisted analysis were sufficiently accurate to provide useful information only for the Shortgrass and Water categories (Tables 47 and 48) for the Eleven Mile Unit. The classification accuracy for Mountain Bunchgrass (73.8 percent) of the Manitou unit approached the established accuracy standards, but it would be risky for the resource manager to base decisions on these results. The accuracy of classification for Mountain Bunchgrass of the Eleven Mile unit was only 1 percent. The very low accuracy could be due to small sample size, only 136 points, used for establishing the training class statistics for the complete classification. Sixty-six percent of the computer classified points of Mountain Bunchgrass in the Eleven Mile unit were verified by photo interpretation to be Shortgrass. This indicates that the two Series classes are not separable using the ERTS-1 digital data even though Mountain Bunchgrass showed a fairly high level of accuracy for the Manitou unit. However, there was no Shortgrass in the Manitou unit so there could be no misclassifications between the two classes.

Accurate evaluation of the Coniferous Forest Series levels could not be done due to the various mixing in the computer-aided classification for the training class statistics. For example, for the Manitou unit,

TABLE 47. Total Series classification evaluation--Manitou Unit

Class category	Number of samples	Percent correct	Computer-assisted classification - category						
			MB	WM	A	PP[1]	MC[1]	LP[1]	W
Mountain Bunchgrass	244	73.8	(180)	25	9	21	8	1	0
Wet Meadow	11	72.7	3	(8)	0	0	0	0	0
Aspen	21	23.8	7	1	(5)	6	2	0	0
Ponderosa Pine[1]	930	38.4	128	5	22	(357)	385	33	0
Mixed Conifer[1]	294	44.9	14	0	2	49	(132)	97	0
Lodgepole Pine[1]	17	29.4	0	0	1	0	11	(5)	0
Water	3	66.7	0	0	0	1	0	0	(2)
Total	1520	45.3[2]	332	39	39	434	538	136	2

[1]The "Mixed Conifer" Series include part of the Ponderosa Pine, all of the Douglas-fir, and part of the Lodgepole Pine Series.

[2]Overall performance = number correctly classified/total number of samples.

TABLE 48. Total Series classification evaluation--Eleven Mile Unit

Class category	Number of samples	Percent correct	Computer-assisted classification - category							
			MB	SG	WM	A	PP	MC[1]	B	W
Mountain Bunchgrass	183	0.5	(1)	120	6	2	53	0	1	0
Shortgrass	188	87.8	3	(165)	4	1	9	2	4	0
Wet meadow	62	41.9	14	8	(26)	4	10	0	0	0
Aspen	94	51.1	0	10	25	(48)	8	3	0	0
Ponderosa Pine	369	66.9	0	37	15	62	(247)	8	0	0
Lodgepole Pine[1]	4	0.0	0	0	0	1	3	(0)	0	0
Spruce/fir[1]	135	54.8	0	5	1	42	13	(74)	0	0
Douglas-fir[1]	231	35.5	0	9	9	70	61	(82)	0	0
Barren	54	1.9	0	33	1	1	13	5	(1)	0
Water	60	95.0	0	0	0	0	0	3	0	(57)
Total	1380	50.8[2]	18	387	87	231	417	177	6	57

[1]The "Mixed Conifer" Series includes all the Spruce/Fir, Douglas-fir, and Lodgepole Pine Series. Hence, the "Mixed Conifer" column identifies the number of points occuring in each of the other Series identified from aerial photos and vegetation type maps.

[2]Overall performance =number correct/total number of samples.

a "Mixed Conifer" Series included part of the Ponderosa Pine, all of the Douglas-fir, and part of the Lodgpole Pine Series. This indicates that the apparent spectral responses of these classes were so similar that discrimination among them with ERTS-1 digital data was not possible with the procedures used in this study.

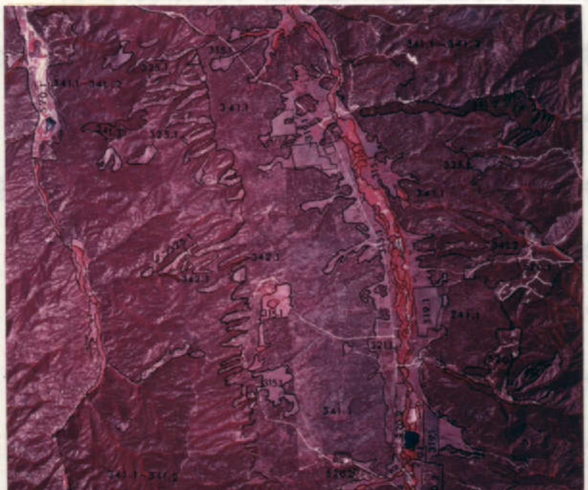
Aspen was not classified with sufficient accuracy to provide usable information to the resource manager. This Series was misclassified as Wet Meadow due to similar spectral responses of the two units as detected in the mid-August ERTS-1 data. Also, Aspen was confused with various Coniferous Forests units, as verified by relating the computer-aided classification to the aerial photographs. This was caused by an unknown threshold density of Aspen growing within the Coniferous Forest units such that the spectral signature was more like the Coniferous Forest than "pure" Aspen.

The relationships of the computer-aided classification and ground-truth interpretation from aerial photograhs provide insight for using the ERTS-1 digital data for this purpose (Fig. 31). It should be noted that within those units classified as Ponderosa Pine (341.1) on Figure 31b, there occurs varying amounts of tree density as indicated by crown closure (foliar cover) of the trees. Also, the Series occurs on varying slope steepness and aspect positions. 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 of Fig. 31b) or mixed with Ponderosa Pine (the west center of Fig. 31b). Generally, the gradation between the two Series on the ground is quite sharp, but the tree crown density is very similar. Consequently, the chance of misclassification between the two Series is high (Table 47).

(a)

Legend

Color	Class(es)
Red- - - - -	Wet Meadow
Light Gold- -	Mtn. Bunchgrass
Dark Gold- -	Mixed Conifer including Ponderosa Pine/Douglas-fir, Lodgepole Pine/Douglas-fir and high density (foliage cover) Ponderosa Pine.
Light Green- -	Lodgepole Pine
Dark Green- -	Ponderosa Pine
Pink- - - - -	Aspen
Blue- - - - -	Barren
Black- - - - -	Cloud Shadow
White- - - -	Cloud



(b)

Legend

Number	Class(es)
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
341.3- - - - -	Lodgepole Pine
342.1- - - - -	Aspen
341.1-341.2- -	Ponderosa Pine/ Douglas-fir complex
210.1- - - - -	Ponds
520.1- - - - -	Mtn. Home Development
520.2- - - - -	Campgrounds

Figure 31. Color-coded computer recognition map (a) and ground-truth aerial photo map (b), both showing Series classification on an original 1:50,000 scale base. Some features, the 520 units, are shown on the aerial photograph and are important to wild land management. These could not be found in the ERTS imagery.

Edge-effect errors can be seen by detailed examination of Figure 31a, the color-coded computer-assisted Series classification map. One source of edge-effect error was caused by the apparent resolution element of the ERTS-1 scanner including the boundary between two vegetation classes. This effect is most noticeable around the black cloud shadow. An anomalous Ponderosa Pine Series classification occurs at the edge of the shadow, when in fact there is no ponderosa pine in that area. Similar anomalies can be seen by the white halos around the edge of the light blue areas--the white areas coded to clouds or snow when no clouds or snow occurred in the area. The effect was also very noticeable by closely examining the digital gray-scale classification maps for evaluation of the Wet Meadow Series. In the Manitou unit, this Series frequently occurs as narrow stringers of vegetation within the Forests (Fig. 31b). On the gray-scale map, Wet Meadows was misclassified to some other Series. This was caused by a mixing of materials in the apparent ground resolution scene to create a spectral signature not related to any of the material in the scene. For example, Wet Meadows were classified as Aspen where no aspen trees occurred.

It must be concluded that the resolution of ERTS-1 digital data is excessively coarse to provide the on-the-ground resource manager, i.e., the National Forest District Ranger, the in-place data required for management decisions. This is based on the computer-assisted analysis techniques previously defined. However, ways to account for some of the error sources were examined in depth for one Series, Ponderosa Pine, within the Manitou unit. The effects of slope steepness on apparent spectral responses were determined as described in the previous PROCEDURES section.

There was a significant relationship between spectral response and slope steepness. This response was evident in all four ERTS-I channels for each of the three slope classes (Fig. 32). 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:

$$Y_4 = 20.16+1.38x$$

$$Y_5 = 16.39+1.79x$$

$$Y_6 = 24.62+1.87x$$

$$Y_7 = 12.77+1.26x$$

where Y_i represents the relative spectral radiance in band_i as recorded by the ERTS-I 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 training statistics for the Ponderosa Pine Series class 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 to adjust the training statistics according to terrain changes in the imagery (Smith and Oliver, 1974; Kreigler and Horwitz, 1973). In this study, however, the average values for the medium slope category were used for all three slope classes.

Classification accuracies obtained for the different slope class training fields, applying the original spectral signatures utilized in

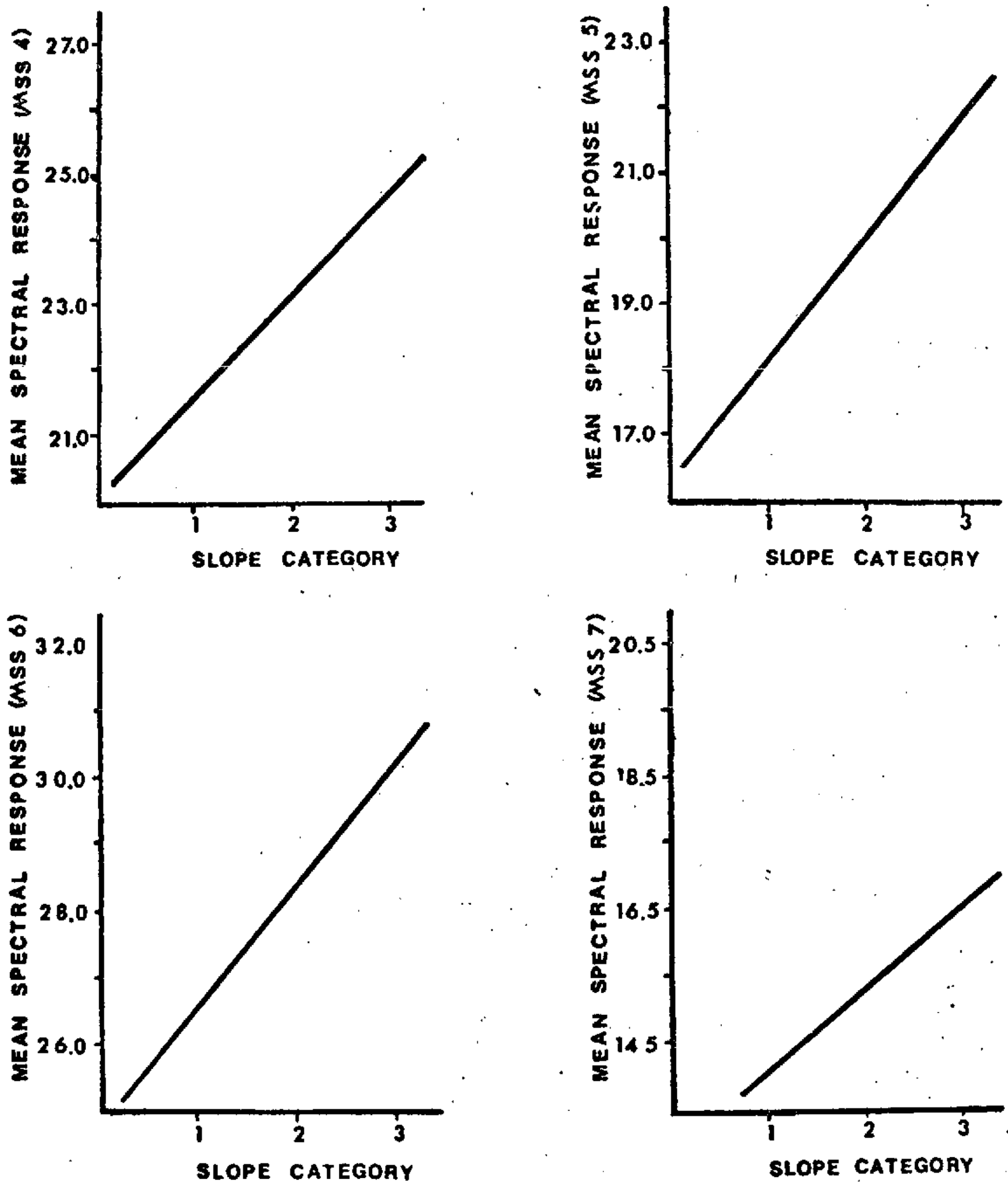


Figure 32. Graphic representation of the mean spectral response of a Ponderosa Pine Series by slope classes: 1 = 0-15 degrees, 2 = 15-30 degrees, 3 = > 30 degrees. As slope steepness increases in relation to a fixed sun and sensor position, spectral response increases linearly.

the initial Series classification task, are given in Table 49. In general, the classification performance decreased and commission errors between Coniferous Series 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 adjustment of the means according to the regression equations and using the values derived for the medium slope category, classification performance increased and commission errors decreased (Table 50). It appears evident that when accounting for terrain variances, both slope and aspect should improve classification accuracy. Intuitively, adjusting for variances in amount of live plant 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.

Microdensitometric Interpretation

Standard "t" tests for unpaired plots with unequal sample sizes for each population indicated highly significant differences in the apparent image density among all Regional classes regardless of which of the two ERTS-1 frames were used (Table 51). Consequently, at the Regional level of classification, those categories could be classified by microdensitometric techniques with a high degree of accuracy regardless of whether late June of mid-August imagery was used. Similar results have been obtained using small-scale aerial photos (Driscoll et al, 1974). However, the validity of these results with the ERTS photographic products needs to be evaluated using additional imagery of the same or other locations taken during other years.

TABLE 49. Computer recognition of selected Ponderosa Pine sites for three slope categories

Slope category	Percent correct	Commission errors (percent)		
		DF[1]	LP[1]	SF[1]
Low	81	10		7
Medium	57	10	4	16
High	33	16		14

[1]DF = Douglas-fir Series
LP = Lodgepole Pine Series
SF = Spruce/fir Series

TABLE 50. Computer recognition of selected Ponderosa Pine sites for three slope classes after signature adjustment

Class category	Percent correct	Commission errors (percent)		
		DF[1]	LP[1]	SF[1]
Low	83	17		
Medium	73	14	3	2
High	80	10		2

[1]DF = Douglas-fir Series
LP = Lodgepole Pine Series
SF = Spruce/fir Series

TABLE 51. Comparisons of apparent optical image density among Regional categories for two dates

ERTS-I ID No.		Sample size[1]	Mean image density
1334-17142 (6/22/73)	Deciduous forest	36	2.141**
	Coniferous forest	307	2.232**
	Grassland	66	1.079**
1388-17142 (8/15/73)	Deciduous forest	44	1.983**
	Coniferous forest	408	2.294**
	Grassland	69	0.991**

[1]Sample sizes for a category are different between dates due to clouds or cloud shadows obscuring sample points in the June imagery.

**Highly significant difference (p = 0.99) between all combinations at each date.

The results of microdensitometric interpretation for classification to the Series level were varied. For the three Grassland Series, there were no significant differences (p = 0.95) in image density estimated from the June imagery among any of the classes (Table 52). At that time of year, the grassland vegetation was in the primary stages of growth, there was little green foliage cover and most of the grassland scene was comprised of dead plant material and bare soil. Hence, discrimination among the Series classes did not occur.

Significant differences in the mean optical image densities of the Grassland Series did occur in the August imagery (Table 52). The mean density values between Mountain Bunchgrass and the Wet Meadow, and Shortgrass and Wet Meadow, were sufficiently different (p = 0.95) that there exists high probability for acceptably accurate discrimination between the groups. 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 Series. There was no significant difference (p = 0.95) between Mountain Bunchgrass and Shortgrass. These results were similar to those obtained with the computer-assisted analysis evaluations between the two Series (Table 48). The reason for this lack of difference and inability to discriminate between the two classes using the ERTS-I imagery is not fully understood. Mountain Bunchgrass stands are usually of higher stature with more lush vegetation than the lower stature Shortgrass stands. However, total live herbage cover is similar for both classes (35 percent Shortgrass; 45 percent Mountain Bunchgrass). Consequently, the spectral response to

TABLE 52. Comparison of apparent optical image density among Grassland Series for two dates

ERTS-I ID No.	Series category	Sample size[1]	Mean image density[2]
1334-17142 (6/20/73)	Mountain bunchgrass	21	1.079
	Shortgrass	27	1.069
	Wet meadow	18	1.093
1388-17134 (8/15/73)	Mountain bunchgrass	22	0.979a
	Shortgrass	27	0.931b
	Wet meadow	20	1.086ab

[1]Sample size for a category varies between dates due to clouds or cloud shadows obscuring sample points in the June imagery.

[2]Any two values with common letters are significantly different ($p = 0.95$).

the ERTS-I sensors appears to be influenced more by amount of live vegetation cover and less by 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. Since some representatives of both units had more than half the total samples with less than 50 percent live foliage cover, this could be the threshold in spectral response of live dry grassland cover to have much influence on the spectral signature detected by the ERTS-I multispectral sensors. These are new concepts that need to be tested to potentially improve Grassland Series regonition 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-I scenes (Table 53). Aspen and Ponderosa Pine were discriminated from the other Forest Series 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 the August imagery. The reason for this is not completely understood, but perhaps it was caused by changes in sun azimuth and elevation between the two times the ERTS-I imagery was recorded.

Lodgepole Pine and Spruce/Fir did not discriminate at either date on the basis of optical image density. 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-I imagery was obtained resulted in very similar spectral signatures recorded by the sensors. Corrections for mountain shadows and apparent minor

TABLE 53. Comparison of apparent optical image density among Forest Series for two dates

ERTS-I ID No.	Series category[1]	Sample size[2]	Image density ($\bar{X}$)	Location of significant differences (p = 0.95)				
				SF	LP	DF	PP	A
1334-17142 (6/20/73)	SF	53	2.300	0		*	*	*
	LP	31	2.254		0		*	*
	DF	83	2.238			0	*	*
	PP	139	2.199				0	*
	A	36	2.141					0
1388-17134 (8/20/73)	SF	119	2.341	0			*	*
	LP	55	2.296		0		*	*
	DF	90	2.323			0	*	*
	PP	144	2.236				0	*
	A	44	1.983					0

[1]SF = Spruce/fir
LP = Lodgepole Pine
DF = Douglas-fir
PP = Ponderosa Pine
A = Aspen

[2]Sample size for a category varies between dates due to clouds or cloud shadows obscuring sample points in the June imagery.

differences in spectral responses relative to the ERTS-I sensors may improve classification. These ideas need to be investigated since similar classification problems were encountered at the Series level using the digital tapes.

Visual Photo Interpretation - Region Level

A factorial design for analysis of variance was used to test for differences between the appropriate factors of film type, photo scale, flight date, photo interpreter, 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.

Satellite imagery and underflight aerial photographs, regardless of the dates used, provided highly acceptable levels of interpretation accuracy for the Conifer and Grassland classes (Table 54). There were no significant differences for interpretation of the two categories considering film type, date, or photo scale. However, interpretation of the Deciduous class was date-dependent. For the satellite imagery, there was a significant difference (p = 0.95) between dates. The best date was August 1973 with an acceptable level of interpretation at 92.3 percent (Table 55). Also, there was a significant difference (p = 0.95) among underflight photo scales for classifying the Deciduous category. Only the 1:50,000-scale CIR provided an acceptable level of accuracy at 82.7 and 83.3 percent for the June and September dates, respectively (Table 56). The underflight photos showed no significant difference between dates when using CIR. There was a difference (p = 0.95) between dates using 1:100,000-scale normal-color film; the Deciduous class was more easily identified (82.0 percent) in September when foliage was changing color.

TABLE 54. Visual interpretation and commission errors for Regional vegetation classification by satellite imagery and underflight aerial photographs.

	Vegetation Region	Correct classification	Commission errors (mean percent)		
			Coniferous	Deciduous	Grassland
Satellite imagery	Conifer	95.4[1]		3.4	1.2
	Deciduous	62.6[1] [3]	33.4		4.0
	Grassland	96.4[1]	2.3	1.3	
Under-flight Photographs	Conifer	98.2[2]		1.8	
	Deciduous	64.8[2] [4]	35.2		
	Grassland	99.0[2]	0	1.0	

[1]Mean percent for 3 dates, 3 PI's.

[2]Mean percent for 3 scales, 2 dates, 2 films, 3 PI's.

[3]See Table 55.

[4]See Table 56.

TABLE 55. Satellite visual classification and commission errors for the Deciduous class--August 1973

Interpreter	Correct classification (percent)[1]	Commission errors (percent) conifer	grassland
A	83	17	0
B	100	0	0
C	94	6	0
Mean	92.3		

[1]Rounded to nearest percent.

TABLE 56. Underflight visual classification and commission errors for the Deciduous class--1:50,000 scale-CIR-2 dates

Interpreter	Correct classification (percent)[1]		Commission errors (percent)		
			Conifer		Grassland
	June	September	June	September	
A	82	75	18	25	0
B	83	75	18	25	0
C	83	100	17	0	0
Mean	82.7	83.3			

[1]Rounded to nearest percent.

In most cases, photo interpreters (PI) were significantly different ($p = 0.90$) for both satellite imagery and underflight photos. The PI who had the most knowledge about vegetation and the test site produced the best interpretation score.

There was no overall significant difference between satellite imagery and underflight photos for classifying the three Regional categories.

The majority of commission errors for the Conifer classification were 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 (Table 54). Misclassifications from the satellite imagery were primarily due to the lack of visible topographic relief on the ERTS composites. This made the separation difficult between Deciduous and the Wet Meadow component of the Grassland category. These two classes occasionally occurred at the interface of the northeast edge of South Park and the mountains. The misclassifications between Conifer and Deciduous were caused by the normal intermixing of species between the two classes and resulted in large commission errors on satellite imagery and underflight photos.

Visual Photo Interpretation - Series Level

Satellite imagery provided no acceptable results for classifying either total or individual forest classes to the Series level for all factors combined (Table 57).

Table 57. Satellite visual classification and commission errors for vegetation Series

	Vegetation Series	Correct classification[1]	Commission errors (mean percent)							
			Timber					Grassland		
			A	DF	LP	PP	SF	MB	SG	WM
FOREST	Aspen	62.5[2]		2.7	8.2	11.5	11.6	1.8	0.8	0.8
	Douglas-fir	43.4	1.3		2.0	39.2	14.1			
	Lodgepole Pine	41.5	2.4	12.7		12.7	30.7			
	Ponderosa Pine	77.7[3]	1.9	14.4	1.7		2.4	0.2		1.7
	Spruce/fir	58.2	10.9	5.3	12.3	11.8		0.6		0.9
	Forest Total	61.9								
GRASSLAND	Mountain Bunchgrass	50.0[4]			0.9	3.1			46.0	
	Shortgrass	98.6						1.4		
	Wet Meadow	87.9	4.1		1.0	1.0	2.0	4.0		
	Grassland Total	79.4								

[1]Mean percent for 3 dates, 3 PI's.
[2]See table 58.
[3]See table 59.
[4]See table 63.

However, significant differences (p = 0.99) were obtained from the satellite imagery for both date and forest Series class when individual factors were considered. The only class that provided a consistently acceptable classification between three PI's was Aspen (Table 58).[11] This occurred for the August 1973 imagery with a classification accuracy of 92.3 percent. Ponderosa Pine approached a consistently acceptable classification of 81.3 percent among three PI's for the June 1973 imagery (Table 59). None of the other forest Series classes were accurately classified to an acceptable level.

The underflight aerial photos provided no acceptable results for classifying either total or individual forest classes to the Series level for all factors combined (Table 60). No significant differences were obtained between film type or flight date. However, CIR had a slight (but nonsignificant) advantage over color film and the best flight date was mid-September. Photo scales were significantly different (p = 0.95) with the 1:50,000 scale being the best and the 1:400,000 scale the poorest for all forest Series classes taken as a group. Individual classes were also significantly different (p = 0.99).

Only Aspen had an acceptable classification which was not date-dependent but scale-dependent (Table 61). Classification accuracy on the 1:50,000 scale CIR photos was 82.7 and 83.3 percent for the June and September flight dates, respectively. However, only the June date provided a consisently acceptable classification between the PI's.

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[11]A consistently acceptable classification is defined as all three PI's having obtained an acceptable classification for any specific Series class by date, or as any single factor having produced an acceptable classification for any specific Series class.

TABLE 58. Satellite visual classification and commission errors for the Aspen Series--August 1973

Interpreter	Correct classification (percent)[1]	Commission errors (percent)[1]				
		A[2]	D[2]	LP[2]	P[2]	SF[2]
A	83			11	6	
B	100					
C	94					6
Mean	92.3					

[1]Rounded to nearest percent.

[2]A = Aspen
D = Douglas-fir
LP = Lodgepole Pine
P = Ponderosa Pine
SF = Spruce/fir

TABLE 59. Satellite visual classification and commission errors for the Ponderosa Pine Series --June 1973.

Interpreter	Correct classification (percent)[1]	Commission errors (percent)[1]					
		A[2]	D[2]	LP[2]	P[2]	SF[2]	WM[2]
A	61		22	2			15
B	95	5					
C	88		12				
Mean	81.3						

[1]Rounded to nearest percent

[2]A = Aspen
D = Douglas-fir
LP = Lodgepole Pine
P = Ponderosa Pine
SF = Spruce/fir
WM = Wet Meadow

TABLE 60. Underflight visual classification and commission errors for vegetation Series

	Vegetation series	Correct classification[1]	Commission errors (mean percent)							
			Timber					Grassland		
			A	DF	LP	PP	SF	MBG	SG	WM
FOREST	Aspen	63.8[2]		2.0	4.2	0.9	29.1			
	Douglas-fir	49.9	2.0		3.8	32.9	11.4			
	Lodgepole Pine	39.7	3.8	7.9		9.8	38.8			
	Ponderosa Pine	70.2	0.8	25.8	1.8		1.4			
	Spruce/fir	73.9	1.8	4.1	17.7	2.5				
	Forest Total	62.6								
GRASSLAND	Mountain Bunchgrass	70.4[3]							29.6	
	Shortgrass	89.0						10.7		0.3
	Wet Meadow	97.1						2.2	0.7	
	Grassland Total	84.2								

[1]Mean percent for 3 scales, 2 dates, 2 films, 3 PI's.

[2]See tables 61 and 62.

[3]See table 64.

TABLE 61. Underflight visual classification and commission errors for the Aspen Series--1:50,000 scale--CIR--two dates

Interpreter	Correct classification (percent)[1]		Commission errors (percent)[1]									
			A[2]		D[2]		LP[2]		P[2]		SF[2]	
	June	Sept.	June	Sept.	June	Sept.	June	Sept.	June	Sept.	June	Sept.
A	82	75					13				5	25
B	83	75									17	25
C	83	100									17	
Mean	82.7	83.3										

[1]Rounded to nearest percent.

[2]A = Aspen
D = Douglas-fir
LP = Lodgepole Pine
P = Ponderosa Pine
SF = Spruce/fir

Aspen was date-dependent when using color film. It was classified accurately at 82.0 percent from the September 1:100,000 scale photos (Table 62). Classification using color film was acceptable at this date due to the aspen leaves changing color. This was not a consistently acceptable classification however.

Ponderosa Pine and Spruce/Fir approached an acceptable classification for most scales, dates, and film types, but none of these were consistent except for one factor combination for Spruce/Fir. For that class, a consistent classification of 81.3 percent was obtained for the 1:100,000-scale/CIR/June photos. In view of the fact that the 1:50,000 scale was the "best overall" scale, it was believed that the preceding classification was a random occurrence.

There was no overall significant difference between satellite imagery and underflight aerial photos for classifying forest categories to the Series level. However, the underflight photos did provide more accurate within-class results even though these were not always consistent and significant.

Generally, commission errors for the forest classes were similar for both satellite imagery and underflight photos (Tables 57 and 60). The apparent major reason for these commission errors was overlapping of areas on the ground where the species grow. This caused class mixing which resulted in similar photo textures on the underflight photos and similar color signatures on both satellite and underflight data. The lack of apparent topographic relief on the satellite imagery resulted in difficult determinations of aspect, slope, and other terrain features.

TABLE 62. Underflight visual classification and commission errors for the Aspen Series--1:100,000 scale--color--September date

Interpreter	Correct classification (percent)[1]	Commission errors (percent)[1]				
		A[2]	D[2]	LP[2]	P[2]	SF[2]
A	64		9	9		18
B	82					18
C	100					
Mean	82.0					

[1]Rounded to nearest percent

[2]A = Aspen
D = Douglas-fir
LP = Lodgepole Pine
P = Ponderosa Pine
SF = Spruce/fir

For example, Ponderosa Pine and Douglas-fir were often confused. Douglas-fir generally occurs on north slopes in the study area, but ponderosa pine also occurs in some north-slope situations. Aspect was difficult to determine on satellite imagery, but even with stereoscopic coverage of the underflight photos, confusion was due to mixing of the two classes on north slopes. This made it difficult to determine whether a test plot was a relatively homogeneous class, or at least a dominant class. This determination was further complicated by heavy shadows in steep north slope situations. No commission errors were made into the Grassland classes for the underflights because of the added advantage of stereo coverage and better resolution as contrasted with the satellite imagery.

Generally, both satellite imagery and underflight photos provided acceptable levels of accuracy for overall Grassland classification to the Series level (Tables 57 and 60). Neither the satellite imagery nor the underflight photos showed any significant difference between dates. In both cases late season overflights did provide a slight (5 to 10 percent) advantage for overall classification.

A significant difference ($p = 0.99$) between Grassland Series classes was obtained from the satellite imagery (Table 57). Both Shortgrass and Wet Meadow had acceptable accuracies. However, the Mountain Bunchgrass class fell far below an acceptable level, except for one PI who had a consistently acceptable classification of 87.7 percent (Table 63).

The underflight photos showed no significant difference between film types for Grassland Series classification. There was a significant difference ($p = 0.95$) between photo scales. The best scales were 1:50,000 and

TABLE 63. Satellite visual classification for the Mountain Bunchgrass Series--three dates

Interpreter	Correct classification (percent)[1]			
	Aug. 1972	June 1973	Aug. 1973	Mean
A	13	59	50	40.7
B	25	0	42	22.3
C	88	92	83	87.7
Mean	42.0	50.3	58.3	50.0

[1]Rounded to nearest percent.

1:100,000 with classification accuracies of 87.0 and 88.1 percent, respectively. The poorest scale was 1:400,000, but it still provided an acceptable level of 82.7 percent.

A significant difference ($p = 0.99$) between Grassland Series classes existed for the underflight photos (Table 60). Both Shortgrass and Wet Meadow had acceptable accuracies. Mountain Bunchgrass did not have an acceptable classification by all PI's for all scales but did have a significantly ($p = 0.95$) higher level (20 percent better) on the underflight photos than on the satellite imagery. However, one PI did have a consistently acceptable classification for two scales, and one PI had an acceptable classification for one scale regardless of date or film type (Table 64).

There was generally a significant difference ($p = 0.95$) between PI's. The PI with the most consistently acceptable classification had the most knowledge about vegetation and the test site.

Commission errors for the Grassland classes were similar for both the satellite imagery and the underflight photos (Tables 57 and 60). An exception was that no commission errors were made to the forest classes on the underflight photos. This was due to the added advantage of stereo coverage and better resolution to provide topographic relief and apparent vegetation height.

Most of the commission errors for Mountain Bunchgrass on the satellite imagery occurred through confusion with Shortgrass (Table 57). 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 Series. Commission errors for Wet Meadow

TABLE 64. Underflight visual classification for the Mountain Bunchgrass Series--two scales

Interpreter	Correct classification (percent)	
	1:50,000	1:100,000
A	100.0	87.5
B	72.5	81.3

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 in the northwest corner of South Park where their color signatures overlapped. It was especially difficult to separate these two classes in that specific area due to the lack of topographic relief in the satellite imagery. In some cases low density Wet Meadows had similar color signatures to those of high density Shortgrass and Mountain Bunchgrass and therefore were easily confused.

Commission errors for Mountain Bunchgrass were lower on the underflight photos (Table 60) as compared to the satellite imagery. This was because stereo coverage was available on the underflights which allowed the interpreters to see topographic features. The stereo coverage allowed the interpeters to better distinguish the interface between the mountains and South Park and thus better classify this particular vegetation Series. However, commission errors to the Shortgrass class for Mountain Bunchgrass were still relatively large due to the continuum between the two Series classes. Shortgrass also was incorrectly called Mountain Bunchgrass a few times (commission errors). Low density Wet Meadow sites were sometimes confused with high density Mountain Bunchgrass due to similar color signatures and textural characteristics.

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

Larger scale, 1:20,000, aircraft CIR photos are required to subsample the Regional classes for specific Series categories (Fig. 33). The crown shapes of trees and the subtleties of Grassland Series boundaries become more discrete at this photo scale than at smaller photo scales. This provides the 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 by examining the stereo pair of Figure 33. The coarse-textured image in the stream area at the bottom of the illustration 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 1:2,000 (Fig. 34) 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 herein due to both the uncertainty of when ERTS data was in fact taken and malfunctions of some ground instruments. However, previous research substantiates that the previously discussed parameters about plant communities can be estimated.

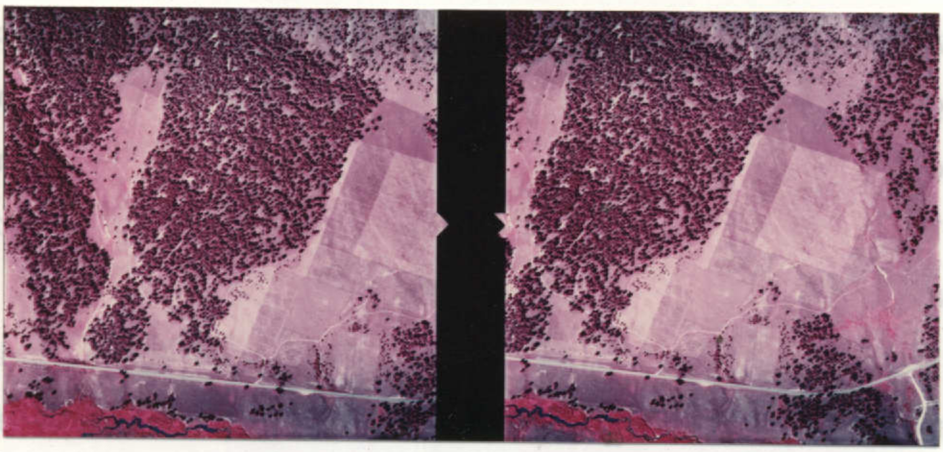

Figure 33. A 1:20,000 scale CIR stereo pair representing requirements to classify and map to the Series, and in most cases, the Habitat Type level of ECOCLASS. This material is used to subsample the Regional stratification done with ERTS-I type of imagery.

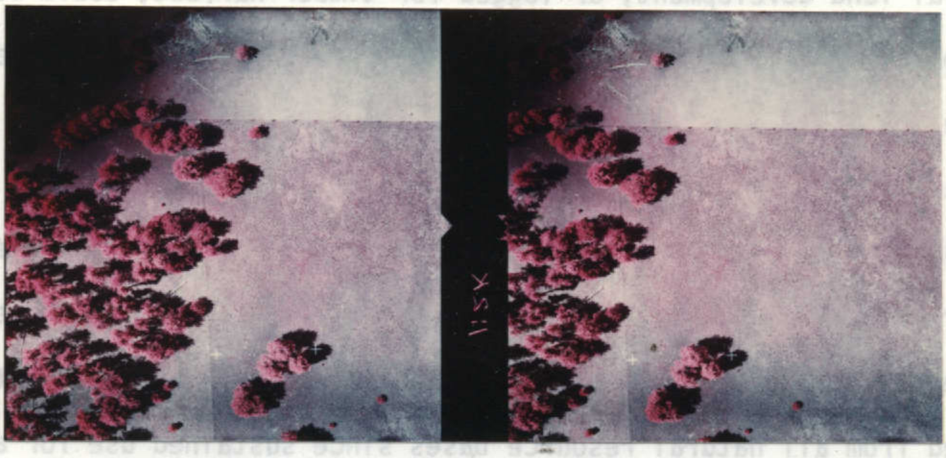

Figure 34. A 1:2,000 scale CIR stereo pair representing the boundary between a Ponderosa Pine and Mountain Bunchgrass Series. Tree heights and crown diameters can be measured from this imagery. Relative amounts of herbaceous plant cover and bare soil in the Mountain Bunchgrass unit can be estimated provided the original photography is used.

APPLICATIONS

Some applications on the use of ERTS-I multispectral scanner type 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 Regional vegetation, most of which are in excess of 10 years old, are outdated due either to changing land-use patterns or catastrophic events since the original maps were developed. For example, areas of forest land in excess of one hectare (2.5 acres) devasted 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. Areas devastated by fire or logged for timber 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 and/ 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 Regional level could also be monitored. Although the research reported herein was not specifically designed toward these objectives due to the short life of the work, it can be concluded that these kinds of changes can be effectively monitored with a high degree of probable success. This is based on the success of classifying the vegetation to the Regional level by any of the three techniques used.

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 high-contrast Series units within the grasslands, such as Wet Meadows, can be delineated provided the width of the high-contrast unit exceeds the width of the apparent ERTS-1 resolution element by at least one resolution 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, Regional classes would be the minimum level in the ECOCLASS hierarchy that could be delineated unless one were concerned only about the Aspen or Ponderosa Pine Series. These classes 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 variances in canopy cover of forest trees and kinds of Habitat Type in Grassland Series.

Photo scales of 1:2,000 and larger are required to evaluate Habitat Types, especially in grassland systems, 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.

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APPENDIX A

PRODUCING STANDARDIZED COLOR COMPOSITE INTERNEGATIVES FROM ERTS 70 mm TRANSPARENCIES ON AN ADDITIVE COLOR VIEWER

A photographic technique was developed to produce standardized color composite negatives (8 by 10 inches) at a precise scale of 1:1,000,000 for our ERTS investigators. We believed we could control the enhancement and color saturation of the composites by careful monitoring of the light and filter levels within each ERTS band. Also, by using large-format color negatives, we could then furnish the interpreters with enlarged color transparencies and prints. The method described can be used by any investigator having access to a four-band additive color viewer. Either two or three MSS bands are combined on an additive color 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 (Figure 35b). 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 we used a diffused junction silicon diode detector and amplified its output with an integrated circuit a b

c d

Figure 35. Equipment required to make color internegatives from ERTS 70 mm transparencies. (a) I^{2}S additive color viewer with photometer and high-speed timer, (b) Forest Service-designed photometer being used to measure light intensity of each MSS band and of color composite, (c) 8- by 10-inch vacuum film holder--note vacuum hose on left, and (d) Lektra Decade Interval Timer (right) with heavy-duty relay and switching circuit box (left).

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.

We conducted a series of film test exposures to determine proper exposure time 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 (Figure 36). A special timing device needed to be assembled to handle the short exposure times (less than 1 second) required by the I^2S illumination in conjunction with the internegative film (Figure 35d). A standard timer (Lektra, Model TM-8, Decade interval timer) with 1/10-second increments 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^2S for extremely short intervals. Such a high amperage timer was not readily available on the market.

Our additive color viewer, I^2S, has a removable screen which 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 appeared on the screen. The film is then exposed according to the times computed from the photometer (Figure 36).

A special vacuum system for holding the film flat was required in order to eliminate misregistration due to variations in film flatness within the holder. The vacuum system consists of an 8- by 10-inch vacuum

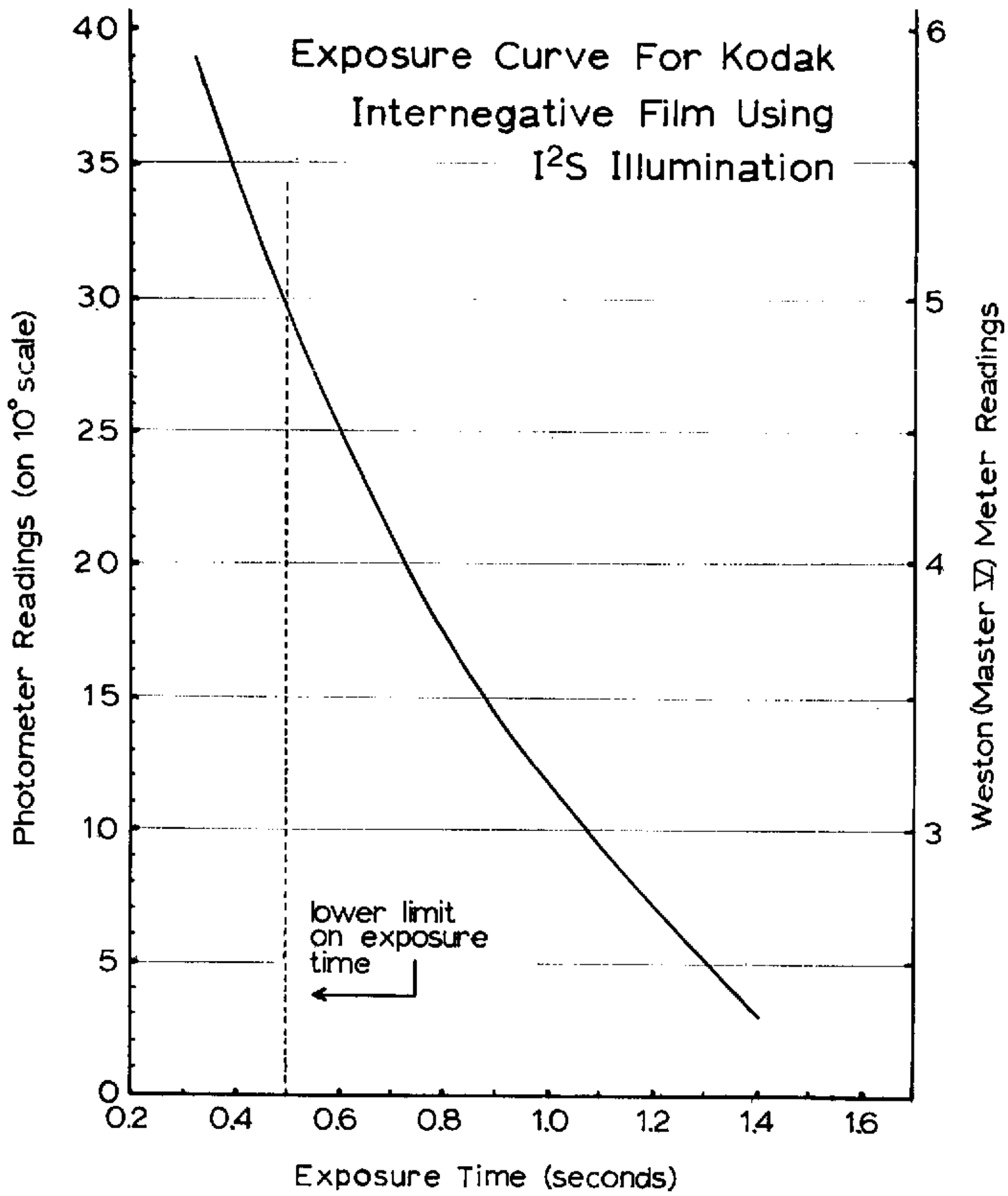

Figure 36. Determination of exposure in seconds of Kodak Ektacolor Internegative Film (Type 6110) from Forest Service-designed photometer. Equivalent light intensity readings may be taken from a Weston Master V light meter (right side of graph) and exposure time determined from curve.

film holder specially modified to fit the I^2S screen frame (Figure 35c). An inexpensive vacuum source was provided by adapting a vacuum hose to the end of a portable vacuum cleaner's hose and connecting it to the film holder (Figure 35c). 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 were produced that closely resembled the original color-combined image that was produced in the I^2S screen.

APPENDIX B

LAND-USE CLASS DEFINITIONS FOR ERTS-1 DATA

The colors described below of images on color infrared representations are equivalents of Munsell Notations and renotations as referenced in footnotes 4 and 5.

01 Conifer

Density of the conifer stands and the number of hardwoods mixed in the stand influence the Munsell Standard color value and chroma. Dense stands are darker with less chroma. In the fall before advanced hardwood coloration and leaf fall have occurred, conifer stands appear dark purplish red. The separation between conifer and hardwood is less distinct in the fall than in the winter or early spring. In stands where hardwoods and conifers are mixed, the hardwood color predominates, and the stand is usually classified as hardwood. In the spring before hardwoods are foliated, conifer appears moderate to dark purplish red.

02 Hardwood

Appear moderate grayish purplish red in the fall and a pale purple to moderate purplish red in the spring. In the fall, upland hardwoods cannot be distinguished from bottomland hardwoods. In the spring before foliation, upland hardwoods appear pale purple to light grayish purplish red. Bottomland hardwoods are generally a moderate purplish red.

03 Grassland

A deep pink in both fall and spring. Is sometimes mistaken for immature cropland in spring.

04 Cropland

Mature crops in the fall appear bluish gray to grayish blue. In the spring immature crops appear a deep pink and may be called grassland because of the similarity.

05 Bare Soil

In fall and spring appears cream colored. There is no distinction between plowed agricultural fields and sites prepared for new commercial developments. Generally in the spring most areas of bare soil are newly plowed fields prior to, or immediately after, planting.

06 Wild Vegetation

In the fall this class ranges from the grayish purple of idle land, to grayish purplish red of abandoned land, to the deep pink of wild Kudzu vine. Marsh and alder swamps are a moderate purple due to the wet background. In the spring, idle land becomes a light grayish red to dark pink due to the influx of new IR reflectant vegetation. Abandoned-transitional land (reverting to forest), on the other hand, is a grayish purplish red and marsh and alder swamps are a grayish violet. The deciduous Kudzu vine, a purplish gray in the spring, easily separates itself from all other vegetation when fall and spring images are viewed together.

07 Water

Dark greenish blue in the fall and light greenish blue in the spring. Farm ponds of less than one acre can be seen on ERTS images if sufficient contrast exists with the surrounding background.

08 Urban

A light, light blue in the fall and very pale blue in the spring. Unfortunately, because of the low resolution of ERTS data, secondary roads, minor roads, and most utility lines are not resolved.

APPENDIX C

DEFINITIONS OF NINE DISTURBANCE CLASSES THAT CAN BE RECOGNIZED ON MEDIUM- TO SMALL-SCALE AERIAL PHOTOGRAPHS

No disturbance

Areas where there are no detectable changes in the forest cover.

Harvesting

Forest areas which have been subject to a timber removal operation. This operation usually results in a rather severely disturbed area with 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 their vigor or growth. Although high-grading is a poor practice and not considered a silvicultural treatment in the normal sense, it would appear the same as partial removal or intermediate selective type cutting.

Land clearing

Usually preceded by timber removal or harvesting; then the site is prepared by slash and stump removal, and may eventually be replanted with tree seedlings. However, this category can 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; this land is usually still considered commercial forest.

Insects and disease

Under endemic conditions, attacks by insects and disease 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

May include crown fires as well as ground fires. Prescribed burns are restricted to the ground and may appear exactly like wildfires. The actual "going" fires may be detected, but it is usually the noninfrared-reflective burned vegetation and humus material that show as blackened areas on remote sensing imagery.

Flooding

Whether man-made or natural can inundate forest land and cause 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 survive once the water has receded.

Regeneration

Whether natural or artificial means an increase in the forest area base where nonforest land is converted to forest land. Areas of regeneration may be apparent in early years by evidences of fire trails built by the landowner to protect his investment from wildfire. Indications of tree growth will appear in 3 to 5 years after planting.

Other

Land suspected of being disturbed but yet it does not fit any of the above categories. For example, this includes land being worked for turpentine. On remotely sensed imagery such land would appear similar to silviculture cuttings but with little or no removal and slight disturbance of the ground cover.

APPENDIX D

PSW COMPUTER PROCESSING OF ERTS BULK CCT's

An automatic land-use recognition system, designed and implemented by the PSW Remote Sensing Work Unit was greatly expanded for the processing of ERTS bulk CCT 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 off-line plotter (EAI Model) 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.

A number of corrections are applied to the bulk data. First, 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.[12] These means are then subtracted from every pixel

[12] Mod is a standard FORTRAN function.

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. 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.

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. This tape is now the data input to all subsequent programs.

The next step in the processing is to produce what we named EDMAP's or empirical distribution maps. 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 crossproducts 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 using the Bhattacharyya distance theory (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 type 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 type of minimum euclidean distance is assigned to the pixel. This typing can also use any set of weighting factors as described in the above paragraph.

The third and last classification procedure available in our system is a linear discriminant analysis with maximum likelihood and gaussian assumptions. However, we have not yet processed any ERTS data using this program.

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.

APPENDIX E

BLACK HILLS TEST SITE - 226A - TABLES

TABLE 65. Summary of ERTS images received from August 19, 1972, to September 20, 1973, over Black Hills test site 226A.

			TEST SITE AREA[1]			
	IMAGE DATE	ID NUMBER	PERCENT COVERAGE	PERCENT CLOUD COVER	SNOW	IMAGE QUALITY
1	19 Aug 1972	1027-17065	10%	10%		Poor
2	6 Sep 1972	1045-17063	0%			Poor
3	6 Sep 1972	1045-17065	10%	40%		Fair
4	8 Sep 1972	1047-17175	15%	0%		Fair
5	12 Oct 1972	1081-17064	0%			Fair
6	12 Oct 1972	1081-17070	0%			Fair
7	1 Nov 1972	1101-17183	20%			Fair
8	26 Sep 1972	1065-17175	20%	25%	X	Fair
9	31 Oct 1972	1100-17124	100%	0%	X	Good
10	31 Oct 1972	1100-17131	0%			Good
11	5 Dec 1972	1135-17072	5%	0%	X	Good
12	6 Dec 1972	1136-17132	0%			Good
13	6 Dec 1972	1136-17130	100%	0%	X	Excell
14	11 Jan 1973	1172-17130	5%	0%	X	Fair
15	11 Jan 1973	1172-17123	100%	0%	X	Good
16	12 Jan 1973	1173-17182	60%	0%	X	Good
17	29 Jan 1973	1190-17125	100%	0%	X	Good
18	28 Jan 1973	1189-17070	0%			Fair
19	28 Jan 1973	1189-17072	0%			Fair
20	10 Jan 1973	1171-17072	0%			Excell
21	10 Jan 1973	1171-17065	0%			Excell
22	29 Jan 1973	1190-17131	15%	0%	X	Fair
23	30 Jan 1973	1191-17184	15%	0%		
24	10 Jan 1973	1171-17065	5%	0%	X	Good
25	16 Feb 1973	1208-17133	10%	0%	X	Excell
26	16 Feb 1973	1208-17131	100%	0%	X	Excell
27	20 Aug 1972	1028-17121	100%	30%		Poor
28	15 Feb 1973	1207-17075	0%			Good
29	6 Mar 1973	1226-17131	30%	40%	X	Good
30	7 Mar 1973	1227-17190	0%			Good
31	25 Mar 1973	1245-17190	0%			Poor
32	11 Apr 1973	1262-17132	100%		X	Fair
33	11 Apr 1973	1262-17134	0%			Fair
34	12 Apr 1973	1263-17190	0%			Fair
35	28 Apr 1973	1279-17073	0%			Fair
36	28 Apr 1973	1279-17075	15%	80%	X	Fair
37	10 Apr 1973	1261-17073	0%			Fair
38	10 Apr 1973	1261-17080	0%			Fair
39	16 May 1973	1297-17072	0%			Fair
40	16 May 1973	1297-17074	0%			Fair

[1]See Fig. 12 for coordinates of Forest Stress test site area.

TABLE 65 (continued)

			TEST SITE AREA			
	IMAGE DATE	ID NUMBER	PERCENT COVERAGE	PERCENT CLOUD COVER	SNOW	IMAGE QUALITY
41	17 May 1973	1298-17130	65%	30%		Fair
42	18 May 1973	1299-17175	0%			Fair
43	3 Jun 1973	1315-17071	5%	5%		Good
44	4 Jun 1973	1316-17125	40%	80%	X	Fair
45	10 Jul 1973	1352-17123	100%	30%		Good
46	5 Jun 1973	1317-17183	0%			Poor
47	9 Jul 1973	1351-17064	15%			Excell
48	9 Jul 1973	1351-17071	15%			Excell
49	11 Jul 1973	1353-17181	35%			Poor
50	21 Jun 1973	1333-17070	10%	10%		Fair
51	22 Jun 1973	1334-17124	100%	0%		Excell
52	22 Jun 1973	1334-17130	30%			Excell
53	23 Jun 1973	1335-17182	20%			Good
54	15 Aug 1973	1388-17122	15%	10%		Good
55	15 Aug 1973	1388-17120	70%	60%		Fair
56	20 Sep 1973	1424-17114	15%	40%		Fair
57	16 Aug 1973	1389-17174	15%			Good
58	14 Aug 1973	1387-17061	5%			Good
59	14 Aug 1973	1387-17064	20%			Good

SUMMARY

Number of images providing 100% coverage of the study site: 9.
1) Number of those images with less than 35% cloud cover: 9.
2) Number of those images without snow over entire study site: 3.

APPENDIX E

BLACK HILLS SITE - 226A - TABLES

TABLE 66. Channel assignements for ground truth sensors and multiplex hookup are shown for data collection platform number 6175 located at the Black Hills, South Dakota, test site (N44°16' 103°47'W) during 1972.

Channel Number	Multiplexer Commutation Level 1	2	3
1	scene radiance (0.5 to 9.6 μm) healthy pine	scene radiance (0.5 to 0.6 μm) grass pasture	irradiance (0.5 to 0.6 μm)
2	scene radiance (0.6 to 0.7 μm) healthy pine	scene radiance (0.6 to 0.7 μm) grass pasture	irradiance (0.6 to 0.7 μm)
3	scene radiance (0.7 to 0.8 μm) healthy pine	scene radiance (0.7 to 0.8 μm) grass pasture	irradiance (0.7 to 0.8 μm)
4	scene radiance (0.8 to 1.1 μm) healthy pine	scene radiance (0.8 to 1.1 μm) grass pasture	irradiance (0.8 to 1.1 μm)
5	scene radiance (0.5 to 0.6 μm) beetle-killed pine	scene radiance (0.5 to 0.6 μm) rock outcrop	evapotranspiration
6	scene radiance (0.6 to 0.7 μm) beetle-killed pine	scene radiance (0.6 to 0.7 μm) rock outcrop	rain gauge
7	scene radiance (0.7 to 0.8 μm) beetle-killed pine	scene radiance (0.7 to 0.8 μm) rock outcrop	air temperature
8	scene radiance (0.8 to 1.1 μm) beetle-killed pine	scene radiance (0.8 to 1.1 μm) rock outcrop	water temperature

TABLE 67. Channel assignments for ground truth sensors and multiplex hookup are shown for data collection platform number 6317 located at the Black Hills, South Dakota, test site (N44°16' 103°47'W) during 1972.

Channel Number	Multiplexer Commutation Level 1	2	3
1	soil moisture, F-1 (0.05-meter level)	soil moisture, F-1 (1.0-meter level)	soil moisture, F-3 (0.5-meter level)
2	soil moisture, F-2 (0.05-meter level	soil moisture, F-2 (1.0-meter level)	soil moisture, F-4 (0.5-meter level)
3	soil moisture, F-1 (0.15-meter level)	soil moisture, F-3 (0.05-meter level)	soil moisture, F-3 (1.0-meter level)
4	soil moisture, F-2 (0.15-meter level)	soil moisture, F-4 (0.05-meter level)	soil moisture, F-4 (1.0-meter level)
5	soil moisture, F-1 (0.5-meter level)	soil moisture, F-3 (0.15-meter level)	leaf temperature healthy pine
6	soil moisture, F-2 (0.5-meter level)	soil moisture, F-4 (0.15-meter level)	leaf temperature beetle-killed pine
7	totalized wind speed	totalized wind speed	totalized wind speed
8	totalized wind speed	totalized wind speed	totalized wind speed

APPENDIX E

BLACK HILLS TEST SITE - 266A - TABLES

TABLE 68. Channel assignments for ground truth sensors and multiplex hookup are shown for data collection platform number 6140 located at the Black Hills, South Dakota, test site (N44°16' 103°47'W) during 1972.

Channel Number	Multiplexer Commutation Level 1	2	3
1	downwelling radiation (0.4 to 4.1 μm)	net allwave radiation rock outcrop (0.4 to 15 μm)	wind speed, forest (22-meter level) downwind component
2	upwelling radiation healthy pine (0.4 to 4.1 μm)	thermal exitance healthy pine (8.0 to 15.0 μm)	wind speed, forest (22-meter level) crosswind component
3	upwelling radiation beetle-killed pine (0.4 to 4.1 μm)	thermal exitance beetle-killed pine (8.0 to 15.0 μm)	wind speed, forest (22-meter level) vertical component
4	upwelling radiation pasture (0.4 to 4.1 μm)	forest dewpoint 3-meter level	soil temperature, forest 1 (surface)
5	upwelling radiation rock outcrop (0.4 to 4.1 μm)	forest dewpoint 22-meter level	soil temperature, forest 1 (0.15 meter)
6	net allwave radiation healthy pine (0.4 to 15.0 μm)	pasture dewpoint 1-meter level	soil temperature, forest 2 (surface)
7	net allwave radiation beetle-killed pine (0.4 to 15.0 μm)	soil temperature, pasture (surface)	soil temperature, forest 2 (0.15 meter)
8	net allwave radiation pasture (0.4 to 15.0 μm)	soil temperature, pastrue (0.15 meter)	air temperature, forest (22-meter level)

APPENDIX E

BLACK HILLS TEST SITE - 226A - TABLES

TABLE 69. Channel assignments for ground truth sensors are shown for data collection platform number 6140 located within the healthy pine subsite (Level III, 02)[1] in fall 1973. The DCP transmitted from the Black Hills test site at N44°16' 103°47'W.

Channel Number	Parameter	Sensitivity
1	upwelling radiation	0.4 to 4.1 μm
2	net allwave radiation	0.4 to 15 μm
3	scene radiance	2.1 to 2.5 μm[2]
4	thermal exitance	10.3 to 12.5 μm[3]
5	scene radiance	0.5 to 0.6 μm
6	scene radiance	0.6 tp 0.7 μm
7	scene radiance	0.7 to 0.8 μm
8	scene radiance	0.8 to 1.1 μm

TABLE 70. Channel assignments for ground truth sensors are shown for data collection platform, number 6175 located within the dead pine subsite (Level III 00)[1] in fall 1973. The DCP transmitted from the Black Hills test site at N44°16' 103°47'W.

Channel Number	Parameter	Sensitivity
1	upwelling radiation	0.4 to 4.1 μm
2	net allwave radiation	0.4 to 15 μm
3	scene radiance	2.1 to 2.5 μm[2]
4	thermal exitance	10.3 to 12.5 μm[3]
5	scene radiance	0.5 to 0.6 μm
6	scene radiance	0.6 to 0.7 μm
7	scene radiance	0.7 to 0.8 μm
8	scene radiance	0.8 to 1.1 μm

[1]Refer to Table 19 for classification code.

[2]Matched to Skylab, S192 channel 12.

[3]Matched to Skylab, S192 channel 13.

APPENDIX E

BLACK HILLS TEST SITE - 226A - TABLES

TABLE 71. Channel assignments for ground truth sensors used in fall 1973 are shown for data collection platform number 6317 which transmitted from the Black Hills site at N44°16' 103°46'W. Data fed into multiplex level 1 came from the main sampling tower where the incident energy sensors were located. Multiplex level 2 data came from the pasture subsite (level III, 02)[1] and level 3 data came from rock outcrop subsite (level III, 01)[1].

Channel Number	Multiplexer Commutation Level		
	1	2	3
1	downwelling radiation diffuse (0.4 to 4.1 μm)	open channel	open channel
2	ambient air temperature	net allwave radiation (0.4 to 15 μm)	net allwave radiation (0.4 to 15 μm)
3	irradiance[2] (2.1 to 2.5 μm)	scene radiance[2] (2.1 to 2.5 μm)	thermal exitance[3] (10.3 to 12.5 μm)
4	downwelling radiation, total (0.4 to 4.1 μm)	thermal exitance (10.3 to 12.5 μm)	open channel
5	irradiance (0.5 to 0.6 μm)	scene radiance (0.5 to 0.6 μm)	scene radiance (0.5 to 0.6 μm)
6	irradiance (0.6 to 0.7 μm)	scene radiance (0.6 to 0.7 μm)	scene radiance (0.6 to 0.7 μm)
7	irradiance (0.7 to 0.8 μm)	scene radiance (0.7 to 0.8 μm)	scene radiance (0.7 to 0.8 μm)
8	irradiance (0.8 to 1.1 μm)	scene radiance (0.8 to 1.1 μm)	scene radiance (0.8 to 1.1 μm)

[1]Refer to Table 19 for classification code.
[2]Matched to Skylab, S192 channel 12.
[3]Matched to Skylab, S192 channel 13.

APPENDIX F

PHOTO INTERPRETATION PREDICTION MODEL

An important part of the research program in the Black Hills has been to photograph mountain pine beetle infestation areas on an annual basis. Supplementing Forest Service resource photography, NASA provided RB-57 and C-130 coverage as requested. Table 72 shows the photographic coverage obtained during the ERTS-1 program in the Black Hills.

The availability of photography made it possible to monitor bark beetle activity and to inventory the number of trees destroyed each year by the mountain pine beetle (Table 73). It is evident from Table 73. that in recent years bark beetle activity has increased. With greater commercial interest in Black Hills ponderosa pine, especially for pulpwood purposes, the need for reliable and economical methods of inventorying bark beetle damage has become evident. Forest Service resource photography in the 1:30,000-scale range is reasonably reliable for counting dead trees with an individual tree count error of 20 to 30 percent. However, at a scale of 1:30,000, 100 or more photographs are required to obtain complete stereo coverage of the 11-township area surveyed in the Black Hills.[13] Decreasing scale to 1:60,000 would reduce the number of photos required to 25 and each photograph would provide much greater coverage. However, interpretation accuracy drops off as tree counts become less reliable and smaller infestations are missed completely. Can interpretation errors in small-scale or microscale photography be accounted for in some reliable way, thus providing a more economical yet reliable method of bark beetle

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[13]The 11-township area covered 102,326 hectares (252,850 acres) in the northern Black Hills.

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TABLE 72. Supporting aerial photography obtained for the ERTS-1 Black Hills study during 1972-73.

DATE	SCALE	FILM TYPE	AIRCRAFT	SOURCE
5/15/72	1:34,000	8443 CIR	Aero Commander	USFS
9/08/72	1:32,000	2443 CIR	Aero Commander	USFS
9/14/72	1:5,500	2443 CIR	C-130	NASA
9/14/72	1:100,000	2443 CIR	RB-57	NASA
9/14/72	1:400,000	2443 CIR	RB-57	NASA
8/26/73	1:32,000	2443 CIR	Aero Commander	USFS

TABLE 73. A three-year summary of mountain pine beetle-killed pine shows increased impact in the 102,326-hectare (252,745-acre) survey area of the northern Black Hills.

May 1972			September 1972		August 1973	
Infestation Class[1]	Total Spots	Total Trees	Total Spots	Total Trees	Total Spots	Total Trees
0	1,128	1,128	8,201	8,201	10,681	10,681
1	821	7,395	1,393	12,537	1,793	16,137
2	217	3,019	317	4,438	411	5,754
3	96	3,821	131	5,240	176	7,040
4	6	973	8	1,296	10	1,520
5	3	750	3	750	4	1,000
TOTAL	2,271	17,086	10,053	32,462	13,075	42,132

[1]See Table 21 classification index for size of infestation.

Photography obtained in May 1972. Depicts trees infested during August 1970 and which faded during the summer of 1971.

damage inventory? It is toward this question that the remainder of this discussion is directed. Specifically, can a method be developed using statistical and calibration techniques to adjust for the interpretation errors encountered in the use of small-scale or microscale aerial photography?

Keeping in mind statistical and budgetary constraints, one or several small scales and/or microscales of aerial photography were selected that cover the area of interest. Large-scale photography representative of the area was selected as a source of ground truth data. It was not necessary for complete coverage but had to be representative in terms of infestation distribution and sizes. The tree count and location of each infestation was recorded. Some ground checking was done to determine the reliability of the interpretation. However, for purposes of analysis the data from the large-scale photo interpretation was assumed to represent all the infestations in the area covered. The interpreted areas were delineated and transferred precisely to the smaller scales of photography, where they were interpreted completely for bark beetle infestations. Tree counts and location of each infestation were recorded. The interpretation data from each scale were reconciled so that infestations from the smaller test scales could be matched for comparison to the corresponding infestations in the large-scale photographs. From the matched tree counts a regression model was developed for each photographic scale. These regression models could then be used to adjust tree counts for scale error. The infestations for each scale were divided into suitable size categories based on the large-scale photographic tree counts. The proportion of the total distribution each category occupied was determined from the large-scale data. The empirical probability of detecting an infestation of a given size category at a given scale was determined from a ratio of infestation in that category, i.e., the ratio of infestations counted on the smaller scale photograph to the infestations counted on the large-scale photographs.

CIR photography taken at a scale of 1:5,500 from NASA Mission 213 was chosen as the source of ground truth data although some actual checking was done on the ground to determine the reliability of the tree counts from the 1:5,500-scale photography (Figure 37). The quality of the 1:5,500-scale photography was very good, the color separation was excellent, and most single-tree infestations were readily detected.

Since the coverage of the 11-township area at a scale of 1:5,500 was incomplete, the following criteria were used in selecting the large-scale photographs for interpretation: (1) the photograph had to be inside the infestation area and (2) collectively the photographs selected had to contain a representative sample of infestation size classes. Seven photographs were found to meet these criteria.

Two interpreters examined the seven 1:5,500-scale photographs, and each was interpreted completely for bark beetle infestations. The actual photo interpretation was done using stereo pairs and an Old Delft stereoscope mounted on a Richards light table. The test areas covered by the 1:5,500-scale photography were transferred precisely to each of the corresponding smaller scale photographs (1:32,000, 1:110,000, and 1:400,000), which in turn were fully interpreted proceeding from the smallest to the largest. In all cases, both infestation locations and tree counts were recorded. To avoid interpreter bias, an interpreter did not look at the same test area as was interpreted on the preceding smaller scale and a third interpreter was used to reconcile the data between scales.

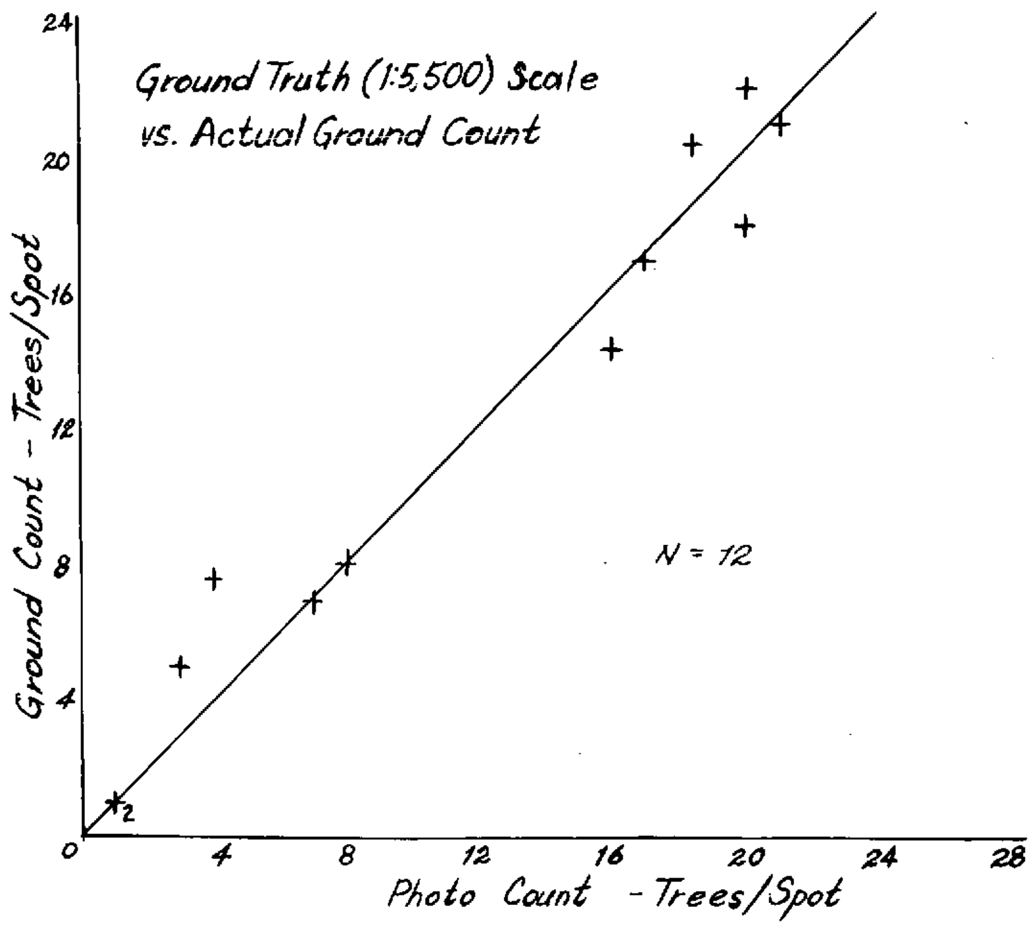


Figure 37. The relationship between the number of trees counted per infestation on the 1:5,500-scale CIR photography and the actual ground count is illustrated.

Reconcilation was done by matching the detected infestations from the test scale to the corresponding infestations on the 1:5,500-scale. This meant that an infestation detected on the test scale was placed in a size category based on the 1:5,500-scale tree count regardless of its own tree count. Errors encountered were of two types: (1) commission errors and (2) omission errors. Commission errors such as interpreting a rock outcrop as a beetle infestation were very few, and they were simply disregarded in the reconciliation. Omission errors were recorded as zero counts and included in the subsequent analysis. One type of commission error necessitated some adjustment of the 1:5,500-scale data. During the interpretation of the 1:5,500-scale photography, if four trees separated a group of beetle-killed trees they were recorded as two separate infestations. Infestations that were in close proximity on the 1:5,500-scale photography tended to appear as one infestation on the smaller scale. This tendency increased with decreasing scale. The problem was reconciled by using the test scale grouping, such that the separate infestations on the 1:5,500-scale were grouped to correspond to the test scale infestation size. This procedure was not considered inappropriate as the spacing which constitutes a separate infestation is somewhat subjective, and in this case the scale simply determined the spacing.

For purposes of analysis the infestation spots detected on the 1:5,500-scale photography were assumed to represent all of the infestation spots in the area covered by the photography. Furthermore, it was assumed that the number of trees counted in each infestation was correct. This is a reasonable assumption since those few trees missed are usually suppressed trees with little commercial value and harbor a relatively small population of beetles.

Regression equations were calculated for the relationship between ground truth tree counts and each of three scales shown in Figure 38 . Although there are many data points clustered around the lower values, the configuration of the data in Figure 38 appears to be linear. A linear-regression least-squares analysis yielded the equation $X = Y - 3.75/4.069$, where Y equals photo count and X equals ground count of infested trees. In practice with 1:32,000-scale photography, one can predict (X) the actual ground count given (Y) the photo interpretation count.

Several tests were applied to the regression equation to determine reliability (Table 74). A value for the F-test was determined from the ratio between the regression mean square and the residual mean square. This value represents the ratio of the variation explained by the fitted regression to the variation not explained by the regression. The value obtained for the 1:32,000-scale ($F=3.85$) and 1:100,000-scale ($F=3.79$) are both significant and well within the 95 percent limit. The value for the 1:400,000-scale photography ($F=1.15$) was not significant at the 70 percent limit which is well below the acceptable level. The 1:400,000-scale photography was of poor quality with only a 20 mm square in the center of the 70 mm frame interpretable. Subsequent statistical tests on the data were not encouraging, as shown in Table 74. The second test was the correlation coefficient test which was significant at the 95 percent level for both the 1:32,000 and 1:100,000-scale photography. Although this test is not as powerful as the F-test, it further substantiated the suitability of the linear regression

TABLE 74. Results of the regression analysis relating tree counts made on small-test-scale photography to tree counts made on large-scale photography (ground truth).

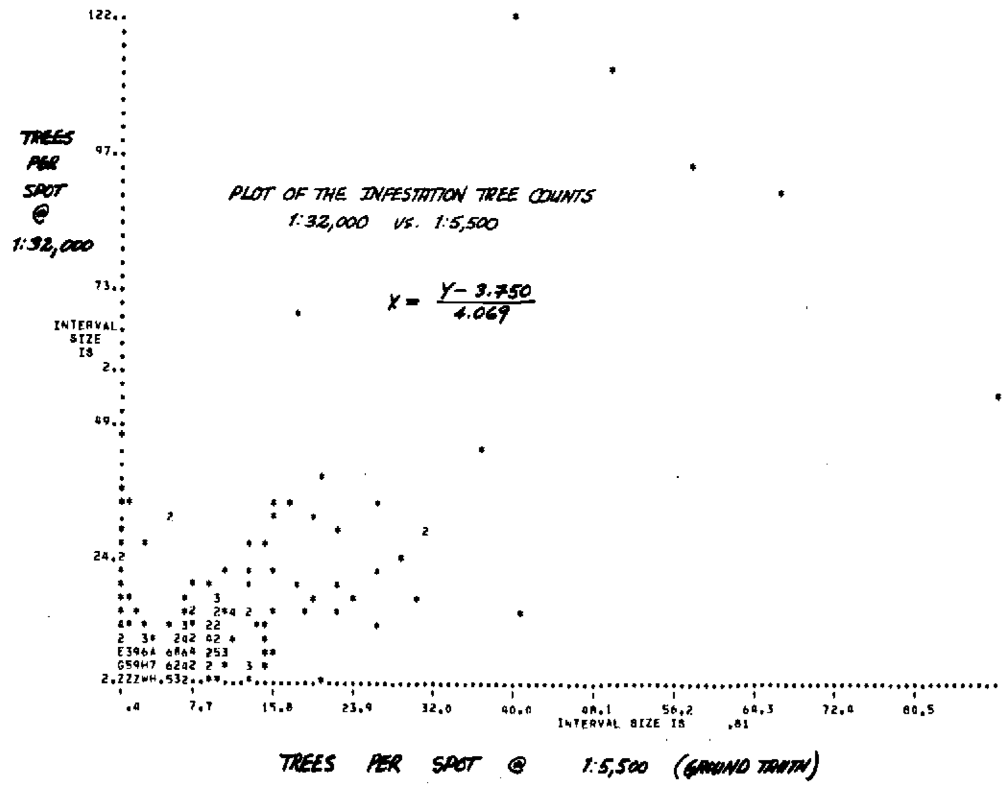
STATISTICS BY PHOTO SCALE			
	1:32,000	1:100,000	1:400,000
F-test of variance[1]	7.138[3]	6.432[3]	0.010[4]
Correlation Coefficient[2]	0.872[3]	0.867[3]	0.099[4]
Coefficient of Determination	0.761	0.752	0.010

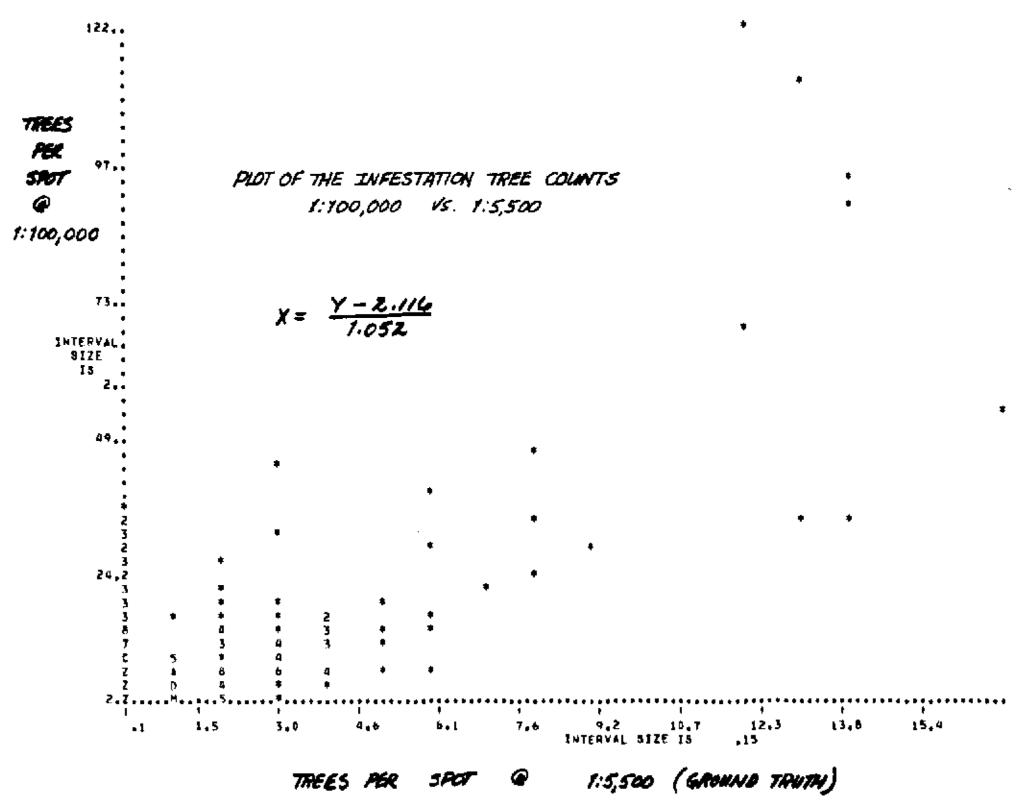
[1]Degrees of freedom = 1/528

[2]Degrees of freedom = 528

[3]Statistical Significance > 95%

[4]Statistical Significance < 70%





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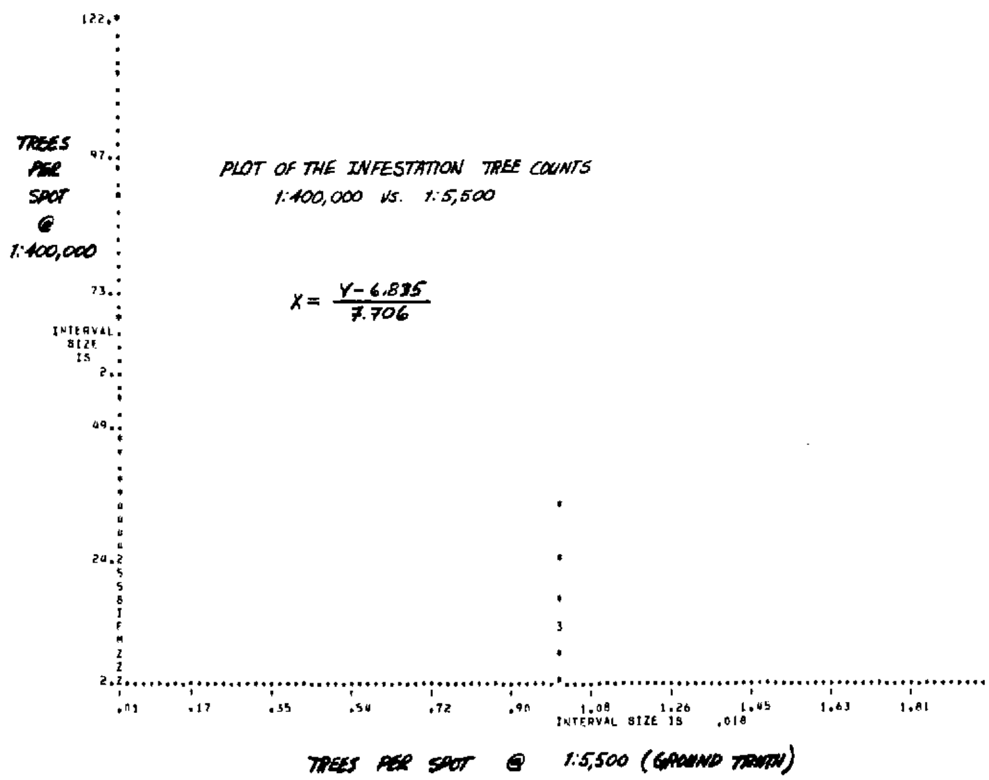

Figure 38 . Regression equations are presented for the relationship between the number of trees per infestation spot on the ground and the number counted on three different scales of photography.

model. The final statistic computed for the regression was the coefficient of determination, which is the correlation coefficient squared (Table 74). It is interpreted in the following way. The value of 0.761 for the 1:32,000 scale means that 76 percent of the variation is associated with the regression, a value which is high.

The next step in the utility of the prediction data was to divide the infestations for each scale into size categories. Infestations were placed into the size category corresponding to the tree count of their corresponding infestation on the 1:5,500 scale. The proportion each size category occupied in the total number of infestations based on the 1:5,500 scale data was determined as shown in Table 75. In addition, the probability of detecting an infestation of a given size category on each of the test scales was determined (Table 75).

In operation, a suitable regression equation would be developed as above, along with a table of probabilities and proportions for the scale being used. The tree counts for the detected infestations are adjusted using the regression equation and placed in the proper size category. Then the total number of infestations in each category is divided by the probability of detecting a spot in that category giving the adjusted total number of infestations. Multiplying this total by the average number of trees in that category gives the adjusted total number of beetle-killed trees in that category. In the event a category is missed entirely, the proportion for that category is used to make an estimate of the number of infestations in that category.

In order to substantiate the existing data for operational surveys the reliability of the beta coefficients, detection probabilities, and infestation size distributions should be tested with supplementatary large-scale photography and ground checks.

TABLE 75. Number of trees by infestation size category, the proportion of infestations by size category (1:5,500 scale), and the probability of detecting an infestation by photo scale.

Infestation Size		No. of infestations found at	Proportion By Size	Probability of Detection by Photo Scale		
Code	No. of Trees	1:5,500*	(ground truth)	1:32,000	1:100,000	1:400,000
00	1 to 3	256	0.500	0.588	0.104	0.000
01	4 to 10	179	0.337	0.783	0.337	0.006
02	11 to 20	51	0.096	0.824	0.588	0.098
03	21 to 50	29	0.055	0.690	0.448	0.069
04	51 to 100	4	0.008	1.000	1.000	0.000
05	100+	2	0.004	1.000	1.000	0.000
TOTAL		530	1.000			

*Ground truth scale

APPENDIX G

PUBLICATIONS WRITTEN AND RELATED TO ERTS-1 EXPERIMENT BY PSW AND RM STAFF

1. Aldrich, R. C. 1974. Detecting disturbances in a forest environment. Technical Papers from the 40th Annual Meeting of the American Society of Photogrammetry. St. Louis, MO, March 1974. In Press.

2. Aldrich, R. C., J. von Mosch and W. J. Greentree. 1972. Projection-viewer for microscale aerial photography. USDA, Forest Service, Pacific Southwest Forest and Range Experiment Station. Research Note PSW-277. 4 p.

3. Driscoll, R. S. 1974. The use of remote sensing in range and forest management. Proceedings Great Plains Agricultural Council. July 25-26, 1974. Sioux Falls, South Dakota.

4. Driscoll, R. S., R. E. Francis, J. A. Smith and R. A. Mead. 1974. ERTS-1 data for classifying plants communities--central Colorado. Ninth International Symposium on Remote Sensing of Environment. Ann Arbor, Michigan.

5. Heller, R. C. 1972. Remote sensing in forestry--promises and problems. Proceedings of Society of American Foresters National Convention, Hot Springs, Arkansas, October 1-5, 1972.

6. Heller, R. C. 1973. Analysis of ERTS imagery--problems and promises for foresters. Proceedings Interim Working Group "Remote Sensing" Division 6, Subject group S 6.05, Freiburg, Germany, September 17-21, 1973.

7. Myhre, R. J. 1973. Producing high-quality negatives from ERTS black-and-white transparencies. USDA, Forest Service, Pacific Southwest Forest and Range Experiment Station Research Note PSW-287. 6 p.

8. Weber, F. P. 1973. DCP-collected absolute target reflectance signatures assist accurate interpretation of ERTS-1 imagery. Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1, NASA, Goddard Space Flight Center. Greenbelt, Maryland. Volume I, Section B, pp. 1513-1522.