

PACIFIC SOUTHWEST Forest and Range Experiment Station

RECEIVED IN

DEC 27 1976

FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE
P.O. BOX 245, BERKELEY, CALIFORNIA 94701



EVALUATION OF SKYLAB (EREP) DATA FOR FOREST AND RANGELAND SURVEYS



EVALUATION OF SKYLAB (EREP) DATA FOR FOREST AND RANGELAND SURVEYS

Technical Coordinator
ROBERT C. ALDRICH

USDA FOREST SERVICE RESEARCH PAPER PSW-113

Published by

Pacific Southwest Forest and Range Experiment Station
Berkeley, California 94701

in cooperation with

Rocky Mountain Forest and Range Experiment Station
Fort Collins, Colorado 80521

Forest Service, U.S. Department of Agriculture

1976

Technical Coordinator

ROBERT C. ALDRICH, who heads the Station's Remote Sensing Research Work Unit, joined the Berkeley staff in 1965. He is a graduate of the State College of Forestry, Syracuse, New York (bachelor of science, 1944; master of forestry, 1948).

The Authors

ROBERT W. DANA, a physicist, has been a member of the Unit since 1969. He earned a bachelor's degree in physics (1963) and master's degree in geophysics (1969) at the University of Washington. **RICHARD S. DRISCOLL** is in charge of the Range Inventory and Evaluation Research Work Unit at the Rocky Mountain Forest and Range Experiment Station, Fort Collins. He studied at Colorado Agricultural and Mechanical College (baccalaureate in range management, 1951), Colorado State University (master's degree in range management, 1957), and Oregon State University (doctorate in range ecology, 1962). **RICHARD E. FRANCIS**, an associate range scientist, is also assigned to range inventory research at the Rocky Mountain Station. He earned a bachelor's degree (1967) in wildlife management at Humboldt State College, California. **WALLACE J. GREENTREE** also attended Humboldt State College (bachelor of science degree in forest management, 1961). A forestry technician, he has been with the Pacific Southwest Station's Remote Sensing Research Work Unit since 1967. Unit mathematical statistician since 1966, **NANCY X. NORICK** holds bachelor's (1964) and master's (1969) degrees in statistics from the University of California, Berkeley. **EDWIN H. ROBERTS**, a research forester with the Unit, is a forestry graduate of the University of California, Berkeley (bachelor's, 1965, and master's degrees, 1969). He joined the Station staff in 1974. **THOMAS H. WAITE**, formerly a forestry technician with the Unit, is also a graduate of the University of California, Berkeley (bachelor of science in forestry, 1970). He is now employed by Bechtel Corporation, San Francisco, California. **FREDERICK P. WEBER**, formerly with the Unit, is now remote sensing coordinator, Forest Economics and Marketing Research Staff, Forest Service, Washington, D.C. He was educated at the University of Minnesota (baccalaureate in forestry, 1960) and the University of Michigan (master's degree in forestry, 1965; doctorate in forestry, 1969).

NOTE: The Remote Sensing Research Work Unit, stationed at Berkeley at the time this publication was prepared, became in July 1976 a part of the Resources Evaluation Techniques Program at Fort Collins, Colorado. The Program, under the direction of Richard S. Driscoll as program manager, was established to aid in Forest Service compliance with the Forest and Rangeland Renewable Resources Planning Act of 1974, which requires inventory and evaluation of the forest, rangeland, and other renewable resources of the United States every 10 years.

Cover: An enlarged portion (11X) of a false-color composite made from Skylab S190A multiband photographs (green, red, and near infrared bands) taken on September 12, 1973. Clark Hill Reservoir and the Savannah River are shown in the center. Scale is approximately 1:250,000.

FOREWORD

The launching of Skylab in 1973 was linked with the development of large manned space workshops which may orbit the earth in the 1980's. One of these workshops, the reusable space shuttle, would have the exciting prospect of responding to critical renewable-resource problems with near-real-time information. Forest and range investigators, recovering from their disappointment with LANDSAT (ERTS-1) data, turned to Skylab with expectations of improved resolution and greater sensor sensitivity. Some of their expectations were rewarded, but as this report shows, reliability of the sensor systems must be improved before a space shuttle can respond to many forest and range problems.

This report evaluates the usefulness of the Skylab Earth Resources Experiment Package (EREP) data in identifying forest, rangeland, nonforest, water, and forest stress as a first level of resource information. The experiments described here were performed under Contract No. T-4106B (March 7, 1973 to December 7, 1975) between the U.S. National Aeronautics and Space Administration/Johnson Space Center (NASA/JSC) and the U.S. Department of Agriculture. The research was conducted by professional staff members of the Remote Sensing Research Work Unit, Pacific Southwest Forest and Range Experiment Station (PSW), Berkeley, California, and the Range Inventory and Evaluation Research Work Unit, Rocky Mountain Forest and Range Experiment Station (RM), Fort Collins, Colorado.

Robert C. Heller was originally identified as principal investigator and Robert C. Aldrich, Richard S. Driscoll, and Frederick P. Weber were identified as coinvestigators. Robert C. Aldrich was made principal investigator upon the retirement of Mr. Heller in August 1974. Technical Monitors for NASA were Ryborn Kirby and Clayton D. Forbes. This Research Paper is based on the final report submitted to NASA in fulfillment of the contract.

Various portions of the Skylab data products were processed and analyzed at the Pacific Southwest Station and the University of Kansas Space Technology Center, Lawrence, Kansas.

Although this Research Paper points out some limitations of Skylab sensors, these weaknesses probably will be resolved before the reusable space shuttle is launched in the 1980's. Meanwhile, the Forest Service will continue to develop its capabilities to use remote sensing data to inventory and manage forest and related resources.

ROBERT W. HARRIS, *Director*
Pacific Southwest Forest and Range Experiment Station

ACKNOWLEDGMENTS

We gratefully acknowledge the assistance of Professor Robert C. Heller, College of Forestry, Wildlife, and Range Sciences, University of Idaho, who coordinated the original proposal, and until his retirement from the Forest Service in August 1974, gave valuable technical direction to this research.

Members of the staffs of the two cooperating Experiment Stations contributed substantially to the study. Richard J. Myhre, scientific photographer, Pacific Southwest Station, was responsible for all photographic work required by the investigations, and prepared the illustrations included in this report.

The S192 data analysis reported in the Forest Stress Detection section was performed under subcontract by Robert Haralick of the Remote Sensing Laboratory, University of Kansas Space Technology Center, Lawrence, Kansas, with the assistance of Gary Minden, graduate student, Department of Electrical Engineering.

Clayton D. Forbes, technical monitor, Johnson Space Center, was responsible for technical advice, and for expediting shipments of Skylab imagery and computer-compatible tapes.

Robert Mattson, forester, Black Hills National Forest, Deadwood, S.D., assisted in maintaining the field data collection system.

CONTENTS

	<i>Page</i>
Foreword	iii
Acknowledgments	iv
Summary	1
Glossary	4
Introduction	5
Objectives	5
Study Areas	6
Data and Techniques	7
Forest Inventory: Forest Resource Evaluation, Sampling Design, and Automated Land Classification	9
<i>by Robert C. Aldrich, Edwin H. Roberts, Wallace J. Greentree, Nancy X. Norick, and Thomas H. Waite</i>	
Study Area	10
Classification System	10
Skylab Data	10
Ground Truth	14
Procedures	15
Forest Resource Evaluation	15
Forest Sampling Designs	19
Automated Land Classification	22
Results and Discussion	23
Forest Resource Evaluation	24
Forest Sampling Designs	27
Automated Land Classification	31
Applications	32
Classification Systems Alternatives	33
Cost Comparisons	33
Range Inventory: Classification and Mapping of Plant Communities	35
<i>by Richard E. Francis and Richard S. Driscoll</i>	
Study Area	35
Classification System	36
Skylab and Support Data	37
Ground Truth	37
Procedures	38
Plant Community Classification by Photointerpretation	38
Plant Community Mapping	39
Cultural Feature Mapping	39

Foliar Cover Estimation	39
Plant Community Classification by Microdensitometer	39
Results and Discussion	40
Plant Community Classification by Photointerpretation	40
Plant Community Mapping	44
Cultural Feature Mapping	47
Foliar Cover Estimation	47
Plant Community Classification by Microdensitometer	50
Applications	52
Forest Stress Detection: Ponderosa Pine Mortality from Mountain Pine Beetle	55
	<i>by Frederick P. Weber</i>
Study Area	55
Classification System	57
Skylab Data	58
Ground Truth	58
Procedures	59
Photointerpretation	59
Multispectral Scanner Data Analysis	59
Results and Discussion	60
Photointerpretation	60
Multispectral Scanner Data Analysis	62
Applications	62
Measurement of Forest Terrain Reflectance: Determination of Solar and Atmospheric Effects on Satellite Imagery	64
	<i>by Robert W. Dana</i>
Study Area	65
Instrumentation	65
Radiometer	66
Irradiance Meter	66
Data Recorder	67
Video Equipment	67
Filter Sets	67
Skylab Data	68
Procedures for Data Analyses	68
Aircraft Radiance and Irradiance Data	68
Skylab Photographic Data	69
Results and Discussion	70
Applications	72
Literature Cited	73

SUMMARY

Aldrich, Robert C., *technical coordinator*

1976. Evaluation of Skylab (EREP) data for forest and rangeland surveys. USDA Forest Serv. Res. Paper PSW-113, 74 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Oxford: U629.19[+587.7+44]

Retrieval Terms: Skylab; Earth Resources Experiment Package; photo-interpretation; microdensitometric analysis; remote sensors; forest classification; range inventory, plant communities; forest stress

Skylab photographic and multispectral scanner data products were studied during a period of 2½ years to test potential applications for forest and range surveys. Four separate studies tested classification of land use and forest and range vegetation, detection of stress on forest vegetation, and measurement of solar and atmospheric effects in satellite imagery. Sites selected for these studies were near Augusta, Georgia; Manitou, Colorado; the Black Hills of South Dakota; and Redding, California. The Manitou and Black Hills sites were used in previous remote sensing studies of aircraft photography and LANDSAT-1 (ERTS-1) multispectral scanner data.

Skylab data were supplied by NASA as photographic transparencies or computer-compatible tapes for analysis by photointerpretative and computer-assisted techniques. Photographic products included duplicates of S190B terrain mapping camera exposures on color or color infrared (CIR) films. Also included were color and CIR duplicate transparencies and four black-and-white duplicate transparencies from the S190A multispectral camera. The four black-and-white bands representing four spectral regions of the visible spectrum were combined into false-color composites. Computer-compatible tapes included unstraightened conical scan data recorded from the 13-channel multispectral scanner (S192). Different instruments and methods were used at each site to satisfy separate experimental requirements, and problems peculiar to each study were encountered. The approaches to the experimental objectives also varied considerably at each site.

In general, the Skylab photographic data were found useful at two resource-oriented sites for broad classification. Land use classes, such as forest and nonforest, and range vegetation classes at the Region level (Deciduous, Coniferous, and Grassland) were distinguished with acceptable accuracy when checked against ground truth. Maps produced from digitized optical film densities, measured on color film, were acceptable for forest classes but unacceptable for

nonforest. Regardless of interpretation technique, Level II nonforest classes could not be accurately identified on color film, and range plant communities at the Series level could not be classified with consistency on any film/season combination.

Forest stress, in the form of mountain pine beetle-killed ponderosa pine, was detected only on Skylab's terrain mapping camera photography. No individual trees and only infestations over 26 meters (85 feet) in the longest dimension could be detected. Mountain pine beetle infestations could not be detected by analysis of S192 multispectral scanner data. Both photographic data and multispectral data were acquired in June—a period of low insect activity and a period when little discolored foliage remains on the trees killed by the previous year's bark beetle population. Had data been available for September, a period of high insect activity and increasing dead-tree discoloration, results might have been more encouraging.

Additional conclusions drawn from the studies:

1. Systematic or random-sampling designs can be overlaid upon digitized photographic data by computer and classified into broad forest-nonforest classes for estimating area proportions. Acceptable results will depend on improving both the classification system and the classification procedure.

2. Enlargements of Skylab terrain camera photographs (1:125,000) can be used with conventional photointerpretation techniques to estimate proportions of broad land cover classes within large political or administrative boundaries in two-stage sampling designs.

3. Skylab and high-altitude aerial photographs can be used to map areal extent of Conifer and Grassland classes with greater than 90 percent accuracy.

4. Paved and gravel roads, utility corridors constructed within the past 10 years, large mining excavations, and clusters of buildings can be mapped on enlarged Skylab photographs.

5. Radiance from Skylab S190B and LANDSAT sensors was linearly correlated with wide-band terrain reflectance. Coefficients of the regression will be useful as linear conversion coefficients for extending spectral signatures in computer-aided classification using satellite imagery.

Summaries of the individual studies composing this report follow. If Skylab-quality data should become available on a recurring basis, further investigation is needed to support, clarify, and extend these results.

Forest Inventory—Three independent studies were made of the potential application of Skylab photographic data in (1) forest resource evaluation, (2) sampling designs for computer application, and (3) automated land classification and mapping. Multi-spectral scanner data were not analyzed because a change in the test site location was required late in the time period allowed.

Sixteen land use and forest classes, at three levels, were originally defined for both human and computer-assisted classification. Two types of photographic data were used in the tests—multiband false-color composites of S190A data for September 12, 1973, and S190B color for November 30, 1973. These photographs were enlarged to a scale of 1:125,000, 1:250,000, and 1:500,000 for interpretation. Ground truth for forest resource evaluation was provided by a 1971 forest survey. High-altitude CIR photographs (1:120,000) and ground checks were used to map one county into two forest and two nonforest classes for a sampling design study. To evaluate computer-assisted classification, two study blocks were mapped into 31 Level III and Level IV land use classes on high-altitude CIR photographs, and corrected using ground observations.

In one forest resource evaluation, land use proportions were estimated for a four-county area. The estimate of forest area was within 2 percent of the 1971 Forest Survey figure for the four counties. By individual counties, the estimates were within 2 percent for three of the four counties. With the exception of pasture and idle land, the four-county estimates were all close to ± 1 percent of the 1971 Forest Survey estimates. A quasi-operational application test using regression techniques in one county estimated forest area 3 percent above the Forest Survey estimate. The sampling error was ± 3.53 percent.

Using computer-simulation techniques, sampling designs were tested with a digitized ground truth map and digitized Skylab photographic data for one county. The variance in forest area resulting from systematic sampling was always smaller than that from

simple random sampling. When a digitized type-map classified from Skylab S190B microdensitometer data was used in a postsampling stratification strategy, the variance of the forest area estimate was smaller than that from systematic sampling alone—but only when the sample intensity was low.

Computer-assisted analysis of microdensitometer scans made on Skylab S190B color photographs separated forest land from nonforest land with an accuracy of approximately 95 percent. Pine and hardwoods could be separated with an accuracy of approximately 70 percent.

Forest inventory studies in the Augusta, Georgia, site showed that Skylab S190B photographs provide a good base for Level I forest classification. Although conventional photointerpretation can provide acceptable area estimates for some nonforest classes, idle land, pasture, and water were difficult to separate on normal-color film.

Range Inventory—Classification of range plant communities was attempted at two levels of the ECO-CLASS system—three Region and eight Series classes. Skylab photographs from the S190A multiband camera and the S190B terrain mapping camera (June and August 1973), high-altitude aircraft photographs (June and August 1973), and Forest Service-acquired large-scale photography were used in the tests. Both visual and microdensitometer techniques were tested.

Procedures were developed for sampling plant communities for use in photointerpretation training and tests. Procedures were also developed to map cultural features from Skylab photographs. In a separate study, foliar cover estimates made on large-scale color photographs were compared with measurements made on ground transects.

Interpreters classified Grassland and Conifer Region classes with a mean accuracy of 98 percent or greater on both Skylab and support aircraft photography, regardless of date or film type. For the Deciduous (Aspen) class, accuracy was 80 percent or greater on the August CIR aircraft photographs, but was not acceptable on Skylab photographs. Coniferous Series class accuracies were dependent on date and film type, but inconsistently so. Accuracies were greater at small scales, probably because mixed tree species formed homogeneous units with a dominant species signature and a lower resolution. Within the grassland Series, Shortgrass was classified with an accuracy of 95 percent or greater on both Skylab and aircraft photographs, regardless of date or film type. For Wet Meadow, accuracy was greater than 90 percent on both June and August aircraft photographs, regardless of film type or scale, and was also accept-

able on both color and CIR Skylab photographs taken in August. Mountain Bunchgrass was not accurately classified on Skylab photographs, but on the August aircraft photographs the classification was acceptable regardless of film type or scale. Topographic slope and aspect, mountain shadows, ecotones, season, and class-mixing affected classification of plant communities.

In microdensitometer point-sampling, significant differences in mean optical densities at the 95 percent probability level were a measure of separability. At the Region level, Conifer, Deciduous (Aspen), and Grassland classes were separable. However, the Deciduous class could be separated from the other classes with significant differences only on color film. Ponderosa Pine was the only coniferous Series class that was separable from the other three conifers, regardless of date or film type. Spruce/Fir and Lodgepole Pine were not separable at any date or on any scale or film type. Douglas-fir was separable from the other three conifers on both the June CIR and August color S190A Skylab photographs. Grassland classifications at the Series level varied in acceptability. However, Shortgrass, Mountain Bunchgrass, and Wet Meadow were separable on August S190A color photographs. Optical density was more dependent on community mixing than on the growth stage of the plants at the time (season).

Both Skylab and aircraft photographs were useful to map the areal extent of Conifer and Grassland, but the Deciduous (Aspen) class could not be mapped with acceptable accuracy. Except for Wet Meadow, Series level classes could be mapped with acceptable accuracy only if class-complexes were formed: Ponderosa Pine/Douglas-fir, Lodgepole Pine/Spruce/Fir, and Shortgrass/Mountain Bunchgrass.

Paved and gravel roads, utility corridors constructed within the last 10 years, larger mining excavations, and clusters of buildings could be mapped on Skylab photograph enlargements. On the other hand, 1:100,000 scale aircraft photographs were needed to map dirt roads, minor earth excavations, utility corridors older than 10 years, and individual buildings. Foliar cover and plant litter measured on large-scale CIR photographs of non-diverse grasslands were related to ground measurements with a correlation coefficient of 0.75. This is considered acceptable for range surveys. The relationship for foliar cover of shrubs was acceptable only on diverse grasslands.

Forest Stress Detection—An evaluation of Skylab data in the Black Hills showed that mountain pine beetle infestations in ponderosa pine could not be identified on any S190A multiband camera system

photographic product. All positive identifications of bark beetle infestations were made on color photographs taken by the S190B terrain mapping camera. To be detected, infestations had to exceed 26 m (85 ft) in the longest dimension. On one site, only infestations over 50 m (164 ft) in size could be detected. Infestations over 100 m (328 ft) in the longest dimension were located with 100 percent accuracy. The optimum viewing scale with a stereomicroscope was about 1:75,000. Best results were obtained with viewing on a high-quality, variable high-intensity light table; however, stereoscopic viewing was preferred and usually resulted in fewer commission errors than monocular viewing. Interpretation on a rear-projection viewer with high magnification was judged to be inferior to microscopic viewing on a light table.

Because late August through mid-September is the best period for detection of trees killed by mountain pine beetle, the June Skylab imagery used in this analysis was poorly timed. All dead ponderosa pine in the site were killed during the previous year and had lost most of their discolored foliage before the Skylab pass. Since the distinct red-orange color of dead tree foliage is used for recognition, many infestations were missed. Also, the early morning low angle of the sun at the time of the Skylab missions made interpretation difficult. In the steep terrain of the Black Hills, west- and north-facing slopes were in shadow.

Ponderosa pine trees killed by the mountain pine beetle were not detected by computer processing of 13-channel multispectral scanner (MSS) data (S192, June 9, 1973). Only five bands of the MSS were usable, and misregistration of the data seriously detracted from the analysis results. Attempts to correct the registration improved classification somewhat in several instances, but beetle-killed trees were not identified.

The analysis for stress detection in this report was restricted by circumstances beyond the control of the investigators. A Skylab earth resources pass was requested and scheduled during the desirable period (September 18, 1973) and correlative data needed in the analysis were collected by ground-based instruments on that date. However, the Skylab earth resources sensors were turned off unexpectedly during the pass. The results of the analysis in this report are therefore inconclusive, and further investigation is required to determine if forest stress can be detected on Skylab-quality remote sensing data.

Measurement of Forest Terrain Reflectance—Data on terrain radiance and solar irradiance, gathered on or near the Earth's surface, could be valuable for earth resource investigations. Calibrated satellite data

might be more easily interpreted and more fully used if investigators could estimate temporal and locational variations in the effects of solar and atmospheric conditions on the satellite imagery.

An effort was made to use measurements of airborne radiance and irradiance to compute terrain reflectance values. These values (when correlated with satellite radiance of the same terrain elements) yield a first-order measure of solar and atmospheric properties at the time of a satellite overpass. Treating satellite radiance as the dependent variable, the correlation procedure produces an additive coefficient which is the path radiance, and a multiplicative coefficient representing the product of total irradiance and beam transmittance.

The airborne system for reflectance measurements consisted of an upward-pointing irradiance meter, a downward-pointing radiometer, a silicon vidicon camera (for support imagery) and associated data-recording instruments. Spectral matching to the bandwidths of the Skylab S190A and LANDSAT-1 MSS sensors was achieved for all three airborne sensors.

The S190A photographs were scanned by a digital

microdensitometer. Programs were written to convert microdensity values to diffuse density and subsequently to effective film exposure. Finally, the satellite radiance was computed from film exposure values, using a camera radiance equation. Techniques, as outlined, were developed for use of the film samples and the sensitometric package (provided by NASA) necessary for these conversions.

The analysis of one set of Skylab photographs and one set of LANDSAT-1 images resulted in a high linear correlation between satellite radiance and reflectance. The derived path radiance values are in agreement with other published values.

The reflectance measurement technique presents two possible advantages over other empirical methods. One is that the results are derived in terms of the satellite scale of units, without concern for the calibration accuracy of ground-based or airborne radiometers. The other is that during stable periods in terrain reflectance properties, the reflectance measurements need not be made on the same day as the satellite overpass.

GLOSSARY

Band: One of the wavelength bands of the electromagnetic spectrum sensed by a multispectral scanner (MSS) or passed by a band-pass filter and recorded on photographic film.

Band Pair: Any two defined wavelength bands of the electromagnetic spectrum used in signature analysis.

Band-pass Filter: An optical filter that allows only defined portions of the electromagnetic spectrum to pass to the sensor surface.

Bias: The difference between the expected value of a statistic over all possible samples and the true population value of that statistic.

Color Composite: A false-color reconstruction of multiband photographs created from two or more filtered photographic bands. The four filtered bands on Skylab (S190A) were 0.5-0.6 μm (station 1), and 0.8-0.9 μm (station 2).

Computer-Compatible Tape (CCT): A reconstruction of data in magnetic tape form suitable for computer analysis. In this study, CCT's of Skylab MSS data and of digitized photographic optical densities were used.

Confusion Matrix: A tabular presentation of classification data showing the proportion of actual vegetation types that were classified as each of the predicted types.

Digital Element: A single picture element of digital image density recorded on computer-compatible tape by a microdensitometer. The size of the element varies with the microdensitometer aperture.

Irradiance: The amount of light measured on a surface. In physics, the radiant flux density on a given surface. Usually expressed in watts per square meter.

Microdensitometer (MDT): An instrument used to measure the optical density of an image on a photographic transparency, using a calibrated light source.

Multispectral Scanner (MSS): For Skylab, an electronic optical line-scanning device (S192) that collects reflected and emitted radiation in 13 spectral intervals (bands) of the visible, near-infrared, and thermal-infrared regions of the electromagnetic spectrum. The S192 has a conical line scan which meant line scan data had to be straightened for computer analysis.

Postsampling Stratification (PSS): Stratified sampling in which the strata assignments are unknown or are not used at the time of sample selection.

Radiance: The brightness of an object as seen from a remote observation point. In physics, it is a measure of the power radiating from a unit area of a source through a unit solid angle. Typical units of radiance are watts/meter²-steradian.

Sampling Fraction: Percent of units sampled to the total number of units in the population.

UTM: Universal Transverse Mercator map projection.

Zoom Transfer Scope (ZTS): An optical instrument for transferring data from a small-scale photograph to a larger scale photograph or map. The scale change range is from 1X to 13X. (Manufactured by Bausch and Lomb Optical Company.)

INTRODUCTION

High-resolution sensors such as those on board Skylab may play an important part in forest and rangeland surveys in the future. Although conventional aerial photographs have been an aid in resource surveys for several decades, recent developments have moved toward more sophisticated photographic and nonphotographic remote sensors and computer-assisted data analysis. The new technology is valuable for several reasons: (1) costs of acquiring resource data are rapidly increasing, (2) more resource data is required at shorter intervals to measure rapid changes in land use that affect the environment, (3) urban and recreational uses of land are encroaching upon available resources and alternate sources must be planned and provided for, and (4) there is a continuing need for up-to-date resource information for day-to-day land management decisions and program planning.

There were three separate Skylab missions between May 1973 and February 1974. These missions were designated SL-2, SL-3, and SL-4. For each mission a three-man crew was launched in a space vehicle to dock with the Skylab Workshop (SWS) already in orbit: SL-2, launched on May 15, 1973, continued for 28 days; SL-3, launched on July 13, 1973, continued 74 days; and the SL-4 mission, launched on November 14, 1973, continued 84 days. The Skylab experiment was completed on February 8, 1974. During each mission, the Skylab Workshop was in orbit approximately 235 nautical miles (435 km) above the earth. Earth resources coverage was confined by this orbit to the Earth's surface lying between the Equator and 50 degrees north latitude and between the Equator and 50 degrees south latitude. During the missions, crew members were instructed to carry out certain experiments each day. Experiments included human physiology, astronomy, space technology, and earth resources. The Earth Resources Experimental Package (EREP) occupied only a small portion of the astronauts' time and had a lower priority than most of the studies.

Skylab's EREP is only one of several projects in NASA's Earth Resources Program, which began in

1965 with NASA support of studies using photographic and multispectral scanner (MSS) data obtained from aircraft flights. These early studies were made to define earth resource parameters and sensor requirements for projected space experiments, such as a series of LANDSAT (formerly ERTS) unmanned satellites, and Skylab and the Space Shuttle, which are manned satellites. The Remote Sensing Research Unit at Pacific Southwest Forest and Range Experiment Station has been involved in the Earth Resources Program since 1965, and the Rocky Mountain Forest and Range Experiment Station became involved in 1969. First, aircraft data were studied (Personnel of the Remote Sensing Research Work Unit 1972; Driscoll and Francis 1972), and then in 1973, LANDSAT-1 (ERTS) MSS data were evaluated (Heller 1975).

The conclusion from the LANDSAT study was that with improved spectral and spatial resolution, satellite imagery could provide the first-level information required in extensive forest inventory sampling strategies. Skylab data provided an opportunity to investigate and substantiate the conclusion, using machine-assisted classification procedures in addition to those dependent on human skill and judgment.

Objectives

The original objectives of this investigation as outlined in the NASA contract proposal were these:

1. To test the hypothesis that Skylab data will permit identification of forest, rangeland nonforest, water resources, and forest stress.
2. To determine if information in satellite imagery, coupled with information in aircraft photography and ground examinations, will increase efficiency of surveys of forest-related resources.
3. To compare the accuracy and cost effectiveness of various types of data and compare direct visual classification techniques with computer-assisted classification to separate and identify forest and rangeland resources.

4. To develop and test a practical method of correcting satellite radiance data for solar and atmospheric effect in computer-assisted classification.

At each of the four study sites, modifications in specific objectives were necessary because operational and technical problems developed. For instance, when Skylab coverage for the Atlanta study site was found to be unavailable, the forest inventory study was moved to an area north of Augusta, Georgia. This move was made in March 1974 after the Skylab experiment had been completed, and so no supporting aircraft flights or ground truth for the actual times of the Skylab passes could be obtained. The multiseasonal data evaluations were therefore eliminated from the study. Omission of proper filters for the multispectral camera during the November 30, 1973, Skylab pass over the Augusta site prevented our combining these data for analysis. In the Black Hills, a Skylab pass scheduled for September 18, 1973, was canceled at the last moment. Although biophysical data were collected on the ground during the period scheduled for the pass, there were no Skylab data in the proper time frame to analyze for stress detection.

Originally the analysis at all sites was to include all data types and all interpretation techniques. Insufficient data and time constraints, however, required that (1) human photointerpretation techniques be used at all sites, (2) microdensitometric analysis of photographic data be used on the Augusta and Manitou sites only, and (3) an analysis of the multispectral scanner data be performed by a subcontractor for the Black Hills site. These modifications made cost comparisons between all methods impossible.

Study Areas

Experiments were conducted in four widely separated locations across the country (fig. 1). We had originally planned to use the same sites as those used in evaluations of aircraft imagery and LANDSAT-1 (ERTS-1) data: Atlanta, Georgia, for forest inventory; the Black Hills in South Dakota for forest stress; and Manitou, Colorado, for range inventory. By retaining these sites, we could use in the analysis firsthand knowledge of conditions accumulated over a period of years, and make comparisons between systems. However, problems of data acquisition for the Atlanta site made selecting of two new sites necessary to carry out the studies originally proposed. The study to develop techniques for measuring and correcting for atmospheric interference, originally located at Atlanta, was moved to a new site near



Figure 1—The study areas indicated on this map were used for different phases of the Skylab data evaluation: Augusta, Georgia—forest inventory; Manitou, Colorado—rangeland inventory; Black Hills, South Dakota—forest stress from mountain pine beetle; Redding, California—solar and atmospheric effects on data evaluation.

Redding, California. The site change was made early enough so that both Skylab and aircraft underflights could be scheduled on the same day. The forest inventory study was moved to an area near Augusta, Georgia, and the study was redesigned. New ground truth was collected 1 year following the best SL-4 pass (November 30, 1973), and comparisons between Skylab, aircraft, and ground data were made from this new beginning.

The forest inventory site just north of Augusta, Georgia, is representative of a large portion of the Southeastern United States where a high level of forest management is taking place and rapid changes are occurring. Forests here occupy 75 percent of the land area and are found in large contiguous bodies as well as in small woodlots intermingled with nonforest land. Pulpwood, wildlife, and recreation are three major uses of the forest land in this area. With a major lake, varied forest practices, and many forest and field borderlines, this area is a challenge to the photointerpreter.

Rangelands such as the Manitou, Colorado, site are important national resources and need to be inventoried, protected, and managed. They are becoming more valuable as our food and fiber supplies become more critical. Classification of the predominant vegetation according to its relation to other plants and animals and its potential for development is valuable. The Manitou site is appropriate for determination of the classification level at which Skylab data can be used to accurately assess range vegetation types.

In the Black Hills of South Dakota, the third site, a severe outbreak of mountain pine beetle (*Dendroctonus ponderosae* Hopk.) has killed several hundred

thousand ponderosa pine trees (*Pinus ponderosa* Laws.) over the past 10 years. Early detection of the dying pines, which discolor to a yellow and yellow-red hue, would assist forest managers in assessing the severity of the outbreak and in planning control and salvage operations—particularly if the discoloration could be detected accurately and quickly from either manned or unmanned satellites.

The Whiskeytown Reservoir-Redding, California site was selected as an alternate site because it was on a Skylab ground track and convenient for low-altitude reflectance measurements. This site consisted of a strip along one east-to-west flight line from the reservoir to the Redding Airport. Measurements of reflectance by land use and vegetation classes were rather limited because of a partial cloud cover. Only mixed oak and digger pine (*Pinus sabiniana* Dougl.), ponderosa pine, brush species, and water were available for reflectance measurements. The topography ranged from rolling hills to moderately steep foothill slopes and deep gullies. A light, variable cirrus overcast was present during both the aircraft and Skylab passes.

Data and Techniques

Six EREP sensors were on board the Skylab Workshop. These consisted of a multispectral camera, S190A, with six high-precision matched lenses, an earth terrain camera, S190B, an infrared spectrometer (S191), a 13-channel multispectral scanner (MSS), S192, a microwave radiometer/scatterometer and altimeter, S193, and an L-Band radiometer, S194. Only S190A, S190B, and S192 data were evaluated in the studies reported here. We originally intended to use S191 infrared spectrometer data to evaluate the effects of the atmosphere; however, owing to a lack of coverage that could be related to the ground truth measurements, this part of the experiment was eliminated.

The S190A data were provided by NASA/JSC in the form of 2½-inch square film transparencies. The original scale of these data was approximately 1:2,800,000, but they were enlarged to suit the needs of the individual studies. Special filters used on the camera lenses separated the visible and reflected infrared spectrum into bands for multispectral analysis. For each EREP pass over a test site, a set of six pictures was received. The bands, expressed as wavelength in micrometers, for each film type were these: color infrared (CIR): 0.5 to 0.88; high-resolution color: 0.4 to 0.7; black-and-white panchromatic film: 0.5 to 0.6 and 0.6 to 0.7; and infrared sensitive film: 0.7 to 0.8 and 0.8 to 0.9.

For each site covered by an EREP pass, a set of contact duplicate transparencies (5 by 5 inches) was received for all S190B coverage. The original scale of these photographs was approximately 1:900,000 but for special purposes they were photographically enlarged to 1:125,000. These photos were taken on either normal color or CIR film; the decision depended on the requirements of the majority of investigators who had requested coverage on each pass, and in some instances we therefore received normal color when CIR was preferred.

Computer-compatible tapes (CCT's) with S192 multispectral scanner data were received only for the Black Hills test site. These tapes were used by a subcontractor to classify stressed ponderosa pine under attack by the mountain pine beetle. The tapes, with 13 channels of MSS data, covered six discrete bands in the visible spectrum, six discrete bands in the reflected infrared, and one single thermal infrared band from 10.2 to 12.5 micrometers.

Techniques and instruments used by the investigators to analyze Skylab photographic data varied from one site to the next. In both the forest and range inventory investigations, a Bausch and Lomb Zoom Transfer Scope (ZTS)¹ was used for mapping and dual image correlations. In the Black Hills investigation, a Bausch and Lomb 240 zoom stereo microscope was used to test a wide range of image magnifications for stress detection—both stereoscopically and monocularly. The investigator here also used a Variscan rear-projection viewer to interpret images at magnifications up to 29.5 times. On the forest inventory site, conventional photointerpretation was carried out with both an Old Delft scanning stereoscope and a lamp magnifier. A Photo Data Systems (PDS) automatic scanning microdensitometer and process computer were also used to scan and record optical density on one S190B color photograph for computer-assisted classification. At the range inventory site a General Aniline and Film Corp. (GAF) microdensitometer was used to relate film density to plant communities. Similarly, a point-sampling technique was used at the Manitou site to classify plant communities by conventional interpretation. Interpretations were verified on ground-truth maps prepared from high-altitude color infrared photography and ground checks. At the Augusta site, existing forest inventory photo samples and ground subsamples provided a basis for land use and forest-type evaluations.

¹ Trade names and commercial enterprises or products are mentioned solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied.

The investigator at the Black Hills site systematically scanned each sub-block study site to detect bark-beetle-killed trees—the trees were counted, infested spots were mapped, and the Skylab interpretation verified on aerial photography or by aerial observations.

During the studies described here, large quantities of data were gathered over a long period of time. Many of the techniques used were developed and modified in light of required changes in the analysis plan and from

experience. In this report, only enough detail has been included to help the reader understand what was done and evaluate the results. The report is intended primarily to aid those who may be using manned earth resources satellite data in forestry applications in the future. Some additional detailed information is available on request, as noted in later sections of this report. Requests should be addressed to Director, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, California 94701.

FOREST INVENTORY

Forest Resource Evaluation, Sampling Design, and Automated Land Classification

Robert C. Aldrich

Edwin H. Roberts

Wallace J. Greentree

Nancy X. Norick

Thomas H. Waite

The Skylab studies conducted near Augusta, Georgia, are part of a continuing research program to improve extensive forest inventory techniques. Intensive inventory techniques relate to individual forest stands as small as 2 hectares (5 acres), whereas the research reported here deals with the measurement of resource conditions within broad natural, administrative, and political boundaries using sampling procedures. Additional information about specific locations within the survey boundaries is useful but is not usually required.

Three independent studies were carried out by the investigators to evaluate Skylab photographic data for national forest resource surveys:

1. An evaluation of Skylab S190A (multispectral camera) and S190B (earth terrain camera) photographic data for classifying forest and related land use. This study includes a quasi-operational one-county forest evaluation.

2. A study to determine an effective method for sampling digitized remote sensing data. This study includes a one-county evaluation of sampling designs and sampling intensity, using optical densities from an S190B color photograph.

3. A study of microdensitometer techniques for classifying forest and related land use on Skylab S190B photography. Two 10,000-meter-square (6.22-mile-square) blocks are used as experimental areas to map Level II and Level III land use classes.

Synoptic vertical photographs taken from space platforms are of considerable interest to forest inventory specialists. In March 1969, foresters found that color infrared photographs taken by Apollo 9 astronauts could be used to stratify forest land into broad classes (Langley and others 1969; Aldrich 1971). In a multistage forest inventory in the Mississippi Valley, this first-level stratification increased sampling efficiency by over 58 percent. Interest in multistage sampling strategies using satellite imagery coupled with aircraft photography and ground observations has increased as a result (Draeger and others 1971; Hildebrandt 1973; Kuusela and Poso 1972; Nichols and others 1974).

Since the early 1940's, land use classification has been the first stage in extensive nationwide forest resource inventories. This classification is usually done by photointerpreters on available medium-scale panchromatic aerial photographs. Many times these photographs are 5 to 10 years old at the time they are used. Since the primary purpose of land use classification is to determine an accurate forest area base for expanding forest resource statistics, changes in land use since the photographs were taken can be a serious problem. If the forest area base is not accurate, data from ground subsamples expanded by a forest area expansion factor can be inaccurate. Unless up-to-date photography or other remote sensing imagery is available on a wide area basis, adequate measurement of the changes in the forest area base is very difficult.

In 1969, a research program was begun by the Pacific Southwest Station's Remote Sensing Work Unit to study high-altitude aircraft photography and satellite imagery for land use and forest classification as a first level of information in resource surveys. These studies were conducted under the Earth Resources Survey Programs sponsored by NASA. A study near Atlanta, Georgia, using 1:400,000 and 1:120,000 CIR aerial photography, showed that forest land could be identified correctly over 96 percent of the time regardless of scale (Heller and others 1973). During this study, techniques for classifying land use by optical film density were investigated with only limited success. Multispectral scanner (MSS) data from aircraft flights over two 4049-hectare (10,000-acre) study blocks were also analyzed. Although land use classifications were reasonably accurate, distortions in the processed data were a limiting factor (Weber and others 1973). In 1973, LANDSAT-1 (ERTS-1) MSS data for the Atlanta test site were studied by both conventional photointerpretation techniques and by computer-assisted classification procedures (Aldrich and others 1975). Interpreters could correctly classify Level I information (forest, nonforest, water) over 96 percent of the time on false-color photo composites. Computer-assisted classification using four bands of scanner data was 94

to 96 percent correct for the Level I classes. Neither human nor machine classification could separate Level II information with a high degree of accuracy.

Skylab (EREP) data with ground resolutions of from 10 to 30 meters offered an opportunity to find out whether higher resolution data would improve the accuracy of Level I and Level II information for National Forest resource surveys. We also needed to know if Level I information could be obtained from Skylab photographs by microdensitometry and computer-assisted classification and sampling procedures.

Study Area

The study site near Augusta, Georgia, (fig. 2) lies in the Piedmont physical division and is part of Georgia Forest Survey Unit 4.² The area is typical of a large part of the Southern United States, with both broad contiguous bodies of forest land and small farm woodlots mingled with nonforest land use. Forest land is 75 percent of the total land area. Major forest types are loblolly pine (*Pinus taeda* L.), oak-pine, oak-hickory, and oak-gum cypress. Topography is gently rolling to hilly, with many narrow stream valleys. Principal land uses are forest, grassland (pasture), urban, and water. Agriculture is not a major land use, though scattered grain and row crops are found throughout the area. The Clark Hill Reservoir forms the eastern boundary and is the site of recreation homes; it is a base for hunting, fishing, and other recreational uses. Major forest disturbances are caused by forest management practices and by development of recreation home sites.

Classification System

The diversity of techniques used in these studies called for a variety of classification systems. Although somewhat different in nomenclature, these systems have the same objective: to measure the forest area within an error of ± 3 percent per million acres (404,858 hectares).

The classification system used in the forest resource evaluation study included 10 individual land use classes (table 1). Not all of these classes, however,

were found within the four-county site. In some portions of the study the five agricultural classes were grouped as "other miscellaneous" to conform to the system used by the Forest Survey in their first-level stratification on aerial photographs.

The forest sampling design study in McDuffie County used a classification hierarchy of three Level I and two Level II classes. Forest land, nonforest land, and water were mapped at Level I to build a base for testing computer sampling designs. Two Level II classes—pine and deciduous forest—were also delineated to see if they could be separated and stratified on Skylab data digitized by microdensitometer.

To test the value of computer classification algorithms developed for LANDSAT-1 (ERTS-1), a classification system of four levels was developed for Skylab (table 2). The land area in two 10,000-meter-square (6.22-mile-square) blocks was mapped to a 0.4-hectare (1-acre) minimum using this system. On five randomly selected 1000-meter (0.62-mile) sub-blocks within the test blocks, forest land was classified by three stand-size classes to help explain variations in the Skylab film densities.

Skylab Data

Restrictions imposed by short missions, seasonal data requirements, and the scientists' lack of control over scheduling reduced the probability of obtaining a clear photographic day for Skylab data collection. For this reason, remotely sensed data were not obtained for the inventory test site near Atlanta, Georgia, where earlier studies had been made. To complete the proposed research using the most suitable Skylab data products, an alternate site was selected after the Skylab experiment had been completed and all data tabulated. By that time, SL-3 and SL-4 data for the new site were already 4 to 6 months old and it was no longer possible to gather any time-dependent ground truth.

The Skylab data used in these studies include only S190A and S190B photography (fig. 2), taken on September 12 (SL-3; Pass 36, Track 43) and November 30, 1973 (SL-4; Pass 54, Track 19).

The panchromatic and infrared SL-3 S190A multi-band photography was combined and enhanced on an I²S (Stanford Technology Corp.) additive color viewer, and a color internegative was made of the combined image following the technique described by Myhre for combining LANDSAT-1 (ERTS-1) film chips (Aldrich and others 1975). From the inter-

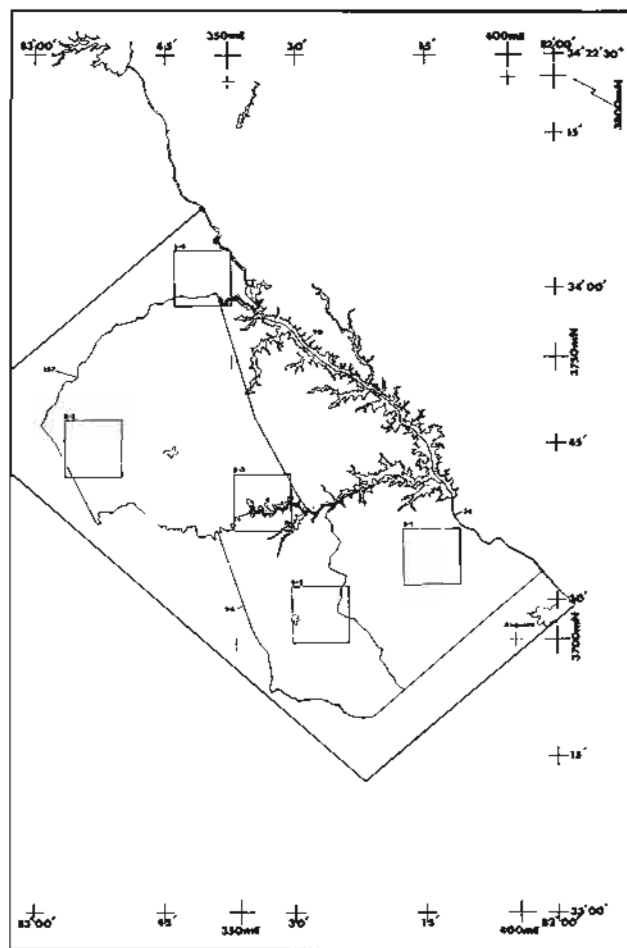
² A state-wide forest resource evaluation is made every 8 to 10 years by the Forest Resource Research Unit at the Southeastern Forest Experiment Station, Asheville, N.C. Section 9 of the McSweeney-McNary Forest Research Act of 1928, as amended, and the Forest and Rangeland Renewable Resources Planning Act of 1974 authorize these forest resource evaluations.



Skylab S190A multiband composite, Sept. 12, 1973



Skylab S190B color photograph, Nov. 30, 1973



Augusta site map

Figure 2—The Augusta site, used for evaluating Skylab data in forest inventory, includes four counties. Two intensive study sites (2 and 4) were used for computer-assisted mapping with digitized photographic film densities. The Skylab S190A multiband composite for September 12, 1973, and the Skylab S190B color photograph for November 30, 1973, were used in the data analysis. Photographic scale is approximately 1:850,000.



Table 1—A land-use hierarchy¹ for forest resource evaluation

Classification	Definition
Forest Land	Areas 0.4 hectare (1 acre) or larger, capable of supporting more than 10 percent cover by forest trees and not developed for nonforest use.
Cropland	Land currently being utilized to produce agricultural crops that are harvested directly and not indirectly as pasture forage consumed by livestock.
Idle farmland	Former cropland, orchards, improved pasture, and farm sites not tended within the past 2 years and presently less than 10 percent stocked with trees.
Improved pasture	Land currently being improved for grazing by cultivation, seeding, irrigation, or clearing of brush and trees.
Grassland	Land other than improved pasture on which the primary natural cover is grass and forbs.
Other agriculture	All other farmland not used for crops, idle, or pasture. Includes farmstead, buildings, and service areas.
Marsh and swampland	Land temporarily or partially covered by water, and poorly drained land capable of supporting more than 10 percent cover of swamp vegetation (marsh grasses, cattails, etc.). Does not include spruce bogs, cypress land, or other hydric forest sites.
Urban and other areas	Areas within legal boundaries of cities and towns; suburban areas developed for residential, industrial, or recreational purposes; schoolyards; cemeteries; roads; railroads; airports; beaches; powerlines and other rights-of-way; or other nonforest land not included in any other specific land class.
Census water	Streams, sloughs, estuaries, and canals more than 0.2 kilometers (1/8 statute mile) in width; and lakes, reservoirs, and ponds more than 16.2 hectares (40 acres) in area.
Noncensus water	Streams, sloughs, estuaries, and canals less than 0.2 kilometer (1/8 statute mile) in width; and lakes, reservoirs, and ponds less than 16.2 hectares (40 acres) in area. Minimum width of streams, etc., and minimum diameter of lakes, etc., are 9.1 meters (30 feet).

¹U.S. Forest Service 1974.²U.S. Forest Service 1968, Definition of Terms, p. D-1 through D-9.

negative, 1:500,000 and 1:250,000 enlargements were made on color transparency film. These films were used in combination with S190B color transparencies for forest and land use classification; however, the lower resolution and graininess of the S190A composite caused eye fatigue, and the effect was to increase interpretation time. Although the spectral information was helpful in making land use and forest-type decisions, we concluded that high-resolution CIR film from the S190B earth terrain camera would have been much more useful. We did not use the S190A CIR or color films in our analysis because, after a careful review of the materials, we felt that they contained only redundant information and at a lower resolution than the S190B imagery.

The S190A multiband photography for SL4 (November 30, 1973) could not be used in the anal-

ysis because the films had been exposed without filters.³

Of the two sets of color photographs produced by the S190B terrain camera, only the SL4 (November 30, 1973) could be effectively used. The SL3 photographs (September 12, 1973) were low in contrast, showed a general haze condition, and did not include overlap for stereoscopic viewing. The SL4 photographs, on the other hand, were taken on a clear day, contained reasonably good contrast between land uses and forest conditions, and had 60 percent overlap for stereoscopic viewing. We found this photog-

³ National Aeronautics and Space Administration. 1974. *Skylab program, sensor performance report, vol. 1* (S190A), MSC-05528. NASA L. B. Johnson Space Center, p. 3-6d.

Table 2-A land use classification hierarchy for remote sensing and ground information sources compatible with current nationwide forest resource evaluation objectives. Color definitions are based on high-altitude color infrared photography and simulated color infrared composites of LANDSAT data.

Classification	Color definitions (based on Munsell 1920-60, NBS 1955)
I FOREST LAND	
II Conifer	Density of conifer stands, number of hardwoods mixed in stand, and stand size influence color value and chroma. Dense stands are darker with less chroma. In the fall, before advanced hardwood coloration and leaf fall, conifer stands appear dark purplish red. Separation between conifer and hardwood classes is less distinct in fall than in winter or early spring. Where hardwoods and conifers are mixed in stands, hardwood color predominates, and stand is usually classified as hardwood. In spring before hardwoods are foliated, conifers appear moderate to dark purplish red. Seedlings and saplings on prepared sites appear lighter than poles and mature sawtimber with closed canopies.
III Pine	
IV Pine-hardwood	
IV Seedling and sapling	
Poles	
Sawtimber	
II Deciduous hardwood	Stands appear moderate grayish purplish red in fall and pale purple to moderate purplish red in spring. In fall, upland hardwoods cannot be distinguished from bottomland hardwoods. In spring, before foliation, upland hardwoods appear pale purple to light grayish purplish red. Bottomland hardwoods are generally a moderate purplish red. Stand size class (texture), density of crown canopy, and ground cover influence color value, density, and chroma but to a lesser extent than in conifer stands.
III Upland hardwood	
Bottomland hardwood	
IV Seedling and sapling	
Poles	
Sawtimber	
I NONFOREST LAND	
II Grassland	Grassland appears deep pink in both fall and spring; sometimes mistaken for immature cropland in spring.
III Undisturbed grass	
Disturbed grass	
Dead grass (annual)	
New improved grass	
II Cropland	Mature crops in fall appear bluish gray to grayish blue. In spring, immature crops appear deep pink and may be mistaken for grassland.
III Immature grain	
Immature crop	
Mature crop	
Harvested crop	
Orchard	
Farmsteads	
II Bare Soil	In fall and spring bare soil appears cream colored on LANDSAT imagery. There is no distinction between plowed agricultural fields and sites prepared for new commercial developments. Generally in spring most areas of bare soil are newly plowed fields either recently or soon-to-be planted.
III Plowed fields	
Erosion	
Urban (site preparations)	
Rock outcrop	
II Wild vegetation	In fall, areas range from grayish purple of idle land to grayish purplish red of abandoned land to deep pink of Kudzu vine. Marsh and alder swamps are a moderate purple because of wet background. In spring, idle land becomes light grayish red to dark pink because of influx of new infrared-reflectant vegetation. Abandoned-transitional land (reverting to forest), on the other hand, is grayish purplish red and marsh and alder swamps are grayish violet. Deciduous Kudzu vine, purplish gray in the spring, easily separates itself from all other vegetation when fall and spring images are viewed together.
III Idle land	
Abandoned land	
Transitional	
Kudzu	
Marshland	
Alder swamp	
II Urban	Areas are light blue in the fall and very pale blue in the spring. Unfortunately, because of low resolution of LANDSAT data, secondary roads, minor roads, and most utility lines are not resolved.
III Transportation & utilities	
Home developments	
Recreation	
I WATER	
II Water	Water is dark greenish blue in fall and light greenish blue in spring. Farm ponds of less than .4 hectare (1 acre) can be seen on LANDSAT images if there is sufficient contrast with background.
III Clear lakes & ponds	
Turbid lakes & ponds	
Rivers & streams	

raphy most useful for forest inventory purposes because (1) a single photograph includes 8 to 10 counties, (2) a photograph can be enlarged to 1:125,000 without loss of information, and (3) a scaled map overlay of county boundaries can be used on the photograph without serious photographic distortion problems.

Generally speaking, forest land can be easily separated from nonforest land on S190B color photographs. There are some conflicts, however, where shadows, small bodies of water, streams, and idle land appear. Where forest land borders on nonforest land, shadows cast by timber stands on west- and north-west-facing edges blend with the forest and can cause misclassification bias in favor of forest land. Small bodies of water within forested areas are not easily separated from the surrounding forest—particularly pine forest—because, to the eye, both features have the same density and hue. Although small bodies of water within hardwood stands show more contrast with surrounding features, they too can be misinterpreted as pine. Idle land in many instances appears very similar to abandoned land stocked with hardwood and pine saplings. The difference is very subtle and can cause a bias in favor of forest land.

Pine land is easily separated from the deciduous hardwoods in November. The separation is made by density (tone) and hue to a limited extent. Pine is much darker than the leafless deciduous forest, and the ground cover under the deciduous forest is a gray-green. Because of a limited range in color hues, pasture, cropland, idle land, and wild range are difficult to separate. Graininess of the film gives the impression of texture that interpreters look for in idle, abandoned, or transitional land use types. Unfortunately, pasture land with this artificial texture appears very much like idle land. This confusion can be a problem in breaking down land use beyond broad classes.

All major roads and secondary roads are clearly visible, as are utility corridors. However, woods roads are difficult to see and secondary roads are not resolved where they pass through areas of little contrast—agricultural land, primarily.

Ground Truth

Ground truth for the forest inventory studies came from a number of sources. High-altitude aircraft (RB-57) color infrared (CIR) photography, Forest Survey ground sample data, and field checks were used independently, or together, as a basis for evaluating Skylab data interpretation. Because we lacked ground observations and aerial photography for these studies taken at the time of the Skylab pass, November 30,

1973, we had to rely very heavily on the RB-57 high-altitude CIR photography taken on April 25, 1974. The quality of these photographs was excellent.

In the forest resource evaluation study we used 16-point photo cluster classifications made in 1971 on Agricultural Stabilization and Conservation Service (ASCS) panchromatic photographs, and a subsample of these clusters on the ground. These photographic and ground classifications included first- and second-level information for land use and forest stratification. Because these data were 2 years old at the time of this study, subsamples of locations were checked on the April 1974 CIR photographs, which were taken within 5 months after the Skylab pass. With only minor differences in agricultural use, the ASCS photographs reflected land use conditions at the time of the Skylab pass and showed where changes had occurred since the ground data were collected.

The ground truth for the forest sampling design study was derived from the April 1974 CIR photography and a ground check in December 1974 that included nearly 20 percent of the county.

Initial ground truth for the automated land classification study was obtained by using the April 1974 CIR photography. Photographs were selected from the coverage for two 10,000-meter-square (6.2-mile-square) sample blocks to be used in developing and testing digitized Skylab film densities for land classification. These two blocks were located by random selection from the total number of 10,000-meter Universal Transverse Mercator (UTM) intersections within the four-county test site.

Ground truth maps were made for the two sample blocks in the following way:

1. The photo for each sample block was mounted on a Zoom Transfer Scope and enlarged five times to match a USGS 1:24,000 quadrangle sheet used as control (*fig. 3*). A 1000-meter (0.62-mile) grid template (10-by-10 grid) was placed over the outlined block in the control map to facilitate mapping.

2. Four forest and 27 nonforest classes (Level III) were delineated within each grid cell.

3. In five randomly selected cells, forest land was further subdivided into three stand-size classes: (1) seedlings and saplings, (2) poles, and (3) sawtimber. Recognition of the classes was based on a combination of crown closure, crown size, amount of bare soil, and arrangement of vegetation. These refined delineations were needed to explain discrepancies in automated classification.

In early December 1974, we visited the test site to check map classifications and to observe conditions

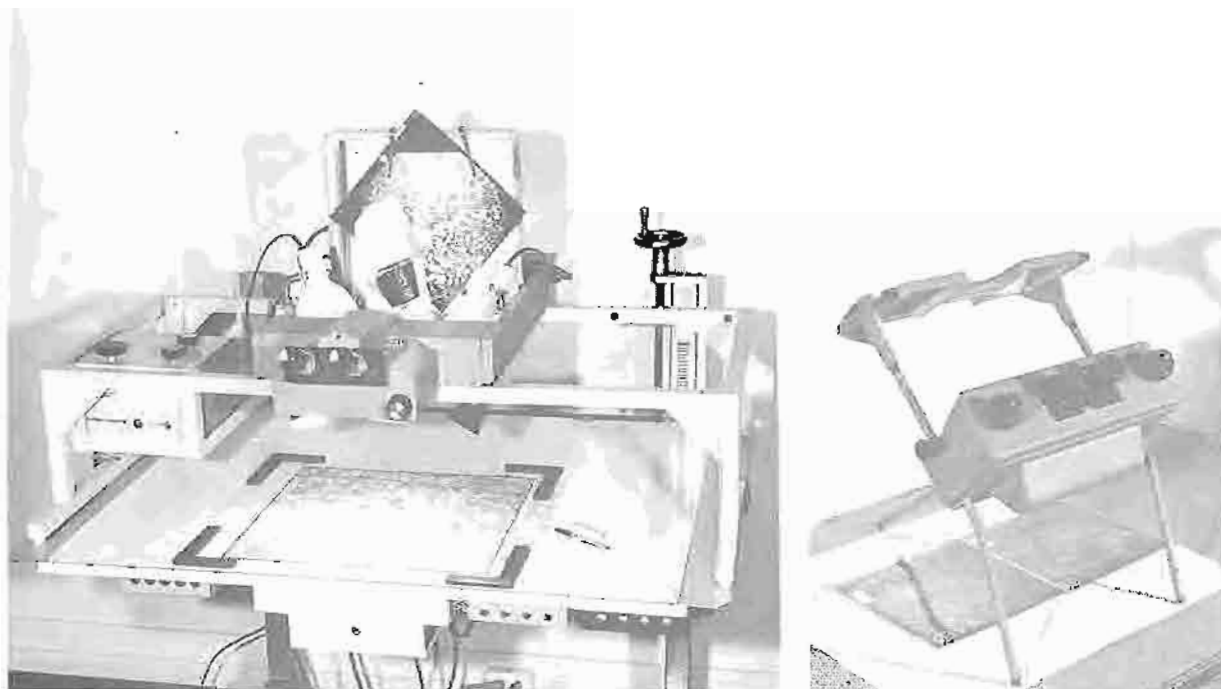


Figure 3—Zoom Transfer Scope (*left*) was used to interpret and transpose forest and related land use classes from 1:120,000 CIR photographs to a map control base. This instrument was also used to verify Skylab interpretations on 1:120,000 scale CIR photographs. An Old Delft scanning stereoscope (*right*) was used at 4X power to interpret overlapping 1:500,000 scale enlargements of S190B color photographs with stereoscopic effect.

that could affect land use interpretation. To aid in this effort, enlargements of the CIR aerial photographs were made on which land use, forest conditions, and other observations could be recorded directly in the field. Several photographic examples of local forest management practices that were found to affect image interpretation are shown in *figure 4*. Examples of land use on Skylab and high-altitude CIR were used in photointerpretation aids (*fig. 5*).

Finally, after the ground checks had been completed, the ground truth maps were adjusted and corrected where necessary. The maps were photographed and both prints and film overlays made to the scale of digital maps produced by the computer-assisted classification procedures. The map for block 4 was used to develop training sets for the computer classification algorithm and the map for block 2 was used to test the system once it was developed.

Procedures

Procedures used for the forest resource evaluation study differed from those for the sampling design study because the objectives were different. One

study was geared to the current photo procedures used by the Forest Survey in the Southeastern United States (U.S. Forest Serv. 1968, pt. 1, p. 1-6). The other was designed to develop the test computer techniques for sampling digitized remote sensing data recorded on computer-compatible tapes.

Forest Resource Evaluation

To evaluate Skylab photographic imagery as a source of first-level information, we adopted the Forest Survey procedure followed in the 1971 inventory of the State of Georgia. This procedure included computing the regression coefficients for the relationship between photointerpretation results and ground truth for land use classes. First, an interpreter examined points in a design printed on 1:20,000 scale panchromatic aerial photographs purchased from the Agricultural Stabilization and Conservation Service (ASCS). The design consisted of 25 clusters of 16 points (4 by 4) in a systematic pattern on each photograph. Each point in a cluster represented a circular 0.4-hectare (1-acre) plot and was classified into one of five classes—(1) forest land, (2) urban and other,

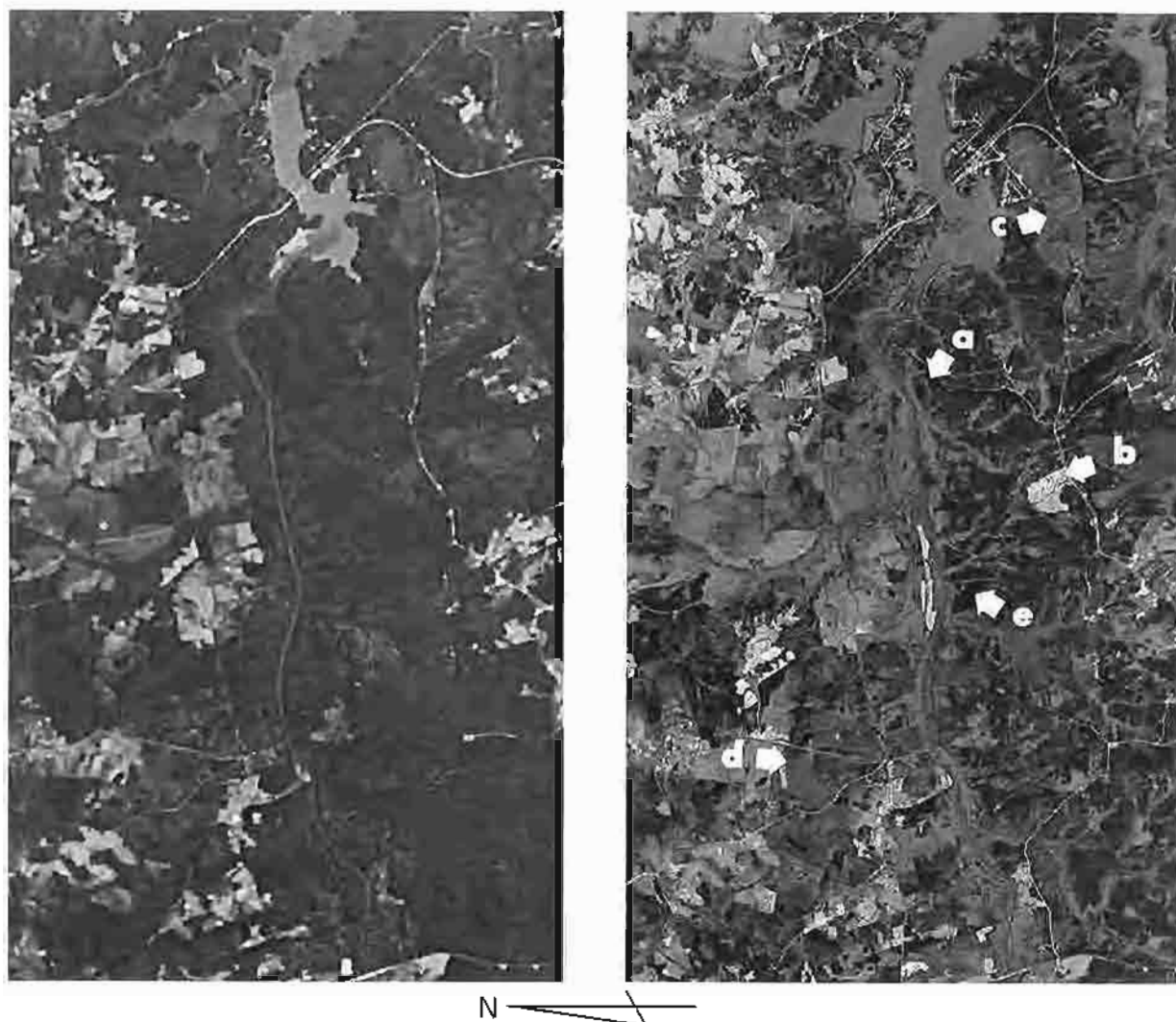


Figure 4—Forest management and other land use practices caused variations in image patterns on Skylab photographs. Examples are shown in the Skylab photo (*left*) and a corresponding CIR aerial photo (*right*), at a scale of 1:120,000. Intensive management of loblolly pine involves pure, even-aged stands. The stand at (a) has an average height of 19.8 meters (65 ft) and d.b.h. of 22.9 centimeters (9 in). These stands are the darkest images in the photograph with the exception of water and shadows. The clearcut area at (b) shows that debris has been windrowed and burned, and the soil harrowed for machine planting. Pioneering weeds and hardwood reproduction have not yet invaded the areas between rows. In (c) the pioneering species have filled in spaces between pine seedlings. Sometimes logging debris is still visible in windrows (d) because sapling-size pines are not large enough to completely cover the ground. Thinning operations before stand maturity remove every other row and appear as in (e).

(3) census water, (4) noncensus water, and (5) other miscellaneous land uses (a grouping of five agricultural classes). This sample was designed to estimate forest area within a sampling error of ± 3 percent per million acres (404,858 hectares).

After interpretation was completed, a subsample of photo clusters was selected for ground examination at the time of the inventory. Each point in the clusters was located on the ground with the aid of the

photographs, and the individual land use class was determined according to the Forest Survey hierarchical classification (*table 1*). Because the photographs, taken in 1967, were 5 years old at the time of the inventory, the subsample provided information that reflected changes.

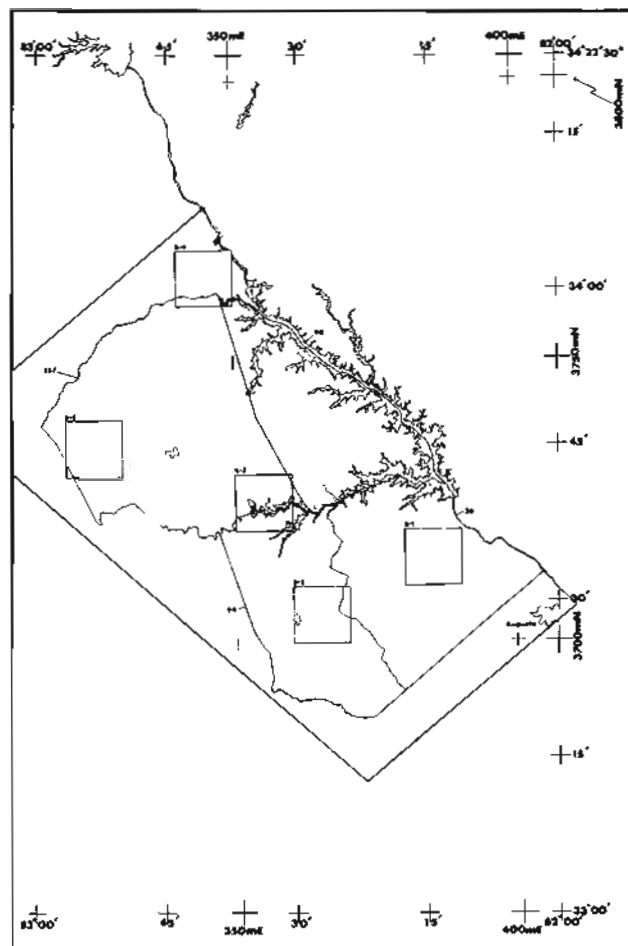
From the photograph and corresponding ground-cluster classifications, the regression coefficients were computed for each land use class in the five-class



Skylab S190A multiband composite, Sept. 12, 1973



Skylab S190B color photograph, Nov. 30, 1973



Augusta site map

Figure 2—The Augusta site, used for evaluating Skylab data in forest inventory, includes four counties. Two intensive study sites (2 and 4) were used for computer-assisted mapping with digitized photographic film densities. The Skylab S190A multiband composite for September 12, 1973, and the Skylab S190B color photograph for November 30, 1973, were used in the data analysis. Photographic scale is approximately 1:850,000.



Table 1—A land-use hierarchy¹ for forest resource evaluation

Classification	Definition
Forest Land	Areas 0.4 hectare (1 acre) or larger, capable of supporting more than 10 percent cover by forest trees and not developed for nonforest use.
Cropland	Land currently being utilized to produce agricultural crops that are harvested directly and not indirectly as pasture forage consumed by livestock.
Idle farmland	Former cropland, orchards, improved pasture, and farm sites not tended within the past 2 years and presently less than 10 percent stocked with trees.
Improved pasture	Land currently being improved for grazing by cultivation, seeding, irrigation, or clearing of brush and trees.
Grassland	Land other than improved pasture on which the primary natural cover is grass and forbs.
Other agriculture	All other farmland not used for crops, idle, or pasture. Includes farmstead, buildings, and service areas.
Marsh and swampland	Land temporarily or partially covered by water, and poorly drained land capable of supporting more than 10 percent cover of swamp vegetation (marsh grasses, cattails, etc.). Does not include spruce bogs, cypress land, or other hydric forest sites.
Urban and other areas	Areas within legal boundaries of cities and towns; suburban areas developed for residential, industrial, or recreational purposes; schoolyards; cemeteries; roads; railroads; airports; beaches; powerlines and other rights-of-way; or other nonforest land not included in any other specific land class.
Census water	Streams, sloughs, estuaries, and canals more than 0.2 kilometers (1/8 statute mile) in width; and lakes, reservoirs, and ponds more than 16.2 hectares (40 acres) in area.
Noncensus water	Streams, sloughs, estuaries, and canals less than 0.2 kilometer (1/8 statute mile) in width; and lakes, reservoirs, and ponds less than 16.2 hectares (40 acres) in area. Minimum width of streams, etc., and minimum diameter of lakes, etc., are 9.1 meters (30 feet).

¹U.S. Forest Service 1974.

²U.S. Forest Service 1968, Definition of Terms, p. D-1 through D-9.

negative, 1:500,000 and 1:250,000 enlargements were made on color transparency film. These films were used in combination with S190B color transparencies for forest and land use classification; however, the lower resolution and graininess of the S190A composite caused eye fatigue, and the effect was to increase interpretation time. Although the spectral information was helpful in making land use and forest-type decisions, we concluded that high-resolution CIR film from the S190B earth terrain camera would have been much more useful. We did not use the S190A CIR or color films in our analysis because, after a careful review of the materials, we felt that they contained only redundant information and at a lower resolution than the S190B imagery.

The S190A multiband photography for SL4 (November 30, 1973) could not be used in the anal-

ysis because the films had been exposed without filters.³

Of the two sets of color photographs produced by the S190B terrain camera, only the SL-4 (November 30, 1973) could be effectively used. The SL-3 photographs (September 12, 1973) were low in contrast, showed a general haze condition, and did not include overlap for stereoscopic viewing. The SL-4 photographs, on the other hand, were taken on a clear day, contained reasonably good contrast between land uses and forest conditions, and had 60 percent overlap for stereoscopic viewing. We found this photog-

³ National Aeronautics and Space Administration. 1974. *Skylab program, sensor performance report, vol. 1 (S190A)*, MSC-05528. NASA L. B. Johnson Space Center, p. 3-6d.

Table 2—A land use classification hierarchy for remote sensing and ground information sources compatible with current nationwide forest resource evaluation objectives. Color definitions are based on high-altitude color infrared photography and simulated color infrared composites of LANDSAT data.

Classification	Color definitions (based on Munsell 1920-60, NBS 1955)
I FOREST LAND	
II Conifer	
II Pine	
Pine-hardwood	
IV Seedling and sapling	Density of conifer stands, number of hardwoods mixed in stand, and stand size influence color value and chroma. Dense stands are darker with less chroma. In the fall, before advanced hardwood coloration and leaf fall, conifer stands appear dark purplish red. Separation between conifer and hardwood classes is less distinct in fall than in winter or early spring. Where hardwoods and conifers are mixed in stands, hardwood color predominates, and stand is usually classified as hardwood. In spring before hardwoods are foliated, conifers appear moderate to dark purplish red. Seedlings and saplings on prepared sites appear lighter than poles and mature sawtimber with closed canopies.
Poles	
Sawtimber	
II Deciduous hardwood	
III Upland hardwood	Stands appear moderate grayish purplish red in fall and pale purple to moderate purplish red in spring. In fall, upland hardwoods cannot be distinguished from bottomland hardwoods. In spring, before foliation, upland hardwoods appear pale purple to light grayish purplish red. Bottomland hardwoods are generally a moderate purplish red. Stand size class (texture), density of crown canopy, and ground cover influence color value, density, and chroma but to a lesser extent than in conifer stands.
Bottomland hardwood	
IV Seedling and sapling	
Poles	
Sawtimber	
I NONFOREST LAND	
II Grassland	Grassland appears deep pink in both fall and spring; sometimes mistaken for immature cropland in spring.
III Undisturbed grass	
Disturbed grass	
Dead grass (annual)	
New improved grass	
II Cropland	Mature crops in fall appear bluish gray to grayish blue. In spring, immature crops appear deep pink and may be mistaken for grassland.
III Immature grain	
Immature crop	
Mature crop	
Harvested crop	
Orchard	
Farmsteads	
II Bare Soil	In fall and spring bare soil appears cream colored on LANDSAT imagery. There is no distinction between plowed agricultural fields and sites prepared for new commercial developments. Generally in spring most areas of bare soil are newly plowed fields either recently or soon-to-be planted.
III Plowed fields	
Erosion	
Urban (site preparations)	
Rock outcrop	
II Wild vegetation	In fall, areas range from grayish purple of idle land to grayish purplish red of abandoned land to deep pink of Kudzu vine. Marsh and alder swamps are a moderate purple because of wet background. In spring, idle land becomes light grayish red to dark pink because of influx of new infrared-reflectant vegetation. Abandoned-transitional land (reverting to forest), on the other hand, is grayish purplish red and marsh and alder swamps are grayish violet. Deciduous Kudzu vine, purplish gray in the spring, easily separates itself from all other vegetation when fall and spring images are viewed together.
III Idle land	
Abandoned land	
Transitional	
Kudzu	
Marshland	
Alder swamp	
II Urban	Areas are light blue in the fall and very pale blue in the spring. Unfortunately, because of low resolution of LANDSAT data, secondary roads, minor roads, and most utility lines are not resolved.
III Transportation & utilities	
Home developments	
Recreation	
I WATER	
II Water	Water is dark greenish blue in fall and light greenish blue in spring. Farm ponds of less than .4 hectare (1 acre) can be seen on LANDSAT images if there is sufficient contrast with background.
III Clear lakes & ponds	
Turbid lakes & ponds	
Rivers & streams	

raphy most useful for forest inventory purposes because (1) a single photograph includes 8 to 10 counties, (2) a photograph can be enlarged to 1:125,000 without loss of information, and (3) a scaled map overlay of county boundaries can be used on the photograph without serious photographic distortion problems.

Generally speaking, forest land can be easily separated from nonforest land on S190B color photographs. There are some conflicts, however, where shadows, small bodies of water, streams, and idle land appear. Where forest land borders on nonforest land, shadows cast by timber stands on west- and north-west-facing edges blend with the forest and can cause misclassification bias in favor of forest land. Small bodies of water within forested areas are not easily separated from the surrounding forest—particularly pine forest—because, to the eye, both features have the same density and hue. Although small bodies of water within hardwood stands show more contrast with surrounding features, they too can be misinterpreted as pine. Idle land in many instances appears very similar to abandoned land stocked with hardwood and pine saplings. The difference is very subtle and can cause a bias in favor of forest land.

Pine land is easily separated from the deciduous hardwoods in November. The separation is made by density (tone) and hue to a limited extent. Pine is much darker than the leafless deciduous forest, and the ground cover under the deciduous forest is a gray-green. Because of a limited range in color hues, pasture, cropland, idle land, and wild range are difficult to separate. Graininess of the film gives the impression of texture that interpreters look for in idle, abandoned, or transitional land use types. Unfortunately, pasture land with this artificial texture appears very much like idle land. This confusion can be a problem in breaking down land use beyond broad classes.

All major roads and secondary roads are clearly visible, as are utility corridors. However, woods roads are difficult to see and secondary roads are not resolved where they pass through areas of little contrast—agricultural land, primarily.

Ground Truth

Ground truth for the forest inventory studies came from a number of sources. High-altitude aircraft (RB-57) color infrared (CIR) photography, Forest Survey ground sample data, and field checks were used independently, or together, as a basis for evaluating Skylab data interpretation. Because we lacked ground observations and aerial photography for these studies taken at the time of the Skylab pass, November 30,

1973, we had to rely very heavily on the RB-57 high-altitude CIR photography taken on April 25, 1974. The quality of these photographs was excellent.

In the forest resource evaluation study we used 16-point photo cluster classifications made in 1971 on Agricultural Stabilization and Conservation Service (ASCS) panchromatic photographs, and a subsample of these clusters on the ground. These photographic and ground classifications included first- and second-level information for land use and forest stratification. Because these data were 2 years old at the time of this study, subsamples of locations were checked on the April 1974 CIR photographs, which were taken within 5 months after the Skylab pass. With only minor differences in agricultural use, the ASCS photographs reflected land use conditions at the time of the Skylab pass and showed where changes had occurred since the ground data were collected.

The ground truth for the forest sampling design study was derived from the April 1974 CIR photography and a ground check in December 1974 that included nearly 20 percent of the county.

Initial ground truth for the automated land classification study was obtained by using the April 1974 CIR photography. Photographs were selected from the coverage for two 10,000-meter-square (6.2-mile-square) sample blocks to be used in developing and testing digitized Skylab film densities for land classification. These two blocks were located by random selection from the total number of 10,000-meter Universal Transverse Mercator (UTM) intersections within the four-county test site.

Ground truth maps were made for the two sample blocks in the following way:

1. The photo for each sample block was mounted on a Zoom Transfer Scope and enlarged five times to match a USGS 1:24,000 quadrangle sheet used as control (*fig. 3*). A 1000-meter (0.62-mile) grid template (10-by-10 grid) was placed over the outlined block in the control map to facilitate mapping.

2. Four forest and 27 nonforest classes (Level III) were delineated within each grid cell.

3. In five randomly selected cells, forest land was further subdivided into three stand-size classes: (1) seedlings and saplings, (2) poles, and (3) sawtimber. Recognition of the classes was based on a combination of crown closure, crown size, amount of bare soil, and arrangement of vegetation. These refined delineations were needed to explain discrepancies in automated classification.

In early December 1974, we visited the test site to check map classifications and to observe conditions

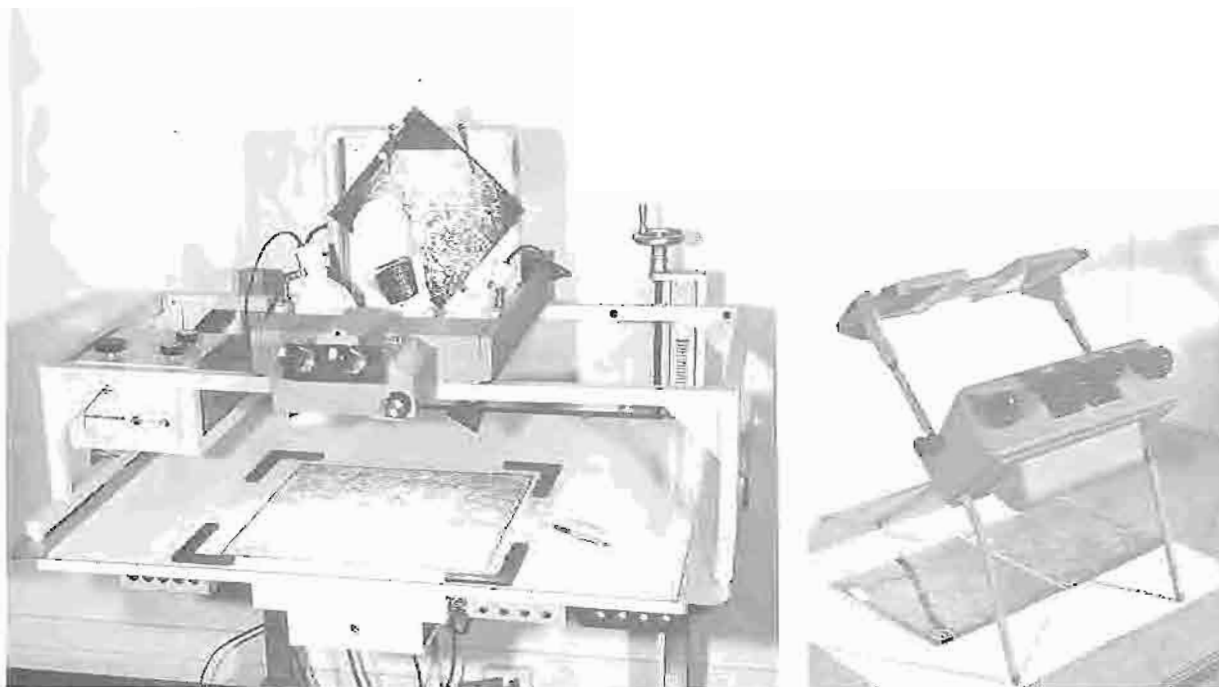


Figure 3—Zoom Transfer Scope (*left*) was used to interpret and transpose forest and related land use classes from 1:120,000 CIR photographs to a map control base. This instrument was also used to verify Skylab interpretations on 1:120,000 scale CIR photographs. An Old Delft scanning stereoscope (*right*) was used at 4X power to interpret overlapping 1:500,000 scale enlargements of S190B color photographs with stereoscopic effect.

that could affect land use interpretation. To aid in this effort, enlargements of the CIR aerial photographs were made on which land use, forest conditions, and other observations could be recorded directly in the field. Several photographic examples of local forest management practices that were found to affect image interpretation are shown in *figure 4*. Examples of land use on Skylab and high-altitude CIR were used in photointerpretation aids (*fig. 5*).

Finally, after the ground checks had been completed, the ground truth maps were adjusted and corrected where necessary. The maps were photographed and both prints and film overlays made to the scale of digital maps produced by the computer-assisted classification procedures. The map for block 4 was used to develop training sets for the computer classification algorithm and the map for block 2 was used to test the system once it was developed.

Procedures

Procedures used for the forest resource evaluation study differed from those for the sampling design study because the objectives were different. One

study was geared to the current photo procedures used by the Forest Survey in the Southeastern United States (U.S. Forest Serv. 1968, pt. 1, p. 1-6). The other was designed to develop the test computer techniques for sampling digitized remote sensing data recorded on computer-compatible tapes.

Forest Resource Evaluation

To evaluate Skylab photographic imagery as a source of first-level information, we adopted the Forest Survey procedure followed in the 1971 inventory of the State of Georgia. This procedure included computing the regression coefficients for the relationship between photointerpretation results and ground truth for land use classes. First, an interpreter examined points in a design printed on 1:20,000 scale panchromatic aerial photographs purchased from the Agricultural Stabilization and Conservation Service (ASCS). The design consisted of 25 clusters of 16 points (4 by 4) in a systematic pattern on each photograph. Each point in a cluster represented a circular 0.4-hectare (1-acre) plot and was classified into one of five classes—(1) forest land, (2) urban and other,

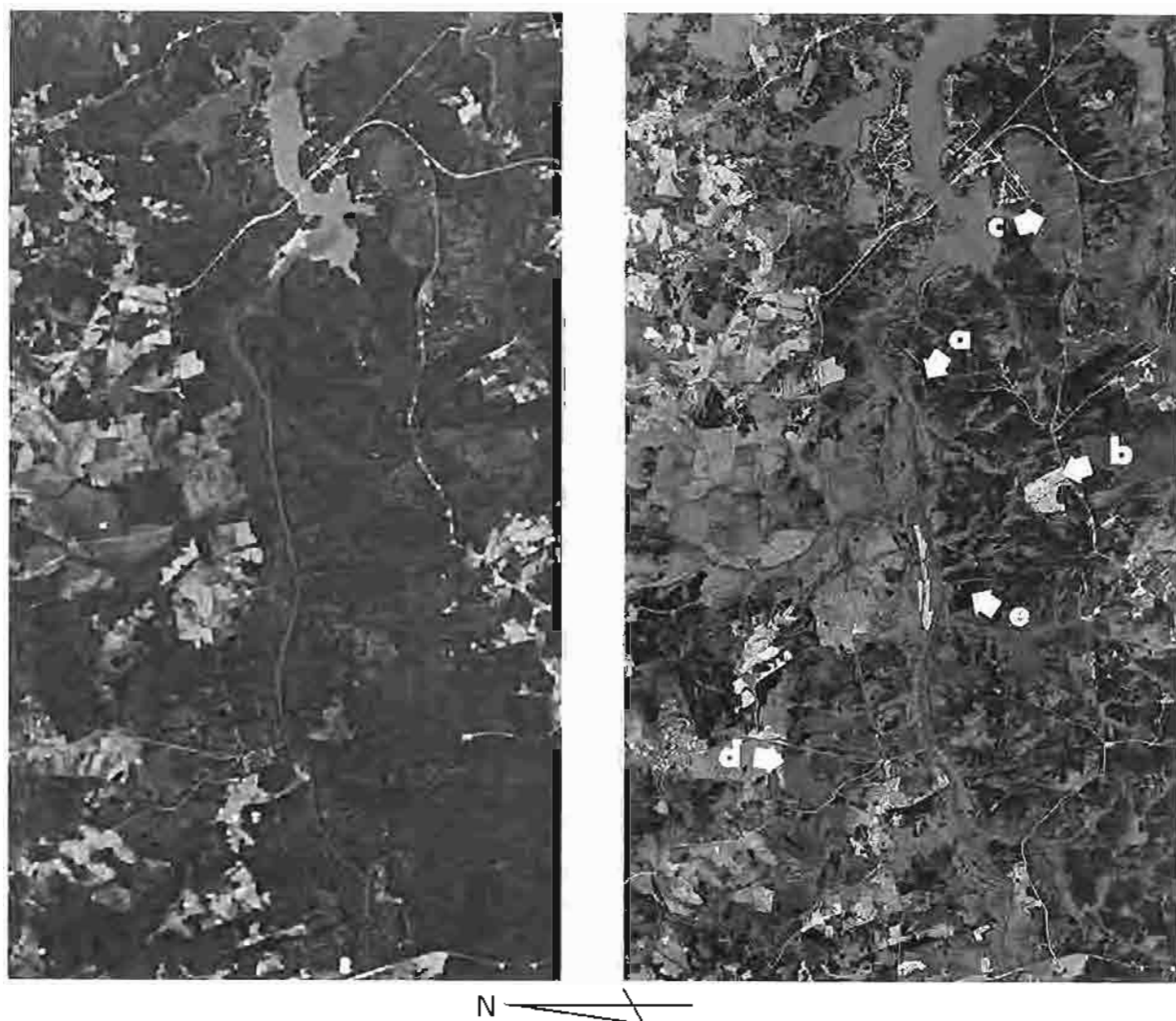


Figure 4—Forest management and other land use practices caused variations in image patterns on Skylab photographs. Examples are shown in the Skylab photo (left) and a corresponding CIR aerial photo (right), at a scale of 1:120,000. Intensive management of loblolly pine involves pure, even-aged stands. The stand at (a) has an average height of 19.8 meters (65 ft) and d.b.h. of 22.9 centimeters (9 in). These stands are the darkest images in the photograph with the exception of water and shadows. The clearcut area at (b) shows that debris has been windrowed and burned, and the soil harrowed for machine planting. Pioneering weeds and hardwood reproduction have not yet invaded the areas between rows. In (c) the pioneering species have filled in spaces between pine seedlings. Sometimes logging debris is still visible in windrows (d) because sapling-size pines are not large enough to completely cover the ground. Thinning operations before stand maturity remove every other row and appear as in (e).

(3) census water, (4) noncensus water, and (5) other miscellaneous land uses (a grouping of five agricultural classes). This sample was designed to estimate forest area within a sampling error of ± 3 percent per million acres (404,858 hectares).

After interpretation was completed, a subsample of photo clusters was selected for ground examination at the time of the inventory. Each point in the clusters was located on the ground with the aid of the

photographs, and the individual land use class was determined according to the Forest Survey hierarchical classification (table 1). Because the photographs, taken in 1967, were 5 years old at the time of the inventory, the subsample provided information that reflected changes.

From the photograph and corresponding ground-cluster classifications, the regression coefficients were computed for each land use class in the five-class

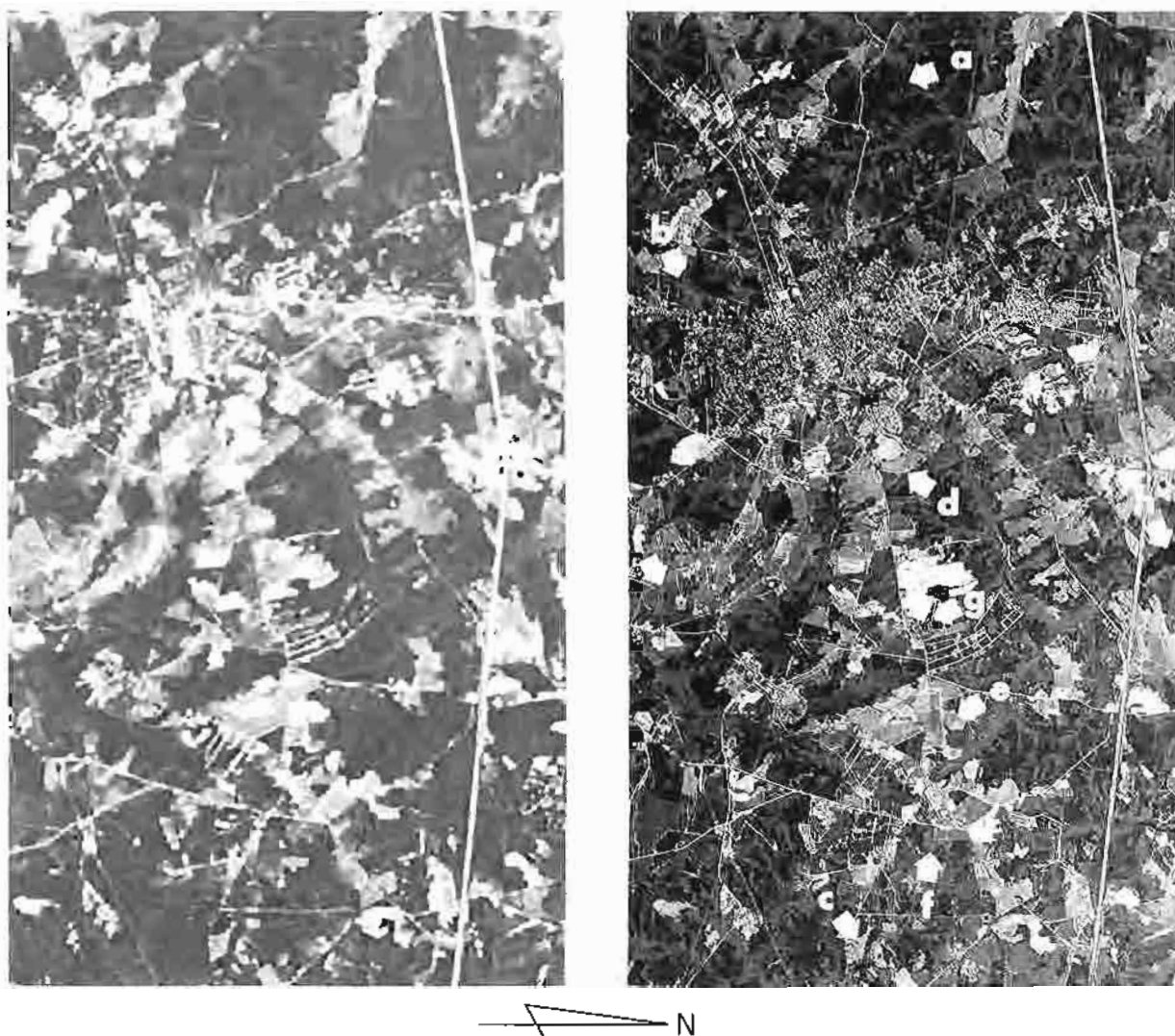


Figure 5—A Skylab photograph (left) and a 1:120,000 CIR photograph (right) were used in interpretation aids to illustrate the forest and related land use classes: (a) pine forest, (b) hardwood forest, (c) grassland, (d) cropland, (e) bare soil, (f) wild vegetation, (g) urban, and (h) water.

grouping. The proportions of points in the clusters were used as continuous variables in the computation.

Our evaluation of Skylab photographic imagery followed the Forest Survey procedure closely. All photo subsample clusters located on 1:20,000 ASCS photographs had to be located on Skylab photographs and the points classified by individual land use. This was accomplished using an Old Delft stereoscope (fig. 3), a scaled cluster template, and a photo illuminator.

Three separate evaluations were made. In the first, Lincoln County was used to test three combinations of Skylab photographic data to find the one most suitable for the remaining evaluations:

Combination 1: 1:250,000 enlargement of an

S190B color photograph (November 30, 1973) made at PSW, and a 1:250,000 enlargement of an *S190A* false-color combination (September 12, 1973) made at PSW. Interpretation was without stereoscopic effect.

Combination 2: 1:500,000 enlargement of an *S190B* color photograph (November 30, 1973) made by NASA/JSC, and a 1:500,000 enlargement of an *S190A* false-color combination (September 12, 1973) made at PSW. Interpretation was without stereoscopic effect.

Combination 3: 1:500,000 enlargement of an *S190B* color photograph (November 30, 1973) made by NASA/JSC, and an overlapping enlargement of an *S190B* color photograph (November 30, 1973) made

by NASA/JSC. Interpretation was with stereoscopic effect.

Forty 16-point photo clusters that had been subsampled on the ground in the 1971 forest inventory were located and interpreted, and the individual land use at each point was recorded. For the center point only, in each cluster, an additional record was made of stand origin, physiographic site, forest type, and disturbance class. This center point corresponds to the plot center used on the ground to record tree and stand conditions. A record of interpretation time was kept for each set of data. The data were then tabulated and processed by computer to determine differences between the three sets and to learn which compared most favorably with the ground truth.

A second evaluation of Skylab photographic imagery was made for the four-county area, using only combination 3, the NASA/JSC 1:500,000 scale color enlargements. We chose this only partly because it gave acceptable results on the first evaluation. In addition, we found that with this combination, the interpretation was faster, and the interpreter felt more confident of his classifications because the stereoscopic effect was helpful in making borderline decisions and the images were sharper.

In this second evaluation we located and interpreted all 210 16-point clusters in the four-county area by procedures identical to those used for the first evaluation. Classifications made on ASCS photography, on Skylab imagery, and on the ground were analyzed by both grouped and individual land use classes.

In the third and final evaluation, Lincoln County was used as a case study to test the hypothesis that Skylab photographic data could be used in the Forest Survey procedure to measure forest area within specified accuracy limits. For this evaluation, a 1:125,000 enlargement was made of one Skylab S190B photograph that covered the entire test site. A grid overlay of 16-point clusters was constructed to sample the photograph at an intensity very similar to that used by the Forest Survey Unit. The boundary of Lincoln County was drawn from a 1:250,000 USGS map sheet and an overlay was made to the scale of the photo enlargement. Interpretation was completed using a lamp magnifier. The grouped land use class was recorded for each cluster point. Forest type and disturbances were recorded for the cluster center. Time to complete interpretation was recorded for cost effectiveness analysis.

Using the proportions in each cluster as a continuous variable, computations were made for each grouped land use class in the photo sample according

to procedures described in the Forest Survey Manual for the Southeast. Terms used in the computations were

- x = proportion of land use in a photo (ASCS) subsample cluster
- y = proportion of land use in a ground or Skylab subsample cluster
- p = proportion of land use in the photo sample cluster
- P = adjusted land use proportion in county
- a = regression constant
- b = regression slope coefficient
- n = number of clusters in subsample
- m = total number of photo clusters
- N = total number of sampling units in the population
- L = adjusted area in land use class
- A = total area being sampled

and

$$SS_y = \text{corrected sums of squares of } y \\ = \sum y^2 - \frac{(\sum y)^2}{n}$$

$$SS_x = \text{corrected sums of squares of } x \\ = \sum x^2 - \frac{(\sum x)^2}{n}$$

$$SP_{xy} = \text{corrected sums of squares of cross products} \\ = \sum xy - \frac{(\sum x)(\sum y)}{n}$$

$$s_y^2 = \text{variance of } y \\ = \frac{SS_y}{n-1}$$

Computations were made for

1. The mean proportions for individual land use classes using ground or Skylab data

$$\bar{y}_j = \frac{\sum_{i=1}^n (y_{ij})}{n}$$

in which

- y_{ij} = proportion of the i^{th} cluster in land use class j
- $\bar{y}_j$ = mean proportion in land use class j

2. The mean proportions for grouped land use classes using ASCS, Skylab, and ground data

$$\bar{y}_k = \frac{\sum_{j=1}^n (y_{jk})}{n}$$

in which:

- y_{jk} = proportion of the j^{th} cluster in grouped land use class k
- $\bar{y}_k$ = mean proportion in grouped land use class k

3. Regression constant (a) and slope coefficient (b) as follows: for (1) the relationship between land use proportions on ASCS photographs and the corresponding proportions on the ground, (2) the relationship between land use proportions on the ground and the corresponding proportions on Skylab photography, and (3) the relationship between land use proportions on ASCS photographs and the corresponding proportions on Skylab photographs. The equation for adjusting land use proportions took the form

$$P = a + b (\bar{p})$$

4. The squared standard deviation from the regression for each method

$$s_{y \cdot x}^2 = \frac{SS_y - \frac{(SP_{xy})^2}{SS_x}}{n-2}$$

5. The adjusted area for each combined land use class for each method

$$L = (P)(A)$$

6. The standard error of the adjusted forest area for each method expressed as a percent

$$s_p = \sqrt{s_{y \cdot x}^2 \left[\frac{1}{n} + \frac{(\bar{p} - \bar{x})^2}{SS_x} \right] \left[1 - \frac{n}{m} \right] + \frac{s_y^2}{m} \left[1 - \frac{m}{N} \right]}$$

$$SE = \left(\frac{s_p}{P} \right) (100) \text{ at the 67-percent level of confidence}$$

Forest Sampling Designs

McDuffie County, in the Augusta site, was used to test the value of using Skylab photographic products in sampling strategies for obtaining Level I and some Level II land use statistics. These statistics are presently obtained for extensive forest inventories from aircraft photography and ground observations.

To provide a data base for evaluating several sampling strategies, a land use map (fig. 6) of the county was made by interpretation of 1:120,000 scale CIR photography from RB-57 Mission 274. All Level I land use classes (forest, nonforest, and water) and two Level II classes (pine and hardwood) were mapped at a scale of 1:50,000 from ZTS interpretation. A control base, enlarged from the 1:250,000 scale USGS Athens, Georgia, quadrangle, was placed on the ZTS mapping table (fig. 3), and class bounda-

ries interpreted from the CIR photo on the easel were drawn on clear acetate overlaid on the map base. This method eliminated cumulative positional errors.

The photography used allowed rather easy, though time-consuming, interpretation into the four land use classes (pine, hardwood, nonforest, water). A ground check which covered nearly 20 percent of the county showed that the only potential classification problem was the distinction between idle farmland and transitional land reverting to forest. The decision on the ground is made on the basis of the density of natural stocking with commercial seedling species. Lands thus classified as forest are often plowed the following season and returned to farmland. Changes back and forth between forest and farmland can be quite rapid in this part of the country.

Besides the 20 percent sampling checked on the ground, 6 percent of the county was intensively mapped on the ground directly onto 1:10,000 scale photo prints, which were used to check the accuracy of the land use classification and correct the map produced from interpretation of high-altitude CIR photography. The resulting land use map is thus an accurate representation of the actual land use on the ground within the limits of the classification system used.

The land use map was used as a data base to try out different sampling strategies and to compare the results of computer classification from microdensitometer scans of a Skylab color transparency. To do this, however, we first had to digitize the map with a Bendix Data Grid. This was done in three steps: (1) a dot grid of 16 dots per square inch, representing approximately 50.3-meter (165-foot) spacing on the ground, was laid over the completed base map, (2) the map and grid overlay were oriented with the digitizer table, and (3) the digitizer Cursor was placed over each grid point and its mapped land use type was keypunched onto magnetic tape. Once the ground truth map was completely digitized and on magnetic tape, each grid point could be relocated on the tape by its line number and position in the line, using a tape-controlled plotting device (fig. 7) and a facsimile map plotted in color. This map could then be used to check against the original hand-drawn map; one data element in the plotted map represents 0.6 hectares (1.5 acres) on the ground.

When the ground truth had been digitized, the next step was to stratify land cover types in McDuffie County on Skylab imagery with a scanning microdensitometer. To determine if stratification would improve the efficiency of sampling, we first tried out a very simple type of land classification for a small

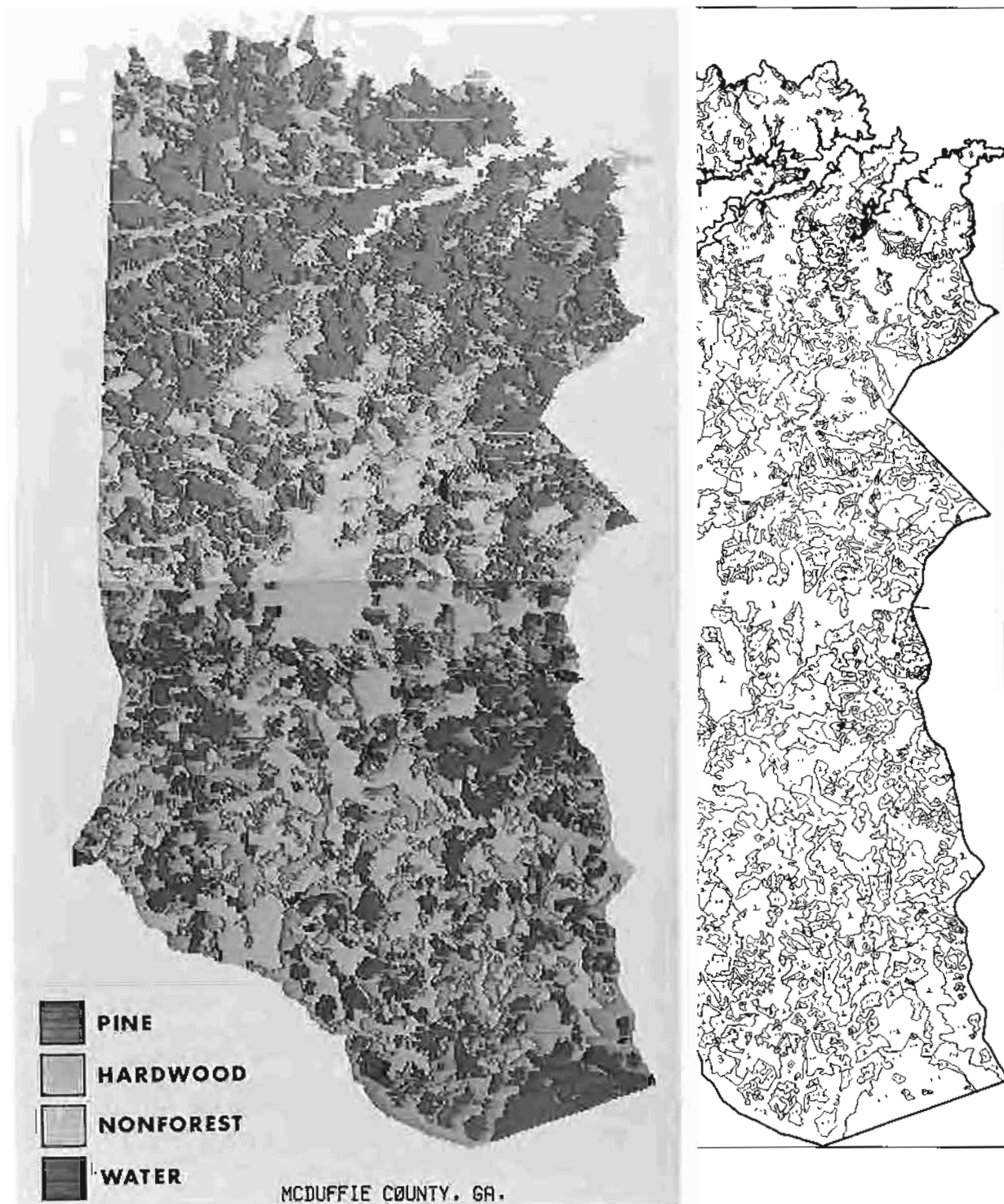


Figure 6—Land use maps of McDuffie County, Georgia, were produced by hand and by machine. The map shown in part at right was produced by conventional interpretation of 1:120,000 CIR photos. Geometric control was obtained by mapping onto a U.S. Geological Survey base map. (Land use classes mapped are 1-1, pine; 1-2, hardwood; 2, forest; and 3, water.) The colored map was produced by digitizing, at a resolution of 0.6 ha (1.5 acres), the hand-mapped data, and replotting with a computer-controlled plotter. The resolution of this map matches that of the microdensitometer data.

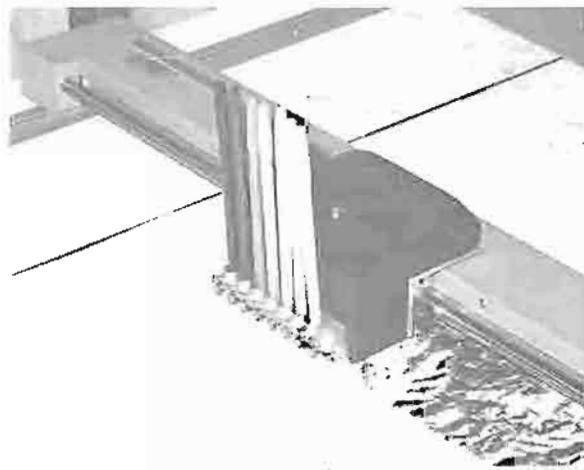


Figure 7—A Photo Data Systems automatic scanning microdensitometer (above) and companion model 2300 process computer were used to read and record film densities on CCT tapes. The Electronic Associates, Inc., tape-driven plotter (below) was used to plot color-coded classification maps.

portion of the county, using density slicing. Using a 9- by 9-inch (1:500,000) S190B color transparency from November 30, 1973 (mission SL-4), we programmed the microdensitometer to scan the selected area with a red filter (Wratten 92), and record film density at the same intervals and in the same matrix used to digitize the hand-drawn ground truth map; that is, in an array of 278 (x) by 539 (y), or 149,842 data elements. Next, using density ranges we had es-

tablished on sample areas before the programmed scanning began, we classified each data point into one of the four land use types. The counterpart of each of these points could then be located on the data tape for the digitized land use map to determine the ground classification.

A facsimile gray-scale map was produced on a line-printer from the red-filtered microdensitometer scan of the Skylab S190B color image. Alphabetic characters were used to represent four optical-density ranges (density slices). These maps are stretched in the y direction because the spacing is greater between rows of characters than between characters along a row. Using this same procedure with digitized data from the ground truth map, we produced a geometrically similar line-printer facsimile for comparison. The two facsimile maps were compared and the registration appeared to be good. Based on this result, we went on to try a more powerful classifier using three spectral bands of microdensitometer data.

A more refined method of classification is linear discriminant analysis, using maximum likelihood and Gaussian assumptions. Training sets were located in the microdensitometer scan data matrices for each of the land use types identified on the ground truth map. Optical densities from the red, green, and blue microdensitometer scans, and generated statistics, were used to develop linear discriminant functions to classify the entire county into land use types from the Skylab data. A facsimile type-map was generated on a line printer using this classification procedure. This type-map is compared with the line-printer ground truth map (fig. 8). The land use map is stratified according to the resulting classification, and sampling effectiveness is compared with random sampling and with systematic sampling.

Having the ground truth map digitized as a regularly spaced grid of data points at 80.5-meter (264-foot) spacing allowed a comparison to be made among simple random sampling (SRS), systematic sampling (SYS), and systematic sampling with postsampling stratification on Skylab data (PSS)—all at 16 different sampling intensities and on a "real" population. Characteristics of the systematic grid sampling at the different intensities are given in table 3. A computer program simulated placing of the grids over the ground truth map at all possible placements for each grid spacing. The percent sampling intensity and ground area per sample point in the table are based on the mean number of sample points falling in the mapped area for each grid spacing.

For each grid spacing the expected values of forest and nonforest proportions and the variance of the

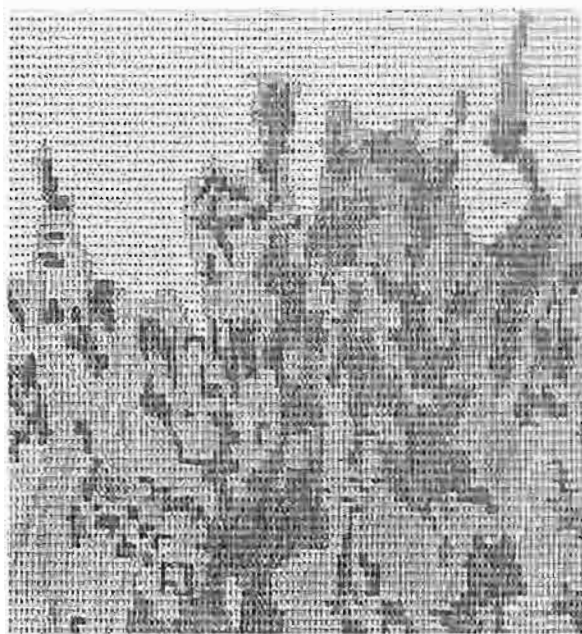
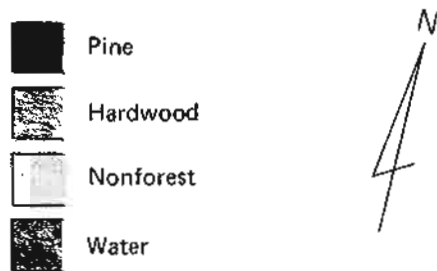
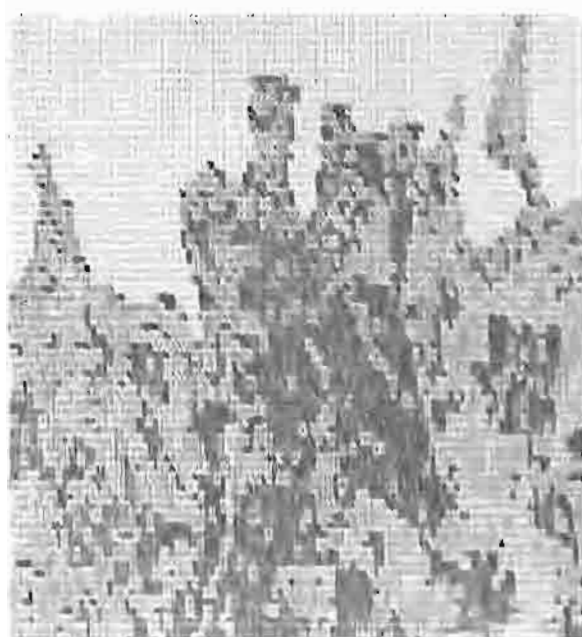


Figure 8—The land use maps shown here cover the northwestern portion of McDuffie County, Georgia, and were used in the test of sampling designs. The "ground truth" map (above) was produced from data digitized from the hand drawn land use map (fig. 6). The other map (below) was produced from the classification of microdensitometer scans on an S190B color transparency. Many nonforest areas, mostly roads or road segments below the minimum mapping size for separation on ground truth map, are shown on the microdensitometer scan map.



estimate were computed for all possible grid placements. From these statistics the sample bias and error of the estimate were measured.

Automated Land Classification

A Photo Data Systems (PDS) microdensitometer and companion Model 2300 process computer (fig. 7), a nearest neighbor classification algorithm developed for LANDSAT data (Aldrich and others 1975), and a CDC 7600 computer at the University of California Lawrence Berkeley Laboratory were used to classify land use in two 10,000-meter-square (6.22-mile-square) study blocks. (A more complete description of the procedure is available on request—see the Introduction.) The study blocks were located on one Skylab S190B color transparency (November

Table 3—Characteristics of grid sizes used to sample data matrix for land use map, McDuffie County, Georgia

Grid spacing (data elements)	Number of sample points	Ground spacing		Sampling fraction	Ground area per sample point	
		Meters	Feet		Hectares	Acres
50	43	4,020	13,189	0.04	1,567	3,873
42	61	3,377	11,078	.06	1,106	2,733
36	82	2,894	9,496	.08	813	2,009
25	171	2,010	6,594	.16	392	969
21	242	1,688	5,539	.23	277	684
18	329	1,447	4,748	.31	203	502
14	544	1,126	3,693	.51	123	304
12	741	965	3,165	.70	90	223
10	1,066	804	2,638	1.00	63	155
9	1,317	724	2,374	1.24	51	126
7	2,176	563	1,846	2.04	31	76
6	2,962	482	1,583	2.78	23	56
5	4,266	402	1,319	4.00	16	39
4	6,665	322	1,055	6.25	10	25
3	11,849	241	791	11.11	6	4
2	26,660	161	528	25.00	3	6

30, 1973). One block was used to develop training sets and forest and nonforest classifiers; the other block was used to test the classifiers on a site some distance from where the classifiers were developed. The study blocks were purposely selected to satisfy two criteria: (1) each had to have a broad representation of land use types with a significant amount of forest and nonforest land and (2) the Skylab photo coverage for each site had to be complete. Boundaries of the two study blocks were delineated on acetate templates. The template was precisely oriented with the photos and fiducial marks; then major highways and other identifiable features were outlined with a fine drafting pen. These templates were used on the microdensitometer to orient the X, Y scans with the block boundaries but were removed before scanning began.

Block 4 was used to develop training sets and classifiers for 16 Level II and Level III forest and nonforest classes to be recognized in the study (table 2). Four scanning apertures (28 μm , 37 μm , 56 μm , and 74 μm) were used, and the microdensitometer was programmed to read densities from the photograph at an interval approximating the aperture diameter. This procedure avoided excessive data integration and redundancy: that is, the smallest area of interest for our classification purposes was 0.4 hectare (1 acre), and the range of aperture settings sampled the 1:900,000 scale photograph in units of effective ground area ranging from approximately 0.05 hectare (0.12 acre) at the 28 μm aperture to 0.35 hectare (0.86 acre) at the 74 μm aperture. The 37 μm aperture sampled approximately 0.09 hectare (0.20 acre).

The microdensitometer was calibrated before each run after the proper aperture setting and optical filter were in position. After each filter run, the filter was changed and the microdensitometer recalibrated. A run for the complete block was made for each aperture setting and for four filter settings—blue (Wratten-94), Green (Wratten-93), red (Wratten-92), and clear (no filter)—before continuing to the next aperture. In addition, a step tablet furnished with the SL-4 data package was scanned before the scanning began and again after the scanning was completed. This made it possible to convert microdensitometer optical density readings to NASA/JSC-PTD diffuse densities. The entire procedure was repeated for each of the four aperture scans.

Originally, we intended to evaluate aperture size by producing an eight-class land use map from each aperture scan. Time limitations would not allow this, however, and we had to modify the plan. Instead, we

produced an eight-level gray-scale map for each aperture scan. From examination of the gray-scale maps, it was apparent that the 37 μm aperture resulted in a ground resolution that best suited the requirements of this study. Classifiers were then developed for the 16 land use classes and applied to the diffuse densities for block 4 using a nearest neighbor classification procedure.

A color-coded land use map was produced on an EAI tape-driven plotter for block 4 (fig. 7). The classifiers developed for block 4 were then extended to the data for block 2 and a plotter map was produced to determine the operational capability of the classification system.

Accuracy of computer classification was checked in two ways. The first method computed the proportional areas in each land use class and compared them with proportions determined from the ground truth map. A second method checked the positional accuracy. That is, the plotter map was overlaid with a systematic grid of 480 points for which the classification on the ground truth map was known. The classification was recorded and compared with its counterpart on the ground. Plotter maps for both blocks were checked in this way and the number of correct calls determined and analyzed. Points falling in five randomly selected 1000-meter cells with detailed classifications were checked to explain any discrepancies.

Results and Discussion

Results of the forest inventory studies—resource evaluation, sampling designs, and automated classification and mapping—varied, and must be compared with caution. Because each of the studies was carried out independently to meet a separate objective, study conditions differed. A recurring source of difficulty, however, was the problem of relating the established classifications used in forest inventory to the actualities of remote sensing data. Such data reveals land cover at a particular time, but does not necessarily indicate the land manager's intention for later use of the land. Ground surveys may determine, for example, that areas lying bare in early spring are in fact designed for agricultural or forest planting, whereas remote sensing can only indicate that the land is bare. A restructuring of land classifications to recognize what is present on the ground, rather than the intended use of the land, would simplify evaluation of the accuracy of remote sensing data for land classification.

Forest Resource Evaluation

The choice of a Skylab data combination for conventional visual interpretation had less effect on accuracy than expected. We reached this conclusion by comparing omission and commission errors for land use classification in one county, using three data combinations (see Procedures). Some omission and commission errors are caused by misinterpretation of the photo images. In many instances, however, the errors are the result of chance judgments. For example, a point falling on a boundary line between forest and cropland may be called "forest" by the interpreter but "cropland" by the field man. Also, the field man may make judgment errors, but they are usually ignored. These facts should be considered in comparing results of the Skylab interpretation with ground truth.

As described in the section on Procedures, combination 3, used to interpret land use in a four-county survey, consisted of overlapping enlargements of S190B color photos produced by NASA, viewed stereoscopically. Scale was 1:500,000.

Four-County Survey—A comparison of individual land use proportions resulting from the four-county survey shows close correlations between Skylab and ground truth for some classes (table 4). Only in pasture and idle land are discrepancies much greater than ± 1 percent. The differences of -6.61 percent for pasture and +4.34 percent for idle land for the most part represent errors in classification—either on the ground or on the Skylab imagery—attributable to several causes. Some represent borderline judgments where a point falls on or near a field boundary; others

reflect seasonal differences between the date of the imagery and the date the field crews located the points, and still others result from changes occurring after the ground data were recorded.

If cropland, pasture, other agriculture, and idle land classes are combined as "other miscellaneous," the difference is less apparent—0.1801 on the ground as compared to 0.1595 on the Skylab data (table 4). Because a major purpose of land use classification in forest resource surveys is to measure the forest area base, some inaccuracies in agricultural land use would not be a drawback—the estimate of forest land would be well within the accuracy limit of ± 3 percent per million acres of commercial forest land. The data do indicate, however, that either "other miscellaneous" is slightly underestimated or there is a real increase in forest and urban area. This problem is discussed further in a later section of this report.

Increases in urban development during the 2-year span between ground and Skylab data acquisition can account for the greater proportion of urban area estimated from Skylab. Noncensus water measured on Skylab normal-color film is underestimated because small bodies of water cannot be distinguished when background contrast is low. This limitation would be overcome using CIR film.

Land use proportions listed by individual counties in table 4 show much greater variation between Skylab and ground data than the grouped county data. The smaller sample size and the peculiarities of sampling are responsible. Normally, if area statistics by county are required, they should be based upon a much larger sample.

Table 4—Summary of individual land use class proportions as determined by ground examination (July 1971) and by interpretation of Skylab photography (November 1973) for four Georgia counties

Land use class	Proportion of land in use class									
	Columbia Co. (n=49)		Lincoln Co. (n=40)		McDuffie Co. (n=44)		Wilkes Co. (n=77)		All counties (n=210)	
	Ground	Skylab	Ground	Skylab	Ground	Skylab	Ground	Skylab	Ground	Skylab
Forest	0.6812	0.7283	0.6984	0.6812	0.6932	0.7088	0.7597	0.7597	0.7158	0.7268
Cropland	.0293	.0268	.0000	.0187	.0909	.0639	.0130	.0381	.0307	.0372
Pasture	.0867	.0166	.1062	.0304	.0582	.0171	.1542	.0811	.1092	.0431
Idle	.0294	.0867	.0110	.0578	.0356	.0852	.0390	.0682	.0307	.0741
Other agriculture	.0128	.0013	.0094	.0062	.0213	.0071	.0008	.0057	.0095	.0051
Other miscellaneous ¹	.1582	.1314	.1266	.1141	.2060	.1733	.2070	.1931	.1801	.1595
Urban	.0816	.0689	.0313	.0625	.0611	.0824	.0227	.0422	.0461	.0607
Census water	.0548	.0574	.1359	.1391	.0341	.0270	.0041	.0049	.0452	.0473
Noncensus water	.0242	.0140	.0078	.0031	.0156	.0085	.0065	.0000	.0218	.0057

¹ Cropland, pasture, idle, and other agriculture classes, grouped.

In this four-county survey of land use classification, we also attempted to classify certain forest conditions useful in resource evaluations: stand origin, physiographic site, forest type, and treatment class. Classification of *stand origin* into two categories, natural and artificial, was unsuccessful. Failure can be attributed to the ground resolution (20 to 30 m or 66 to 98 ft) of the color film. The effect of the ground resolution was to make all stands within types (pine type particularly) look alike.

Physiographic site was classified for 148 forest plots, but the restricted geographical area within the study site placed 90 percent of the plots in one category—rolling upland. Of these plots, 97 percent were correctly classified. No attempt was made to analyze the remaining data because the observations were too few to be relevant to normal operating conditions. It was observed, however, that stereoscopic coverage is essential to successful classification of physiographic site.

Forest types in the four-county area were classified correctly on Skylab S190B color only 50 percent of the time. Accuracies ranged from a low of 16 percent for mixed pine-hardwood to a high of 59 percent for pine. The distribution of 161 plots by Skylab and ground types is shown in *table 5*.

Two conclusions can be drawn from this test. First, mixed pine-hardwood cannot be separated from pine and hardwood with sufficient accuracy to be useful in resource surveys. The problem here is that a pine-hardwood classification is based on the decision rule, "Does pine comprise more than 25 percent but less than 50 percent of the stocking?" This rule can be tested by stem counts on the ground. On photographs, however, the decision must be based on crown counts, which cannot be accomplished at the resolution of the imagery used here. Second, upland and bottomland hardwood cannot be separated on normal-color film except in the most obvious situations. Experience with CIR film, however, indicates that high moisture content in bottomland sites can be detected during late fall, winter, and early spring seasons, with higher classification accuracies as a result.

On Skylab S190B color, forest types must be combined to maximize their usefulness. For instance, when pine and pine-hardwood plots are combined in a single pine class, the accuracy of classification increases to 73 percent—a much more respectable figure. Combining upland and bottomland hardwoods into a single hardwood class improves accuracy to 69 percent.

Treatment classes, redefined as disturbance classes

for remote sensing, were classified for 40 plots in Lincoln County. To compare relative accuracy at three levels of remote sensing, classifications were made on LANDSAT-1, Skylab S190B, and 1:120,000 CIR photographs. The results are shown in *table 6*.

As would be expected, detection varies according to the ground resolution of the sensors and the level of disturbance. The greater disturbances, such as harvesting with artificial regeneration, and clearing or site preparation, are detected on LANDSAT-1 data. However, only 63 percent of the plots were correctly classified on LANDSAT imagery, against 80 percent on both Skylab and the RB-57 imagery. One explanation for failure to detect commercial thinnings and the more subtle disturbances might be the 1½- to 3-year time lapse between the ground observation and the imagery.

One-County Test of Forest Area Estimation—An estimate of the proportion of forest area in Lincoln County was made on a 1:125,000 color enlargement of Skylab S190B (November 30, 1973) using conventional interpretation techniques. As described earlier (Procedures), an overlay with 16-point sample clusters was used for an intensive sampling. The resulting proportion—the number of forest points divided by the total—was adjusted using regression coefficients derived from ground examination of a subsample of the 16-point clusters. The County mean adjusted forest land proportion estimate was compared with existing Forest Survey estimates, which had been determined from ASCS aerial photographs and similarly adjusted. Comparisons were also made between unadjusted grouped land use proportions for Skylab and ASCS, Skylab, RB-57 CIR photographs, and the ground. These comparisons help to evaluate the full potential of the Skylab photography.

The cluster overlay used on Skylab photos for Lincoln County sampled at a slightly higher intensity than the existing Forest Survey design. The Skylab overlay covered the entire county area, whereas the Survey design used every other photograph in alternate flight lines. Our design eliminated the chance of oversampling some classes and undersampling others. The results (*table 7*) show that, according to Skylab, the unadjusted forest proportion is almost 3 percent higher than that obtained from 4-year-old ASCS photographs; also, the "other miscellaneous" class has decreased, urban has increased, and both census water and noncensus water are reduced. These could be real differences detected by the more recent Skylab data and the improved distribution of the photo sample. Unfortunately, there is no way to check this because of the time lapse since the data were collected.

Table 5—Distribution of forest plots by Skylab¹ and ground forest type classes in a four-county area, Georgia (correct calls underscored)

Skylab class	Ground class					Total, Skylab
	Pine	Pine hard-wood	Upland hard-wood	Bottom-land hard-wood	Non-forest	
Pine	<u>54</u>	7	5	1	3	70
Pine-hardwood	20	<u>4</u>	1	1	2	28
Upland hardwood	13	12	<u>13</u>	1	2	41
Bottomland hardwood	1	2	4	<u>4</u>	0	11
Nonforest	3	0	1	<u>1</u>	<u>6</u>	11
Total, ground	91	24	24	8	13	161

¹ Stereoscopic interpretation of overlapping S190B photographs.

Table 6—Accuracy of detecting disturbances by interpretation of data from four sources, Lincoln County, Georgia

Disturbance class	Plots correctly classified			
	Ground	RB-57	Skylab	LANDSAT
No disturbance	22	21	21	19
Prescribed burn	1	0	0	0
Clearing, release, or intermediate cutting	5	4	4	1
High grading	1	0	1	0
Commercial thinning	7	3	2	1
Harvesting with artificial regeneration	1	1	1	1
Clearing of site preparation	1	1	1	1
Natural regeneration on nonforest land	1	1	1	1
Artificial regeneration on nonforest land	1	1	1	1
All classes	40 (100%)	32 (80%)	32 (80%)	25 (63%)

Table 7—Mean proportions for grouped land use classes, computed from an intensive sampling on Skylab and aerial photography, and from a small subsample on Skylab, aerial photography, and ground observation, and used to compute adjusted values (Lincoln County, Georgia)

Data sources	Total clusters	Forest	Other misc.	Urban	Census water	Non-census water
<i>Intensive sample, unadjusted:</i>						
ASCS (1:20,000) ¹	536	0.6472	0.1351	0.0169	0.1725	0.0283
Skylab (1:500,000)	667	.6747	.1201	.0260	.1636	.0150
Difference		+.0275	-.0150	+.0091	-.0089	-.0127
<i>Subsample, unadjusted:</i>						
ASCS	40	.7094	.1313	.0156	.1375	.0062
Skylab	40	.6812	.1151	.0625	.1391	.0031
RB-57 (1:120,000) ²	40	.6984	.1266	.0313	.1359	.0078
Ground	40	.7141	.1250	.0187	.1391	.0031
<i>Intensive sample, adjusted:³</i>						
ASCS	536	.63753				
Skylab	667	.69229				
Difference		+.05476				

¹ Panchromatic aerial photography, by Agricultural Stabilization and Conservation Service.

² High-altitude color infrared aerial photography by NASA.

³ Adjusted using regression equations developed from small subsample. Adjusted forest area and standard error of estimate are 42,123 ha ±3.17 percent for ASCS and 45,741 ha ±3.53 percent for Skylab.

For the 40-cluster subsample examined on Skylab and ASCS photographs and on the ground to classify land use in Lincoln County by grouped classes, the unadjusted forest proportion estimate from Skylab data was almost 2 percent lower than the ground check and 3 percent lower than the ASCS photo estimate (table 7). The latter is a complete reversal from the estimate made from the more intensive sample and reflects differences in the two samples. The subsample apparently fell in areas under development for homes at a greater intensity than the larger sample. The larger proportion of land area estimated in the urban class on both the Skylab photos and the ground seems to indicate this. Interpretation of forested areas within residential developments as urban resulted in an over-estimate of urban and an under-estimate of forest land. Errors of this sort can be avoided by improving the criteria for interpreting urban land.

The 40 subsample clusters were examined on 1:120,000 scale CIR photographs to verify the mean Skylab proportions (table 7). Here forest proportion was found to be more than 3 percent higher and urban 4 percent lower than on the Skylab imagery. This result seems to support the conclusion that urban developments within forested areas are overestimated on Skylab. Because the ground estimate of urban is higher than either Skylab or ASCS, the CIR

estimate can be assumed to be low; the true proportion of urban area is presumably nearer 3 percent.

The adjusted Skylab estimates for forest area, 3600 hectares (8892 acres), were 8.6 percent higher than the ASCS estimates. Despite this, the standard error of the adjusted forest area estimate using Skylab data was ± 3.53 percent—slightly higher than the adjusted estimate on ASCS photography. The difference in the estimates can be attributed to differences in sampling intensity, sample distribution, and misclassification of urban areas as forest land.

Forest Sampling Designs

The area of commercial forest land summarized from the digitized land use map for McDuffie County (hereafter called the ground truth map) and the area of commercial forest from the 1971 Forest Survey agree closely (69.6 percent map, 69 percent Forest Survey). The Forest Survey gives no information, however, on the location of commercial forest and other land use types; therefore, no cross-checks can be made with the ground truth map. The area of noncensus water (defined in table 1) in the county, according to the survey, is less than 2 percent. The mapped area of noncensus water differs from the Forest Survey figure primarily because much of the water was excluded from the land use map where the

Table 8—Bias and variance for estimates of forest proportions made by three sampling methods (SRS, simple random sampling; SYS, systematic sampling; and SYS-PSS, systematic sampling with poststratification) for 16 sampling fractions, McDuffie County, Georgia

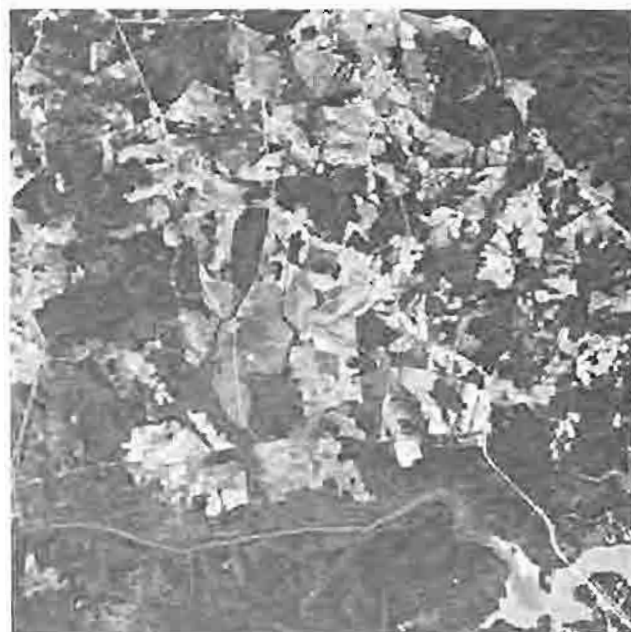
Grid spacing (data elements)	Sampling fraction	Bias of forest proportion			Variance of forest proportion		
		SRS	SYS	SYS-PSS	SRS	SYS	SYS-PSS
	Percent						
50	0.04	0	0.0006	0.0008	0.00495	0.00412	0.00334
42	.06	0	.0000	.0005	.00350	.00278	.00241
36	.08	0	.0002	.0007	.00257	.00231	.00181
25	.16	0	.0001	.0003	.00124	.00075	.00074
21	.23	0	.0000	.0000	.00087	.00057	.00052
18	.31	0	.0000	.0000	.00064	.00035	.00032
14	.51	0	.0000	.0000	.00039	.00015	.00018
12	.70	0	.0000	.0001	.00029	.00014	.00015
10	1.00	0	.0000	.0000	.00020	.00011	.00010
9	1.24	0	.0000	.0000	.00016	.00007	.00008
7	2.04	0	.0000	.0000	.00010	.00004	.00005
6	2.78	0	.0000	.0000	.00007	.00003	.00004
5	4.00	0	.0000	.0000	.00005	.00002	.00002
4	6.25	0	.0000	.0000	.00003	.00001	.00001
3	11.11	0	.0000	.0000	.00002	.00001	.00001
2	25.00	0	.0000	.0000	.00001	.00000	.00001



Ground truth map, Augusta, Ga., block 4; 1:120,000 CIR photo by NASA, April 1974

- | | | |
|-----------------------|-----------------------------|---------------------------------|
| 1 Pine | 12 Harvested crop | 22 Kudzu |
| 2 Pine-hardwood | 13 Orchard | 23 Marshland |
| 3 Upland hardwood | 14 Farmstead | 24 Alder swamp |
| 4 Bottomland hardwood | 15 Plowed field | 25 Transportation and utilities |
| 5 Undisturbed grass | 16 Erosion | 26 Home developments |
| 6 Disturbed grass | 17 Site preparation (urban) | 27 Commercial developments |
| 7 Dead grass | 18 Rock | 28 Recreation |
| 8 New improved grass | 19 Idle land | 29 Clear lakes and ponds |
| 9 Immature grain | 20 Abandoned land | 30 Turbid lakes and ponds |
| 10 Immature row crop | 21 Transitional | 31 Rivers and streams |
| 11 Mature crop | | |

Figure 9—Ground truth, a Skylab photo, and a map made from the Skylab data by computer-assisted methods can be compared point-to-point here. The computer map (*opposite*) was made using diffuse densities converted from optical densities measured on the S190B photograph. The photograph was scanned with a microdensitometer and the optical densities were digitized and recorded on tape. The map was then produced by the computer classification system developed at Pacific Southwest Station, using nearest-neighbor theory and an off-line tape-driven plotter with eight colored marking pens.



Skylab S190B Nov. 1973



Computer map



northern boundary of the county crosses Clark Hill Reservoir, and could not be accurately located. Non-census water, therefore, is included with all other nonforest for stratification purposes in this study.

Linear discrimination functions used to stratify three Level I and two Level II land use types could not separate pine and hardwood with sufficient accuracy for inventory purposes. Thus, all forest land was aggregated into a single forest type for further analysis. The confusion matrix for the training set shows only 5.3 percent of the total forest data elements (506) called nonforest and only 17.7 percent of the total nonforest data elements (615) called forest. For the entire population, 19.5 percent of the total forest data elements (74,290) were called nonforest; 30 percent of the total nonforest data elements (32,351) were called forest. These classifications were used to test systematic sampling with postsampling stratification in the following comparison of sampling methods.

Systematic sampling and simple random sampling for forest proportions are compared in *table 8*. The maximum bias was 0.0006 for the smallest sampling fraction (0.04 percent); for sampling fractions (0.23 percent and greater, the bias was less than 0.00005. The variance for SYS was smaller than for SRS in every case. The advantage increased as the sampling fraction increased.

The systematic sample was repeated, but this time the type-map classified from microdensitometer scans of Skylab imagery was used for postsampling stratification. The biases again were negligible, although larger than for SYS. The variance using SYS and PSS was smaller than for SYS alone for the smallest sampling fractions. At a sampling fraction of 0.04 percent the variance is 19 percent lower than SYS and 50 percent lower than SRS. The advantage of using postsampling stratification with systematic sampling quickly decreases as the sample size is increased.

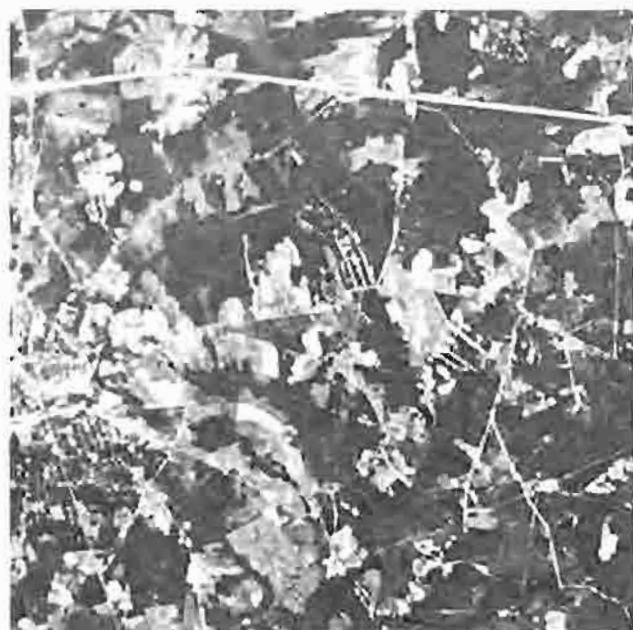
The study has shown that forest area proportion is more efficiently determined using systematic sampling rather than simple random sampling when applied to an area with forest distribution as in McDuffie County, Georgia. The precision of the estimate is further increased by using postsampling stratification from the computer classification of Skylab S190B microdensitometer data. However, there is no advantage when the sampling fraction is larger than 0.16 percent. If it had been possible to direct more effort to developing better discriminant functions for the supervised Skylab data classification, an advantage might have been shown for larger sampling fractions.



Ground truth map, Augusta, Ga., block 2; 1:120,000 CIR photo by NASA, April 1974

1 Pine	12 Harvested crop	22 Kudzu
2 Pine-hardwood	13 Orchard	23 Marshland
3 Upland hardwood	14 Farmstead	24 Alder swamp
4 Bottomland hardwood	15 Plowed field	25 Transportation and utilities
5 Undisturbed grass	16 Erosion	26 Home developments
6 Disturbed grass	17 Site preparation (urban)	27 Commercial developments
7 Dead grass	18 Rock	28 Recreation
8 New improved grass	19 Idle land	29 Clear lakes and ponds
9 Immature grain	20 Abandoned land	30 Turbid lakes and ponds
10 Immature row crop	21 Transitional	31 Rivers and streams
11 Mature crop		

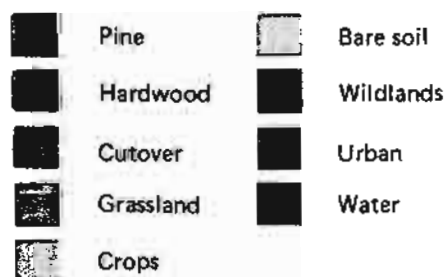
Figure 10--The computer map (*opposite*) was made by the same method used for the map shown in figure 9. Spectral signatures developed for block 4 were used in this classification without modification. Point-by-point evaluations can be made with the ground truth map (*above*).



Skylab 190B Nov. 1973



Computer map



The classification effort pointed out the difficulty of trying to classify photo data into categories which reflect the intent of land use rather than actual ground conditions. With the inevitable revision of resource classification systems into a common and aggregative type of inventory system it should be possible to use unsupervised classification more effectively to provide a useful data stage for future sampling systems.

Automated Land Classification

Optical film densities measured on normal-color film (S190B), and analyzed by the nearest-neighbor classification algorithm, showed promise for computer-assisted land classification. Only broad Level I land classes and Level II forest types, however, could be separated with reasonable accuracy (table 9). For instance, in block 4, pine area was classified 17 percent lower and the hardwood area 40 percent higher than ground measurements. The latter difference seems high, but considered as a percentage of the total area it is only about 6.5 percent (22.82 percent vs. 16.28 percent). In block 2, pine area was classified 19 percent lower and hardwood 14 percent higher than ground truth, even though block 2 was classified using training sets derived from block 4—61 kilometers (38 miles) away. The total forest area in block 4 was 6 percent higher than ground truth. Pine was always underestimated and hardwood was always overestimated.

Total nonforest area, like total forest area, was estimated within reasonable accuracy—block 4 within 11 percent and block 2 within 7 percent—and both were underestimated. Area estimates by Level II nonforest classes varied considerably from the ground truth and can be explained by seasonal differences between the Skylab data (late November) and the ground truth (late spring). This problem will always arise in machine classification unless land classifications are restructured to recognize what is present on the ground rather than an interpretation of the intentions of local land managers. The best time of year to measure the landowner's intended use is in the late spring, when the fields are plowed or planted and can be separated from grassland and idle land.

Areas of water and urban land estimated in both blocks 4 and 2 in some instances appear to be quite accurate. This is misleading, however, because major bodies of water in both blocks were called bare soil, grassland, and crops. Water was misclassified because high levels of sedimentation created false signatures. Urban areas were misclassified as grassland, bare soil,

and crops, because on color film the spectral signatures are very similar. Roads and utility rights-of-way, passing through forested areas, can be detected by the spatial alignment of digital elements but not by their spectral characteristics.

The computer maps shown in *figures 9 and 10* can be visually compared with both the Skylab S190B photograph and the ground truth map. The agreement between Level I forest areas and nonforest areas, and between Level II forest types, is quite apparent. A point-by-point comparison was made between the ground truth map and the computer map. We found that 92 and 93 percent of forest points were correctly classified on the computer map for blocks 4 and 2, respectively, *table 9*). Of the points in pine type, 70 percent (block 4) and 83 percent (block 2) were correct. Points falling in hardwood were correct 68 and 74 percent of the time for blocks 4 and 2, respectively. Although nonforest points were found accurate 74 percent (block 4) and 85 percent (block 2) of the time, the accuracy for individual Level III classes was extremely poor.

The results show that forest area can be stratified on Skylab-quality photographs (20- to 30-meter resolution) with an accuracy of approximately 96 percent. In other words, the forest area can be mapped and an estimate of the area made within the limits that can be met using aerial photographs. We also found this to be true in our LANDSAT-1 experiment (Aldrich and others 1975). Geometric distortions in the LANDSAT image, however, did not allow more than 50 percent accuracy in point-by-point comparisons.

Applications

Under certain assumptions, Skylab-quality photographs will provide a data base for Level I and Level II land use and broad forest-type stratifications (as defined in this report) by both human and machine-assisted procedures. The assumptions are that

1. High resolution color infrared photography is available.
2. Radiometric measurements by supporting aircraft flights are available within a few days of a satellite pass.
3. A high-speed scanning microdensitometer is available for recording optical film density on computer-compatible tape.
4. An off-line minicomputer and interactive display (CRT) are available for preprocessing remotely sensed data for input to a large nondedicated high-speed computer for classification mapping or

sampling. If a minicomputer is not provided, an interactive display—on line with a dedicated large, high-speed computer—must be available.

5. A classification system is designed which is based upon land cover rather than land use intent.

In this investigation, normal-color photography taken from orbital altitudes did not allow complete land use classification even at Level I. Here the failure of both human and automated classification procedures to resolve differences between water, grassland, bare soil, and idle land was important. Examples of Skylab CIR photographs for nearby areas indicated, however, that the infrared reflectance and absorption differences for these classes will provide excellent separation. Thus, if CIR film is available, both human

Table 9—Accuracy, based on ground truth, of area estimates and sample point classification for PSW computer mapping of two test blocks from Skylab S190B color photography, November 30, 1973

Block and land-use class (Levels I & II)	Area, ground ¹		Area, Skylab	Number of sample points	Classification accuracy, Skylab
	Ha	Percent	Percent		Percent
Block 4	6055	60.55	64.41	290	92
Block 4					
I Forest	6055	60.55	64.41	290	92
II Pine	4427	44.27	36.62	217	70
Hardwood	1628	16.28	22.82	73	68
Cutover	— ²	—	4.97	0	—
I Nonforest	3616	36.16	32.14	180	74
II Grassland	1548	15.48	9.51	78	53
Crops	61	0.61	6.57	2	0
Bare soil	881	8.81	6.90	52	37
Wild vegetation	441	4.41	4.96	26	27
Urban	685	6.85	4.20	22	14
I Water	329	3.29	3.45	10	20
Block 2					
I Forest	5151	51.51	53.48	271	93
II Pine	3327	33.27	26.95	150	83
Hardwood	1824	18.24	20.84	121	74
Cutover	— ²	—	5.69	0	—
I Nonforest	4721	47.21	44.04	204	85
II Grassland	1473	14.73	8.25	57	54
Crops	151	1.51	5.00	23	35
Bare soil	700	7.00	22.92	33	67
Wild vegetation	805	8.05	4.41	26	42
Urban	1592	15.92	3.46	65	17
I Water	128	1.28	2.48	5	80

¹ Areas were determined by dot count on ground truth maps at an intensity of approximately one dot per 0.4 hectare (1 acre).

² Cutover land was not classified separately on the ground truth map: cutover forest land was placed in the appropriate forest type.

and computer classification of land use and forest type should be more effective.

In operational applications of machine-assisted classification of Skylab-quality photographs, spectral differences within and between photographs, and between seasonal (temporal) coverage, caused by changes in solar angle and atmospheric interference, will be limiting factors (see "Measurement of Forest Terrain Reflectance"). If, however, satellite photographic coverage is either preceded by, or followed by, radiometric measurements from a low-flying aircraft, then correction factors can be computed and applied to the data. This would permit extension of ground truth and reduce costs. The radiometric data must be collected within a few days of an overpass under similar atmospheric conditions.

Although mapping of all the forest and rangeland (610 million hectares or 1.5 billion acres) in the United States may some day be desirable, limitations in computers and computer storage make this somewhat unlikely for extensive inventories at the present time. Instead, it is much more reasonable to think of sampling applications. For example, this report demonstrates that a systematic sample grid can be overlaid upon digitized land use map data by computer to estimate forest area within a county—the variance was always lower than simple random sampling. Using Skylab normal-color film to classify forest and nonforest land in one county (100 percent) resulted in an accuracy of 80 percent for forest land with a 30 percent commission error. Forest cover types and other land cover types may be estimated by sampling digitized data from future satellite coverage if CIR film is made available and if a classification system on the land cover rather than intended use is designed.

Classification System Alternatives

The Forest Survey definition of forest land illustrates the problems and inefficiencies of using a data-gathering system which views present land cover in order to classify use based on the intent of the manager. Using this definition, a clearcut area prepared for planting would be considered forest although no trees were present. Computer-aided classification would probably classify the area as bare soil. In some parts of the country a forest opening of bare soil might be assumed to be a clearcut to be planted, but in the Southeast the area is just as likely to be agricultural land.

There is much greater probability of high accuracy if classification is made in terms of present land

cover. The spectral signatures of classification based on present land cover have inherently less variability than those based on intended use, which may include diverse land-cover categories. It is true, however, that a system based solely on land cover, although appealing from the standpoint of identification from remote sensing data, may not be amenable to aggregation and disaggregation into the classes desired by the data users.

An alternative classification system might be one that makes use of information directly attainable from satellite data and calls for a separate subsample of those classes not well characterized by the land cover. Before the system could be implemented, however, it would be necessary to know the land cover types that can be recognized in a given region. To date, most studies have concentrated on determining the accuracies attainable when classifying land into predetermined categories. Results of these studies have often been discouraging because a satisfactory classification accuracy could not be attained for the predetermined categories. At the same time, the possibilities for further subdivision within easily identified categories went unexplored. We feel that operational applications of machine-assisted classification

Table 10—Comparative cost of land use and forest stratification on Skylab photographs and on 1:20,000 ASCS photographs

Item and basis		Cost	
		ASCS	Skylab
Photo handling	Ordering, organizing and labeling photographs and transferring plots—\$5 per hour.	\$140.00	\$125.00
Photography cost	1974 ASCS price list; cost of one \$190B color inter-negative and one 1:125,000 color print.	366.00	100.00
Photo-interpretation	Land use: ASCS at 5 clusters per minute, Skylab at 3 clusters per minute—\$5 per hour; forest type classification: ASCS at 40 plots per hour—\$5 per hour.	36.35	50.90
Total		\$542.35	\$275.90

will depend on additional research to determine the land cover categories which are, and those which are not, spectrally separable with acceptable accuracy.

Cost Comparisons

The primary advantage of Skylab-quality photography in forest resource surveys is the broad areal coverage within a single frame. In the four counties used in this experiment, 183 aerial photographs (1:20,000) were required to cover an estimated 80 percent of the total area. This was single photographic coverage without the advantages of stereoscopic overlap. A Skylab S190B photograph, on the other hand, can cover these four counties and two to four additional counties as well. Complete county coverage offers better distribution of photo samples and reduces data handling and photo acquisition costs—assuming that only printing and processing costs are considered.

If all other survey costs are assumed equal, the costs of Level I and Level II land use and forest stratification would be 49 percent lower on Skylab photographs than on conventional 1:20,000 scale photographs (*table 10*). The major difference between the two methods is the cost of photographs. The small scale of Skylab photos and the use of normal-color film meant that more time was required to make interpretative decisions on Skylab. However, if color infrared photographs were available on a regular recurring basis, time would be somewhat reduced, and the advantages of up-to-date information would far outweigh any additional interpretation cost.

Because of variations in system efficiency and effectiveness, it is difficult to compare conventional interpretation and computer-assisted classification and mapping techniques. Numerous computer classification procedures are now available for resource analysis, but there have been no comparative tests. Computers and accessories vary widely. There are non-dedicated computers accessed through terminals on a time-sharing basis, dedicated computers with on-line interactive displays, and complex systems including off-line minicomputers and interactive displays to preprocess data for classification and mapping on large computers. An analysis of the efficiency of one system over another is lacking.

In this study a system was used that included a

Table 11—Comparison of cost of producing classification map for 40,000 hectare (98,800-acre) area using conventional mapping and computer-assisted techniques on CIR photography

Method and task description	Time used		Cost	
	Man-hours	Machine-time	Man-hours ¹	Machine time
— dollars —				
<i>Conventional interpretation</i>				
Map and transfer class boundaries from 1:120,000 CIR to 1:24,000 map base	100.00	0	617	0
<i>Computer-assisted classification</i>				
Microdensitometry	2.00	4 h	12	² 40
Computer classification:				
HIST—rewrites raw density tape and interleaves scans	0.50	356 s	3	³ 41
IGREY—grey-scale printout; area location, training set selection	16.00	560 s	99	³ 50
TAPEJOB—rewrites tape from IHIST in BCD	0.25	700 s	2	³ 63
PROTO—produces sums of data used in TYPEPIX	2.00	6 s	12	⁴ 2
TYPEPIX—produces classification map (4 parts) on EAI plotter	4.00	389 s	25	⁵ 245
Total	24.75	4.56 h	153	641

¹ GS-9, \$6.17 per hour rounded to the nearest dollar.

² Commercial rate, \$60 per hour.

³ Univac 1108; \$0.09 per second.

⁴ CDC 7600; charged for 34 accounting units (AUS) at \$0.07 per AUS. Averages out at \$0.38 per second.

⁵ CDC 7600; average for 4 runs = 218 AUS at \$0.07/AUS. Averages \$0.63 per second.

nearest-neighbor classification algorithm and two time-sharing computers. Without an interactive display, two or more iterations of the classifications were required to improve accuracy. This is more time consuming than an interactive display and less efficient. The cost breakdown in *table 11* compares our PSW computer-assisted technique with conventional mapping and transfer procedures on a ZTS. Although the computer technique was more expensive (\$177 more), it required only one-fourth the man-hours. Thus, when manpower and time are short, the machine-assisted system would be beneficial despite the higher cost.

RANGE INVENTORY

Classification and Mapping of Plant Communities

Richard E. Francis

Richard S. Driscoll

The primary objective of the research at the Manitou site was to determine at what classification level Skylab photographic products, or their equivalent, can be used for plant community classification in a central Colorado mountainous area. Secondary objectives were (1) to determine the kind of aircraft support photography needed to extend these classifications to other levels in the hierarchy, (2) to determine how both Skylab and aircraft support photography can be used to detect and identify cultural features of a mountainous landscape that could affect resource management alternatives, and (3) to make quantitative estimates of certain plant community characteristics from large-scale aircraft photography.

This is the latest in a series of studies that began in 1967 to evaluate remote sensing technology for range inventories. The Rocky Mountain Forest and Range Experiment Station, located in the center of a variety of range plant community systems, was a proper focal point for this research.

Initial studies conducted in 1967 investigated large-scale 70-mm color and color infrared (CIR) photographs (1:600 to 1:4600) for identifying plant species (Driscoll 1969). The conclusion from this work was that major rangeland species can be identified most consistently on 1:600 and 1:1200 scale CIR photographs.

In 1968, the Rocky Mountain Station entered into a 4-year study under the NASA Earth Resources Aircraft Program to evaluate multiband photography and multispectral scanner imagery taken from both aircraft and spacecraft. Results indicated that CIR photographs taken from space (Apollo 9, 100-meter ground resolution) can be used to map general plant community systems (Driscoll and Francis 1972). Larger scale (1:20,000 to 1:80,000) aircraft photographs with 3- to 10-meter ground resolution were required, however, to determine the areal extent of the individual habitat types. Still larger scale aerial photographs ($>1:2400$) were needed to analyze community components. Initial efforts to relate optical film density measured on small-scale CIR photographs to plant communities showed promise.

In 1972, the Rocky Mountain Station and its range inventory research team initiated a study to assess the value of low-resolution (65- to 100-meter ground resolution) LANDSAT-1 (ERTS-1) multispectral scanner data for classifying plant communities (Driscoll and Francis 1975). This study showed that LANDSAT imagery acquired in August was best for the first level of classification. Aspen can be reliably separated from conifer only during this time of year (92 percent accuracy). Conifer and grassland, on the other hand, can be classified on June-to-September LANDSAT and high-flight aerial photos with 95 to 99 percent accuracy. Regardless of season, interpreters could not classify to the second level with acceptable results. An analysis of optical film density measured on LANDSAT photographic color composites showed highly significant differences between all first-level vegetation classes. Thus, automatic scanning of LANDSAT photographic data and computer-assisted classification of first-level vegetation classes seemed possible.

Skylab photographs used in this study have better ground resolution (S190A, 30 to 120 meters; S190B, 20 to 30 meters) than either Apollo 9 or LANDSAT images. An evaluation of this improved data was important for planning future earth resources satellite programs for forest-rangeland assessments.

Study Area

The study area lies between 38°30' and 39°30' north latitude and 104°40' and 106°10' west longitude and covers approximately 14,000 km² (5400 sq mi; fig. 11). Included within the area is the NASA/Manitou Test Site, No. 242. This nonurban, non-agricultural area in central Colorado is characterized by extreme diversity in plant community systems and extreme variations in topography. The vegetation in the area consists of a variety of forests and grasslands. The forests, ranging from approximately 1900 m (6232 ft) above mean sea level to tree line at approximately 3500 m (11,480 ft), include: (1) ponderosa pine, (2) Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco), (3) lodgepole pine

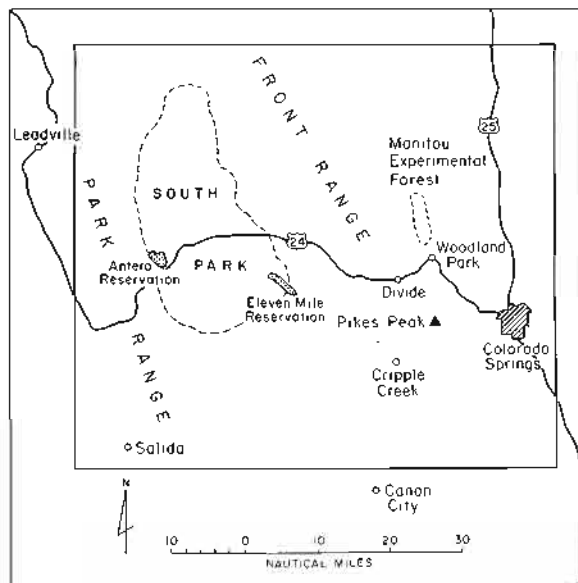


Figure 11—The mountainous central Colorado study area includes two intensive test sites, South Park and the Manitou Experimental Forest. Colorado Springs is near the southeast corner of the area.

(*Pinus contorta* var. *latifolia* Engelm.), and (4) spruce/fir (*Abies lasiocarpa* [Hook.] Nutt.) Intermingled throughout the area are deciduous forests of quaking aspen (*Populus tremuloides* Michx.). 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 are principally associated with the ponderosa pine forests. These dominants are replaced by other species of fescue at higher elevations. In many instances the gradation

from forest to grassland is subtle, and it was difficult even at ground level to establish the line of demarcation between the two systems (fig. 12).

Within the central part of the study area 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.), slimstem muhly (*Muhlenbergia filiculmis* Vasey), and several low-growing shrubs and forbs 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 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. In association with the meadows there are shrubby communities dominated by species of willow (*Salix* L.) and shrubby cinquefoil (*Potentilla fruticosa* L.).

The main portion of the study area varies in elevation from 2100 to 4300 m (6888 to 14,104 ft) above mean sea level. Elevation variations are dramatic—as much as 400 m per kilometer (2000 ft per mile) in many places. The average elevation of South Park is 2750 m (9020 ft) above mean sea level. (A more complete description of the study can be found in the report of the ERTS studies—Driscoll and Francis 1975.)

Classification System

The hierarchical vegetation classification scheme used to evaluate the effectiveness of the Skylab and supporting aircraft data was ECOCLASS (Pfister and Corliss 1973), which was established according to



Figure 12—The gradation and mixing between and within the forest and grassland vegetation system is evident on the ground. The forest system is a mixture of Aspen and Spruce/Fir; Mountain Bunchgrass (on slopes) and a high elevation Wet Meadow (valley floor) are the grassland systems.

ecological principles of polyclimax concepts (Daubenmire 1952). This system is in current use by the Forest Service to classify plant communities for land management planning, and is in accord with that established by the International Biological Program for classifying terrestrial communities (Peterken 1970).

The system defines five categories proceeding from the most general to the most specific, as follows:

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

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

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

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

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

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

<u>IV - Region</u>	<u>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

Skylab and Support Data

Only S190A and S190B photographic data for June 11, 1973 (SL-2, Pass 8, Track 48) and August 4, 1973 (SL-3, Pass 13, Track 48) were used in this analysis. The June mission covered 85 percent of the area; the August mission covered 100 percent on the S190A and 90 percent on the S190B. Of the S190A multispectral camera system products (scale 1:3,000,000), only color and CIR 70-mm photographs could be used. The S190A material was available for both June and August but the overall image quality was only fair. Photographs from S190B earth terrain camera system (1:950,000) were available only from the August mission. The overall quality of these photographs was very good.

Our initial proposal also called for the analysis of data from both the S191 infrared spectrometer and the S192 multispectral scanner systems. The imagery from both of these systems was excluded from the study because delays in obtaining the rectified data made analysis impossible in the time available. The sampling design we used for testing photographic products was based, however, on the expected resolution of the S191 system (435 m, 1427 ft).

Two aircraft missions—June 22, 1973 and August 9, 1973—were flown by the NASA aircraft support program to assist the interpretation of the Skylab products for the defined objectives and provided both color and CIR photographic products at three scales (1:50,000, 1:100,000, and 1:400,000). The quality of the two larger scales was very good, and coverage ranged from 85 to 100 percent. This photography was timed to represent plant phenological conditions on the dates of the Skylab passes. In addition, both color and CIR large-scale 70-mm sampling photography missions were flown by a U.S. Forest Service aircraft at the scale of 1:600, on August 24, 1973—within 3 weeks of the SL-3 photographs. Only the CIR was analyzed to estimate specific quantitative grassland plant community parameters. Film quality was poor because of severe reticulation.

Ground Truth

Base maps made from existing Forest Service range and forest vegetation type-maps were used to verify vegetation maps prepared from Skylab and under-flight photographs. To prepare a base vegetation map from Forest Service type-maps, Series level (ECOCCLASS) class boundaries were traced directly on the base. Because the Forest Service type-maps were functionally developed, however, they had to be reorganized on an ecological basis. This meant com-

binning and integrating some of the existing type-groups to meet our objectives. As an example, on the forest type-map, Aspen was separated into commercial and noncommercial classes, but for our purposes, the two classes were combined.

The revised vegetation maps were checked on the ground with a 10 percent sample of the 569 samples (each 500 m² or 1640 sq ft) used in the photointerpretation study. Less than 5 percent of the ground samples were found to be misclassified.

Foliar estimates made on large-scale color photographs were verified using ground data obtained from two grassland sites within South Park—Eleven Mile and Antero. Five plots were established at the Eleven Mile site and four plots at the Antero site. Each plot was 10 meters (32.8 feet) square. Within each plot, four 10-meter transects were established and marked with white wooden surveyor stakes laid flat on the ground. The transect locations were marked before the photo mission so that they could be located in the aerial photography.

Estimates of plant species foliar cover, litter, and bare soil were obtained using a line intercept technique (Canfield 1942), modified to use 10-meter transects rather than the 100-foot transects specified.

Procedures

Procedures used to meet the study objectives included visual interpretation of photos with high-powered magnifying stereoscopes, mapping with a photo image transfer device, and classification based on machine-measured optical film density.

Plant Community Classification by Photointerpretation

Vegetation type-maps, topographic maps, ground reconnaissance, and aerial photographs were used to select and locate sample cells for interpretation of both the Skylab and support aerial photographs. The sample cells were initially selected and plotted on the maps to represent an area approximately 500 meters (1640 feet) square. The size of the data cell was determined by (1) the expected resolution of the Skylab S191 EREP products (originally part of the analysis but later excluded—see Introduction), (2) the expected positional errors in both the satellite and data collections systems, (3) the probability of plotting errors in transferring sample cells from maps to the Skylab and supporting aircraft photographs, and (4) the need to minimize edge effects of cell-wall lines. For training and testing photointerpretation, at

least 20 cells were selected in each vegetation class, for a total of 569 cells class as follows:

	<i>Number of cells</i>
Region and Series class:	
Coniferous	446
Ponderosa Pine	150
Lodgepole Pine	62
Douglas-fir	94
Spruce/Fir	140
Deciduous	50
Aspen	50
Grassland	73
Shortgrass	29
Mountain Bunchgrass	24
Wet Meadow	20

The number of sample cells in each film, scale, or season test may have varied from these totals because photographic coverage was inadequate.

Transparent overlays were constructed for the Skylab photographs to show the training and test cell locations for the study area. The Universal Transverse Mercator coordinates representing the location of each cell were precisely plotted to a scale of 1:100,000 on the overlay. Obvious landmarks were also plotted to assist in positioning the overlays on the Skylab frames. These overlays were then photographically reduced on 0.004 mil clear positive film to the appropriate scale.

Interpretation covered the SL-2 and SL-3 S190A color and color infrared photographic products, the SL-3 S190B color photographic products, and the June and August color and color infrared support aircraft photography.

With the overlays in position on the photographs, each interpreter independently examined the training cells until he was satisfied that he could identify the classes. Next, he examined the available test cells and classified them into the Region Class and then the Series class. In this study design, interpreters were asked to first identify the Region and then the Series level classification for each sample before moving to the next. (Because Aspen is the only prominent Deciduous species in the area, the Region and Series classifications were the same in this instance.)

The same sample cell locations were used again to interpret the aircraft support photographs. Cell locations were transferred directly from the vegetation and topographic maps to overlays on the aerial photographs.

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

Plant Community Mapping

U.S. Forest Service vegetation type-maps were used as base data to draw plant community classification maps at both the Region and Series level for areal comparison with maps drawn from Skylab and support aircraft photographs. The base map covered 138 km² (54 sq mi) within the Manitou area (fig. 11) and was initially drawn to the Series level. Region level maps were made by consolidating Series classes into the three Region classes of Coniferous, Deciduous, and Grassland.

The base map underestimated the classes. This was due to the difference in criteria used to identify Wet Meadows in the development of the base maps. For instance, the original timber-type base maps had no Wet Meadow category, and the range type-maps had a very limited Wet Meadow category which did not correspond with ground information from the Manitou site. Therefore, artificial Wet Meadow class boundaries were determined from the original type-maps and ground information.

The photographic products used were the SL-3 (August) S190A color transparencies and the MX-248 1:100,000 scale CIR transparencies. These were not truly comparable film types, but they offered the best photographic quality available from the two sources. The area to be typed was imaged within one frame of the aircraft photography, thereby reducing interframe differences. Photographs from SL-2 S190A and SL-3 S190B could not be used because of cloud cover over the Manitou area.

Vegetation maps were made to the Series level from stereoscopic examination of the Skylab and support underflight photographs separately, and were independent of each other. Once the maps were completed, they were brought to the same scale for comparison using a Bausch and Lomb Zoom Transfer Scope.

Areal comparisons between the base map and the Skylab and underflight maps were accomplished using planimetric methods.

Cultural Feature Mapping

To examine ways of using Skylab photography to

interpret and map cultural features, an area of 156 km² (61 sq mi) was selected within the study site. Cultural features were mapped from Skylab and underflight photographs and compared with cultural features traced from a 1956 U.S. Geological Survey quadrangle.

Working under the Zoom Transfer Scope (ZTS), interpreters used SL-3 S190B photographic products enlarged to twice their original scale—1:500,000—and underflight CIR photos at 1:100,000. In attempting to map from the Skylab material, the interpreters found that the majority of the detail was lost in transferring information to a map using a ZTS. Therefore, they first placed an acetate overlay directly on the Skylab photo and with the aid of a stereomicroscope and a needle, they etched the location of road systems into the overlay. The overlay, enlarged on the ZTS, was used as a reference to map the other cultural features from the original Skylab photos.

Next, a photo-revised cultural feature map was made, using additional information obtained from the underflight photos. Because resolution on the underflight photography was better, the road system net was transferred under the ZTS directly to the overlay base map without the etching procedure. Then we mapped the other cultural features from the underflight photos.

Foliar Cover Estimation

Large-scale (1:600) 70-mm CIR photographs taken from a Forest Service aircraft were used to determine the proportionate amounts of live vegetative foliar cover and bare ground for selected grassland sites within the study area. The ultimate intent is to use these kinds of data in quantitative sampling of ground surface characteristics as imaged in the satellite photographs.

Transects measured on the ground were located on the large-scale aerial photographs, and foliar cover was measured using three means of image magnification: a zoom stereoscope, a hand-held measuring micrometer, and the viewing screen of a GAF microdensitometer.

Linear regression correlation analysis was used to determine the relationships between image-measured and ground-measured estimates.

Plant Community Classification by Microdensitometer

A GAF model 650 microdensitometer (fig. 13) was used to evaluate the Skylab photographic products for classifying plant communities. (A micro-



Figure 13—A microdensitometer (General Aniline and Film Corp. Model 650) was used to obtain optical image density. The photograph on the moveable image-holding stage is scanned by the light beam tube. The operator aligns the Skylab sample cell in the view screen before reading the apparent optical density registered on a digital display. The viewing screen and stage also aided in the estimation of foliar cover from large-scale photos.

densitometer measures the optical density of an image on a photographic transparency using a calibrated light source.) Skylab S190A normal-color and CIR photos from SL-2 (June) and SL-3 (August), and S190B normal-color photos from SL-3 were used in the evaluation.

All normal-color photographs were examined using a green filter in the optical system; the CIR photos were examined with a red filter. These filters were inserted into the light-beam path for enhancement of the color and CIR vegetation signatures. An effective circular aperture covering an image area of 6640 square microns was used with the S190A material. For the S190B material, an effective circular aperture covering an image area of 41,500 square microns was used. These effective areas provided a circular image with the diameter approximating the side dimensions of the sample cells used for visual interpretation.

The same sample cells used in the visual interpretation test were measured with the microdensitometer. Optical image density measurements were made of each sample cell. The calibrated light beam of the microdensitometer was aligned with the cell location by means of the sample-cell overlay used for visual interpretation. (Compensating allowance was made for the apparent optical density of the overlay.) Values from all sample cells were obtained.

A two-tailed t test was used to determine presence of significant difference between optical density sample means for both the Series and Region level classifications. Sample variances were assumed equal.

Results and Discussion

Results indicate that Skylab and support aircraft photographic products can be successfully used for classification and areal mapping of native plant communities to the Region level, by visual interpretation. Results of Series level classification from these same photo products are dependent on date, scale, and film type. Areal mapping at the Series level required formation of class complexes.

Optical densities measured on Skylab photos with a microdensitometer provided acceptable classifications at the Region level. The Series level of classification, however, showed film-type and seasonal dependency.

Visual interpretation provided successful cultural feature mapping from both Skylab and aircraft photographs; however, better resolution of the aircraft photos permitted mapping of finer details.

Very large scale aircraft photos were used to estimate quantitative parameters of specific plant communities. The results were successful, but dependent upon species diversity.

The results are discussed in more detail in the following sections.

Plant Community Classification by Photointerpretation

Region Level—Skylab color infrared photographs taken with the earth terrain camera (S190B) should

be acceptable for Region level classification in a stratified sampling design. To stratify Series level plant communities, however, high-altitude CIR photographs can be used only if some classes are combined.

Both the satellite and underflight aerial photographs provided acceptable results for interpreting both the Conifer and Grassland Region classes (table 12). The lowest accuracy level obtained was 89.8 percent for the Grassland class from the June S190A CIR photos. The remainder of the accuracy levels for these two Region classes were above 95 percent regardless of film, date, scale, or interpreter. There was no significant difference between the color and CIR film.

The Deciduous category, which in this study is Aspen, was date, film-type, and scale dependent; only CIR provided acceptable accuracies (table 12). One acceptable level was obtained for the June photos, and the August date provided two acceptable levels, all at different scales. Interpretation accuracy on 1:50,000 scale August photos was not as acceptable as on the June photos of the same scale, probably because of interpreter fatigue or the testing sequence used.

Differences between photointerpreters were generally small and nonsignificant; however, the interpreter most knowledgeable about the physiography and

vegetation of the test area was more accurate, though not significantly so.

The great majority of commission errors for both color (41.2 and 52.9 percent aircraft, 59.9 and 72.3 percent Skylab, June and August respectively), and color infrared (24.1 and 15.4 percent aircraft, 56.7 and 51.5 percent Skylab, June and August respectively) occurred when the Deciduous class was identified as Conifer. Because of the heterogeneous mixing of these two classes of vegetation in the Deciduous test cells (fig. 14) interpreters had difficulty in deciding whether Deciduous dominated within a test cell. Very few of the Conifer class were committed to the Deciduous class, however, because in most of the Conifer test cells Conifer dominance was obvious. Those test cells that were correctly identified as Deciduous were homogeneous (fig. 14). For the June and August dates, on CIR film, there were significantly ($p = 0.99$) fewer commission errors of the Deciduous class to Conifer than on color film. Also on CIR film, for the August date, there were significantly ($p = 0.90$) fewer Deciduous class commission errors to Conifer than for the June date. There was greater separability between Deciduous and Conifer using CIR, and an even greater separation occurred at the August date because leaf-color change of the Deciduous class had begun. Deciduous leaves at the June date were only half to two-thirds developed and

Table 12—Accuracy of visual classification of plant communities at Region level, Manitou, Colorado, test site¹

Date, source, and scale of photographs	Deciduous		Conifer		Grassland	
	Color	CIR	Color	CIR	Color	CIR
Percent						
JUNE 1973						
Aircraft, RB-57:						
1:50,000		88.9		99.4		100.0
1:100,000	58.8	72.2	99.7	98.9	100.0	100.0
1:400,000		63.9		99.7		98.4
Skylab S190A:						
1:2,800,000	33.4	40.0	100.0	97.3	97.5	89.8
AUGUST 1973						
Aircraft RB-57:						
1:50,000		77.8		98.2		100.0
1:100,000	44.2	88.1	98.9	96.8	100.0	100.0
1:400,000	50.0	87.9	98.2	98.6	98.2	98.2
Skylab S190B:						
1:1,000,000	25.0		98.4		95.8	
Skylab S190A:						
1:2,800,000	20.6	41.5	99.3	97.9	100.0	95.8

¹ Mean percent correct for two interpreters. Not all film types were available for all scales and dates.

gave a low infrared reflectance relative to the sensor altitude. Therefore, deciduous foliage was difficult to separate when mixed with conifers.

Commission errors of the Deciduous class to the Grassland class type were often made on the Skylab photographs (percentages were 6.7 and 7.1 color; 3.3 and 7.0 CIR, for June and August respectively). The extremely small scale resulted in difficulty for the interpreters in separation of these two classes in ecotonal situations. This was further complicated by the subtlety of color differences between the Deciduous class and some members of the Grassland class in both the June and August photographs of both film types. Another reason for commission errors was the lack of topographic (stereo) relief near the mountain/grassland interface. Some misclassification was introduced by misregistration of the photo overlay.

A few Conifer-to-Grassland commission errors were made on both film types. Most of these errors were committed on Skylab photographs, because of class mixing and misregistration of the sample location overlay.

Series Level, Forest—In general, of the five tree categories included, only Aspen, the lone Deciduous Series class, was consistently classified with an acceptable level of accuracy and then only on the August

CIR aircraft photos (table 13). At the 1:100,000 and 1:400,000 scales accuracy exceeded the 80 percent level. On the satellite photos, no acceptable accuracy levels for the Aspen Series class were achieved.

The Douglas-fir, Lodgepole Pine, Ponderosa Pine, and Spruce/Fir classes were occasionally classified with accuracies of 80 percent or greater, and then usually with the early-season and smaller scale photos (table 13).

The greater accuracy at smaller scales was achieved because species mixtures blended into a more apparent homogeneous unit, with the dominant species signature predominating. The decreased resolution at these smaller scales allowed the interpreter to classify the dominant characteristics with greater ease. However, some classification difficulty was caused by species mixing and somewhat broad color signatures.

There were commission errors for all categories. The overlap in geographic range caused Aspen to be generally confused with Spruce/Fir regardless of date, scale, or film type. The smallest such error (5.9 percent) was obtained from the August CIR aircraft photos. At this date, CIR provided the necessary separation between the fall foliage coloration of Aspen and the dark green foliage of Spruce/Fir. Douglas-fir and Ponderosa Pine were most often confused with each other for all film types, dates, and

Table 13—Accuracy of visual classification of plant communities at Series level—Conifers¹ and Grassland—Manitou, Colorado, test site²

Date, source, and scale of photographs	Conifers								Grassland					
	Douglas-fir		Lodgepole Pine		Ponderosa Pine		Spruce/Fir		Mountain Bunchgrass		Shortgrass		Wet Meadow	
	Color	CIR	Color	CIR	Color	CIR	Color	CIR	Color	CIR	Color	CIR	Color	CIR
Percent														
JUNE 1973														
Aircraft, RB-57:														
1:50,000		46.2		21.5		71.8		86.1		78.6		92.9		100.0
1:100,000	40.7	49.1	58.9	58.4	77.5	79.1	82.5	75.7	90.0	72.7	100.0	95.9	88.9	94.5
1:400,000		45.4		45.2		73.1		77.8		83.4		100.0		92.9
Skylab S190A:														
1:2,800,000	78.2	81.3	80.0	70.0	80.3	68.2	75.0	60.7	62.5	54.2	96.9	100.0	77.3	40.9
AUGUST 1973														
Aircraft RB-57:														
1:50,000		48.0		33.4		73.2		69.4		85.7		100.0		100.0
1:100,000	56.9	59.1	52.3	48.4	69.9	70.7	78.3	77.3	88.8	74.5	95.9	95.9	94.5	94.5
1:400,000	43.6	39.2	42.9	54.8	73.1	75.1	83.8	66.8	85.5	80.9	100.0	100.0	92.9	100.0
Skylab S190B:														
1:1,000,000	76.3		66.7		75.7		75.0		38.4		100.0		100.0	
Skylab S190A:														
1:2,800,000	65.9	65.8	72.9	66.7	73.2	82.6	70.0	48.6	71.7	20.0	100.0	100.0	75.0	87.5

¹ Aspen was the only Series class of deciduous trees; percent accuracy is shown in table 12.

² Mean percent correct for two interpreters. Not all film types were available for all scales and dates.

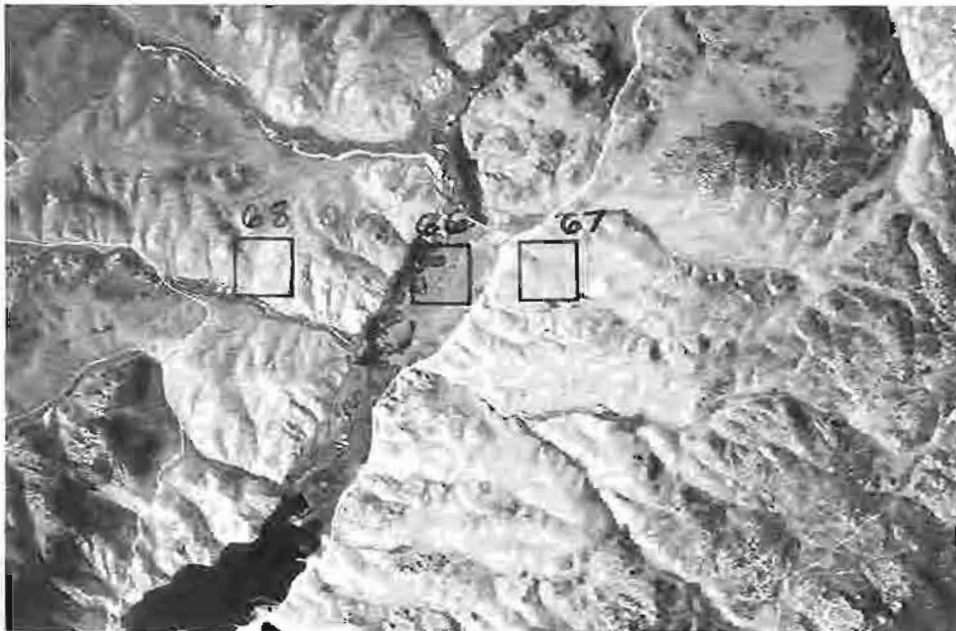


Figure 14—Aircraft support photography (CIR, 1:50,000) was used with acetate overlays showing sample training cells (labeled) and test cells (numbered) for visual classification of native plant communities. In the August photo (*above*), note the Deciduous/Conifer (Aspen/Ponderosa Pine) mixing in cell 68, the variability within and between the Ponderosa Pine cells, and the similarity between the Spruce/Fir (SF) and Ponderosa Pine cell (69). In the June photo (*below*), the test cells represent the three Grassland communities classified: Wet Meadow (66), Shortgrass (67), and Mountain Bunchgrass (68). Here there is maximum distinction between the three Series classes, but cell 68 approaches the ecotone between Mountain Bunchgrass and Shortgrass. The scale of the photo shown is approximately 1:45,000.

scales. Generally, both Douglas-fir and Ponderosa Pine had the least commission errors (15.4 percent) on early-season (June) color and CIR satellite photography. At the same date, and on both color and CIR, commission errors were greatest on the underflight aircraft photos (26.7 percent) and were essentially the same (nonsignificant differences) on the late-season (August) photography.

The large number of commission errors on underflight aircraft photographs resulted because the Ponderosa Pine and Douglas-fir overlap in geographic range but occupy different physiographic positions in the landscape. Douglas-fir generally occurs on north and east slopes while Ponderosa Pine generally occurs on south and west slopes. In some topographic positions, however, depending on the degree of slope and aspect, the two species form a heterogeneous mixture. These facts cause severe interpretation problems in mountainous terrain: (1) where the two species mix, separation is difficult and (2) in heavy shadows on north-facing slopes, it is difficult to determine where Ponderosa Pine forests stop and Douglas-fir forests begin. Therefore, commission errors occur, from one species to the other, on the larger scale photos. Difficulty also arises when the interpreter makes a decision to identify the sample as one type or the other based on crown density. His estimate may in fact be accurate, but the criteria for decision may differ for the vegetation base maps, or the maps may not be entirely accurate; base maps were based upon merchantable timber, not cover-type dominance. Also, the smaller scale (satellite) photos provide a more synoptic view with less resolution, thereby allowing inference to be made based on dominant color signature and topographic aspect, for easier separation of community Series.

Interpretations of the Lodgepole Pine and Spruce/Fir community Series were also often confused. In general, the late-season (August) satellite photos, regardless of film type, provided fewer commission errors (9.9 percent) between the two Series classes. One exception was the lower commission error (2.7 percent) from Spruce/Fir to Lodgepole Pine on late-season CIR underflight photos.

The confusion between the Spruce/Fir and Lodgepole Pine classes most frequently occurred where the geographic range of the two classes overlapped. Within such areas, especially on shadowed north slopes, color signatures and image textures were difficult to separate. Also, the lower resolution on the satellite photos, and the synoptic view they provided, resulted in fewer commission errors between classes. Classification of Spruce/Fir, however, was better on

the underflight photos regardless of date (season) or film type. The Lodgepole Pine class was correctly identified more often from the satellite photos. That is, fewer commission errors were made to Lodgepole Pine or Spruce/Fir. More commission errors went to other tree Series that overlapped or were more difficult to interpret without sound orientation and vegetation knowledge. In general, the photointerpreter with the most knowledge of the study area classified the tree Series most accurately, using inference and deductive reasoning as well as image signatures.

Grassland—The three grassland Series classes (*fig. 14*) were correctly classified, with mean accuracies of 80 percent or better from the underflight photos regardless of film type or season (*table 13*).

In both underflight and satellite photos, most of the commission errors occurred between the Mountain Bunchgrass and Shortgrass classes and between the Wet Meadow and Mountain Bunchgrass classes. Mountain Bunchgrass was most often classified as Shortgrass because they form an ecotone or continuum. They were difficult to classify, especially on the satellite photos. The underflight photos, especially the 1:50,000 scale with improved resolution, allowed a better estimate of the Series class boundaries and therefore had fewer commission errors. Even though the satellite photos provided a more synoptic view, the reduced resolution did not allow Series separation. For Grassland, these characteristics appear to be a disadvantage, although for the tree Series classification, they allowed greater accuracy.

The Wet Meadow Series was generally classified at an accuracy of 80 percent or greater from both underflight and satellite photos (*table 13*). Results for the underflight photos were most consistent, however, and were not dependent on date or film type. Few commission errors (2.7 percent) occurred for this Series class on underflight photos. Commission errors that averaged 21 percent did occur for the satellite photos. Errors for this class were made to the Mountain Bunchgrass class, primarily because of natural mixing near mountain slopes. High-density Mountain Bunchgrass provided the same color signature as lower-density Wet Meadows on the very small scale satellite photos.

Plant Community Mapping

Late-season (SL-3) S190A Skylab color photos and late-season (MX-248) underflight CIR photos were used to determine vegetation boundaries and estimate their areal extent (*fig. 15*).

Region Level—The Skylab and underflight photos were both successfully used (accuracy greater than 80 percent) to map the areal extent of the Conifer and Grassland Region classes (table 14). The extremely small scale of the Skylab material and its lower resolution caused a reduction from the base map area of about 17 percent in the Grassland class. At the Manitou site, Grassland occurred in long narrow stringers between the tree stands. Manitou Lake was distinguishable in the Skylab photos, but it occurred within one of these narrow stringers and was too small to be measured planimetrically. For comparability, it was included with the Grassland class in all three Region maps.

The Deciduous (Aspen) class was not successfully mapped from either the underflight or the Skylab photos (table 14), because of stand sizes and class mixing between Deciduous and Conifer. No Deciduous class areas were mapped from the lower-resolution Skylab photos.

Small areal differences (about 2 percent) between the three maps were attributed to the mapping procedure, planimetric error, and nearly 20 years difference between the original source base map compilation and the current mapping attempts.

Series Level—The Mountain Bunchgrass and Short-grass Series classes could not be distinguished well enough in the Skylab photos to be mapped separately. Therefore, they were combined into a single

Figure 15—Plant communities were mapped at the Series level by visual interpretation at 1:50,000 for a unit within the Manitou site. The base map was compiled from U.S. Forest Service timber and range vegetation type-maps. The underflight map was compiled from late-season, 1:100,000 scale CIR aircraft photos. The Skylab map was compiled from late-season (SL-3) S190A color photos. Successful mapping required formation of several complexes of the individual Series classes. The map scale as shown is approximately 1:110,000.

Legend

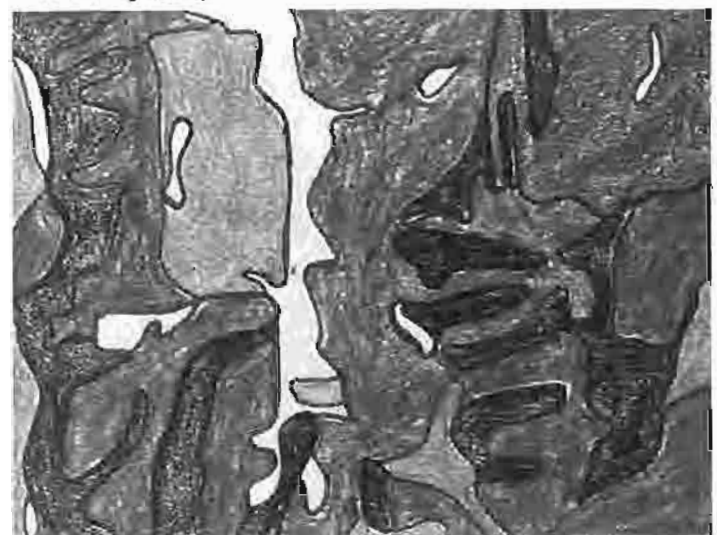
- Spruce/Fir/Lodgepole Pine Complex
- Ponderosa Pine
- Douglas-fir
- Ponderosa Pine/Douglas-fir Complex
- Aspen
- Upland Grassland
- Wet Meadow



Base map



Underflight map



Skylab map

Table 14—Area comparisons between base map, underflight map, and Skylab map for Region and Series classification levels, Manitou, Colorado, test site

Classification level and type	Base map		Underflight map ¹	Skylab map ²	
	Acres	Acres	Percent of base	Acres	Percent of base
Region:					
Deciduous (Aspen)	786	285	36.3	0	0
Conifer	27,687	28,202	101.9	28,923	104.5
Grassland (w/lake)	2,690	2,676	99.6	2,240	83.3
All classes	31,163	31,163		31,163	
	(12,611 ha)				
Series:					
Aspen	786	285	36.3	0	0
Ponderosa Pine	15,729	7,744	49.2	4,887	31.1
Douglas-fir	10,269	8,630	84.0	6,546	63.7
Ponderosa Pine/Douglas-fir complex	25,998	26,707	102.7	25,788	99.2
Lodgepole Pine	1,434				
Spruce/Fir	163		(³)		(³)
Lodgepole Pine/Spruce/Fir complex	1,597	1,495	93.6	3,135	196.3
Grassland ⁴	2,297	2,092	87.3	2,240	93.5
Wet Meadow	277	566	204.3	0	0
Lake	16	18	112.5		
All classes	31,163	31,163		31,163	
	(12,611 ha)				

¹ Late season, CIR, 1:100,000.

² Late season, color, S190A, 1:2,800,000.

³ Area not mapped separately.

⁴ Includes Mountain Bunchgrass and Shortgrass.

Series class. With this Series combination, both the underflight and Skylab photos were used successfully (> 80 percent accuracy) to map the grassland areas (table 14).

The Wet Meadow class was overestimated from the underflight photos when compared with the vegetation base map (table 14). Furthermore, because the Wet Meadow class occurred as long narrow stringers, both within the grasslands and intermingled with the tree classes, the lower resolution of the Skylab photographs would not permit mapping any of the Wet Meadow class (fig. 15).

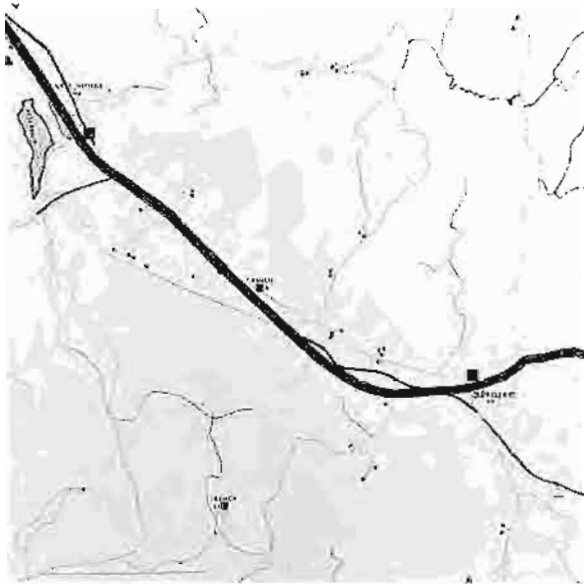
The Douglas-fir Series was the only individual Conifer class that could be mapped successfully (more than 80 percent accuracy) from the underflight photos (table 14). Attempts were made to map the Lodgepole Pine and the Spruce/Fir Series but no area figures could be derived. Species mixing at ecotones, and slope/aspect relationships within these groups made class separation extremely difficult.

To map all the tree Series classes with acceptable accuracy, we formed two class-complexes: Ponderosa Pine/Douglas-fir and Lodgepole Pine/Spruce/Fir. The

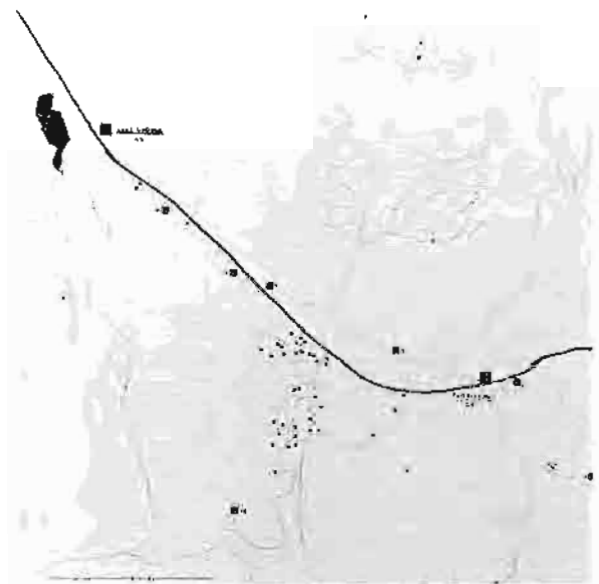
Ponderosa Pine/Douglas-fir complex was mapped within 1 to 3 percent of the base map estimates from both underflight and Skylab photos. These small differences can be explained by mapping and planimetric error. The Lodgepole Pine/Spruce/Fir complex was mapped within 8 percent of the base map estimates from underflight photos, but was overestimated by nearly 100 percent from Skylab photos. This difference was also due to mapping error: Aspen and Wet Meadow classes which were not discernible in the Skylab photos were included in the complex, and areal measurement error increased with smaller mapping units.

The Aspen Series class could not be mapped from either the underflight or Skylab photos at the Manitou site, as explained earlier.

Manitou Lake was successfully mapped from the underflight photos and was distinguishable in the Skylab photos; it was too small, however, to be measured planimetrically (table 14). Because Manitou Lake was not included with the grassland complex or Wet Meadow Series classes, the areal estimate obtained for these two classes was more representative



Base map



Underflight map

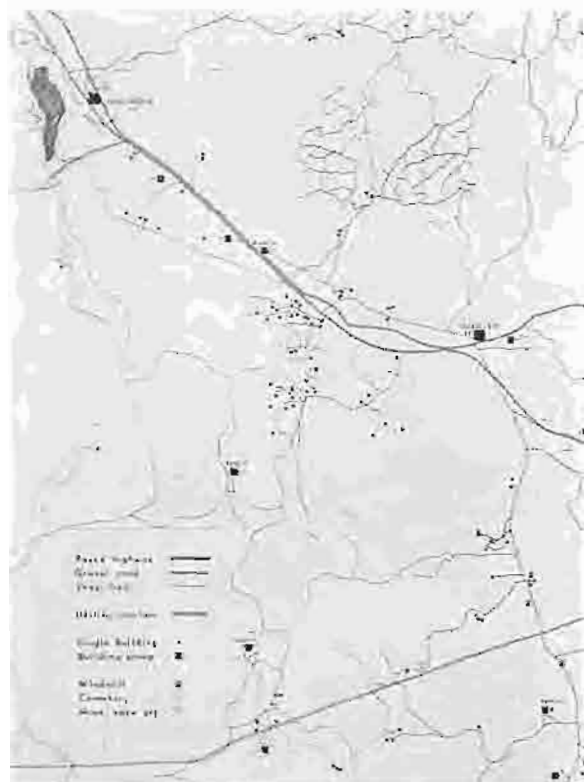
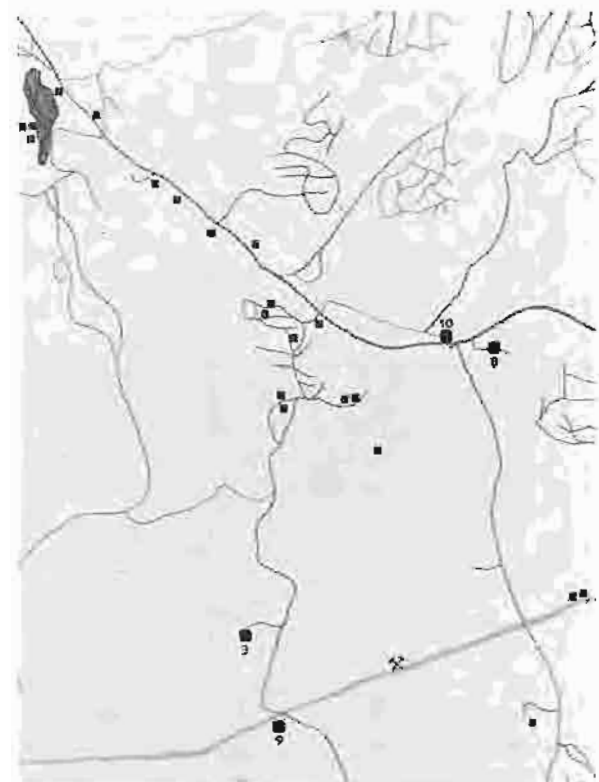


Photo-revised map



Skylab map

Figure 16--Cultural features were mapped by visual interpretation at 1:24,000 from an area of 156 km² (61 sq mi) within the Manitou site. The photo-revised map was compiled using the 1956 USGS quadrangle and the 1973 aircraft photos. The buildings grouped near the reservoir (upper left) in the Skylab map were identified as single buildings in the underflight map, but for simplicity they were considered part of the building complex at Lake George village. Key to features shown on photo-revised map applies to all maps shown.

than that of the Region classification. Water level difference between the two map compilation dates was responsible for the difference between base map and underflight water areas.

Cultural Feature Mapping

Skylab S190B color photographs (August 4, 1973) enlarged two times, and underflight CIR 1:100,000 scale photos (August 9, 1973), were used to update a cultural-feature inventory map (fig. 16). Ground truth information was obtained from the most recent (1956) U.S. Geological Survey quadrangle and was revised from the 1973 underflight photography.

The features most easily identified from both Skylab and underflight photos were paved highways and gravel roads. Lack of scene contrast in open areas, however, prevented differentiation of small segments of gravel roads that passed under tree canopies or across treeless areas. The problem was most severe on Skylab photos. Most gravel road systems could be aligned on the underflight photos; larger scale, better resolution, and occasional openings in tree canopies allowed at least partial viewing.

Identification of infrequently used dirt roads or jeep trails was not possible on Skylab photos and was very difficult on the underflight photos, because of canopy cover and related shadows, low scene contrast, and lack of resolution of the narrow tracks.

Utility corridors through forested areas, and those constructed within the past 10 years, were identifiable from both Skylab and underflight photos. The kind of utility corridor could be determined as either pipeline easement or power line from the underflight photos, but not from Skylab photos. Vegetation regrowth usually prevented detection of corridors older than 10 years from Skylab photos.

Earth excavation activities, including underground mining evidenced by refuse dumps, open stone quarries, and sand or gravel pits, could be identified on Skylab imagery only as a group, because of low resolution and lack of scene contrast. The specific activity could usually be identified from the larger scale underflight photos. These excavations were shown on the USGS base map used as ground truth.

Few individual residential or smaller commercial buildings were detectable from Skylab photos, whereas most were detectable from the underflight photos. From Skylab photos, structures could not be differentiated as to kind, except for larger industrial facilities. From underflight photos, most individual buildings could be differentiated except those in close proximity to one another or near gravel and paved areas. In general, identification was based on color

and reflectivity of the roofing material, building size, and scene contrast. Buildings with bright-colored or highly reflective metal roofs, located on grassy areas, were the easiest to identify.

Cemeteries could not be differentiated on either Skylab or underflight photos, even though they were generally located in treeless areas and the grassland vegetation inside the site differed from that outside.

Windmills could not be identified on either Skylab or underflight photos; however, areas which appeared to be windmill sites could be detected on the underflight photos. These areas were either more lush in vegetation than surrounding areas, owing to water seepage and little animal use, or they were more denuded because animal use was concentrated there. The mills themselves were too small to be seen.

In cultural-feature detection, to aid identification and differentiation of particular features, convergent and divergent inferences can be made by well-trained, knowledgeable interpreters.

Foliar Cover Estimation

Estimates of plant foliar cover, bare soil, and litter were made from two grassland sites (Antero and Eleven Mile) in the South Park portion of the study area. Estimates made from aerial photos by three viewing methods were compared with ground estimates using linear regression techniques. A coefficient of 0.75 accounts for about 50 percent of the variation in the dependent variable (Y), therefore only correlation coefficients of 0.75 or greater were considered valuable. Attempts were made to estimate foliar cover by plant species; however, strong vignetting at the photo edges and extreme emulsion reticulation limited estimation to three cover classes: shrubs, herbaceous vegetation and litter, and bare soil. Results were as follows:

Technique and class:	<i>Correlation coefficients</i>	
	<i>Eleven Mile</i>	<i>Antero</i>
Monocular, micrometer		
Bare soil	0.8423	0.0780
Herbaceous/litter	0.6836*	-0.3698
Shrub	0.4246	-0.7906
Stereo, micrometer		
Bare soil	0.8280*	0.1199
Herbaceous/litter	0.8099*	-0.3315
Shrub	0.4951*	-0.8396*
Monocular, microdensitometer		
Bare soil	0.9299*	-0.5285*
Herbaceous/litter	0.8867*	-0.1433
Shrub	-0.0954	-0.7007

* Significant at 0.05 level.

As shown, the first technique used—the stereoscope and measuring micrometer with monocular optics—provided only two correlation coefficients of 0.75 or greater for the three cover type classes at the two sites. The second technique—stereoscope and micrometer with stereo photos—provided three correlation coefficients greater than 0.75 for the cover classes. Generally the correlation coefficients were higher for all other cover classes within both sites using this technique.

Nevertheless, the micrometer used with the stereoscope was a source of error and inconvenience, for two reasons. First, the micrometer was difficult to align with the imaged transect location markers, and the alignment, once accomplished, was difficult to maintain. The smallest movement of the instrument caused misalignment, and alignment and measurements were difficult or impossible to repeat precisely. Second, the micrometer increments became so large under 20X magnification that it was difficult to “see beyond” the markings onto the image even using stereo pairs.

The microdensitometer, used as a viewing and scanning device, proved most convenient and precise. It allowed the transect location markers to be aligned precisely with the viewing screen crosshairs under 10X magnification and the alignment and measurements were repeatable. The viewing screen also allowed for smaller incremental measurements (0.0001 mm). The major disadvantage was lack of stereo capability. As shown in the tabulation, three correlation coefficients were significantly improved by this technique—the bare soil and litter/herbaceous classes on the Eleven Mile site and the bare soil class on the Antero site.

The test results showed that the correlation coefficients for the three classes were generally higher for the Eleven Mile site than for the Antero site, regardless of technique. The photographs themselves were similar in all respects. Apparently spatial arrangement, stature, and amount of vegetation at the two sites accounted for the difference. Generally, the vegetation at the Eleven Mile site was less complex, less diverse, essentially lacking in shrubs, and of lower stature than that of the Antero site (fig. 17). The vegetation at the Eleven Mile site allowed a more precise estimate of the ground-cover classes. That is, the majority of the vegetative association was mat-forming blue grama and fringed sagebrush (*Artemisia frigida* Willd.), interspersed with definite areas of bare soil and litter. The fringed sagebrush and bare areas were readily interpretable; the remainder was left in the herbaceous/litter class. At the Antero site, fringed



Eleven Mile



Antero

Figure 17—These two sites were used to compare on-ground and aerial photo estimates of plant foliar cover at two grassland sites within the South Park portion of the study area. The vegetation at the Eleven Mile site was less diverse, lacked shrubs, and was of a lower stature than that of the Antero site. The plot frame pictured is 1 m² (3.28 sq ft).

sagebrush was scarce and rabbitbrush (*Chrysothamnus* spp. Nutt.) and actinea (*Hymenoxys* spp. Cass.) were the taller components of the system. These taller plants cast shadows which obscured the low-growing herbaceous plants in the understory.

Results also showed that the range in bare soil estimates between transects within sites was significantly different ($p = 0.99$), even though means for

the sites were not ($p = 0.95$). Individual transect estimates ranged from 10 to 54 percent at the Eleven Mile site and 15 to 45 percent at the Antero site.

Indications from these results are that bare soil, shrubs, and total vegetative cover can be estimated from large-scale photos in two-dimensional space avoiding plant shadows. Also, more accurate and precise estimates could be made by using photography that is not vignettted nor severely reticulated.

Plant Community Classification by Microdensitometer

The MDT was used to point-sample the optical image density of vegetation sample cells of established classes imaged on Skylab photographs. Standard t tests for unpaired plots and unequal sample sizes were used to determine whether there was a significant ($p \geq 0.95$) difference between optical density sample means for the Region and Series level

vegetation classes. If a significant difference was found between classes, then the classes can be separated; this is brought out in the following discussion of the results.

Region Level—The Region level vegetation classes could be separated from each other except for the Deciduous (Aspen) versus Conifer combination. This separation depended on film type, primarily because classes, though dissimilar in visual color signature, had similar optical density on CIR film. Ecotonal mixing of individual type classes also occurred within these two broader classes. Therefore, the mean optical density seemed to be more dependent upon the mixture than the photo date. Deciduous and Conifer classes were separable, however, on color film, even though separability depended somewhat on date. The probability of a correct classification was greater on June S190A photos ($p = 0.99$) than on August S190A photos ($p = 0.95$), probably because the Deciduous

Table 15—Significance of differences between mean optical density¹ values for plant community classes at the Region (Forest) and Series (Grassland) level on Skylab photographs, Manitou, Colorado, test site

Classification level and type	Skylab S190A				Skylab S190B, August, color
	June		August		
	Color	CIR	Color	CIR	
Region:					
Deciduous vs. Conifer	3.32	3.86	4.08	2.06	3.90
Deciduous vs. Grassland	3.45**	3.94	3.88**	2.23	3.63**
Deciduous vs. Conifer	3.32	3.86	4.08	2.06	3.90
Deciduous vs. Grassland	3.01**	3.42**	3.36**	1.79*	3.21**
Conifer vs. Grassland	3.45	3.94	3.88	2.23	3.63
Conifer vs. Grassland	3.01**	3.42**	3.36**	1.79**	3.21**
Series:					
Mountain Bunchgrass vs. Shortgrass	2.98	3.47	3.38	1.86	3.15
Mountain Bunchgrass vs. Shortgrass	2.99	3.42	3.21**	1.75**	3.13
Mountain Bunchgrass vs. Shortgrass	2.98	3.47	3.38	1.86	3.15
Mountain Bunchgrass vs. Shortgrass	2.99	3.42	3.21**	1.75**	3.13
Mountain Bunchgrass vs. Wet Meadow	2.98	3.47	3.38	1.86	3.15
Mountain Bunchgrass vs. Shortgrass	3.12**	3.38	3.77**	1.81	3.63**
Mountain Bunchgrass vs. Wet Meadow	2.99	3.42	3.21	1.75	3.13
Mountain Bunchgrass vs. Wet Meadow	3.12**	3.38	3.77**	1.81	3.63**

* Difference significant at $p = 0.95$.

** Difference significant at $p = 0.99$.

¹ Density (D) = $-\log_{10}$ transmittance (T).



Figure 18—Skylab color photos with sample-square overlays were used for both visual and microdensitometric classification of plant communities at the Region and Series level. In this example (S190B, August, 1:900,000), note the difficulty in discriminating between squares 1 and 2 (*center*). On the ground, square 1 was identified as Shortgrass and square 2 as Mountain Bunchgrass. The overlap between the two squares forms an ecotone between the two classes along a ridge. Square 39 (*lower center*) is a typical Mountain Bunchgrass site at a higher elevation. Two Wet Meadow sites (WM) can be seen left of center. The area imaged is South Park.

class was in the midleaf to full-leaf stage at the early date and the actively growing leaves produced a very strong "light green" reflectance. The new deciduous leaves were lower in optical density than the darker needles of the Conifer class. The late-season Deciduous, with mature leaves, cessation of leaf activity, and some leaf drop at higher elevations, had an optical density nearly as high as that of the Conifer.

Series Level—The MDT interpretation results for classification to the Series level were varied. For instance, all three grassland Series tested could be separated from each other on late-season S190A color photos. The differences were highly significant (*table 15*). Mountain Bunchgrass and Wet Meadow, and Shortgrass and Wet Meadow, on both the early- and late-season normal-color photos could be separated with highly significant differences. Mountain Bunchgrass and Shortgrass Series classes could not be separated, probably because of their very close physiographic proximity. These grassland classes are frequently difficult to separate on the ground. The two

classes form a broad ecotone; Mountain Bunchgrass communities gradually blend into the relatively flat-terrain Shortgrass communities within South Park (*fig. 18*); both classes are short in stature within the ecotone.

The results from CIR early-season S190A photos showed that the three grassland Series classes could not be separated (*table 15*), but results from late-season photos of this film type did show that there was a highly significant difference between the Mountain Bunchgrass and Shortgrass Series classes. Again, the ecotone was partly responsible, and there was some positional inaccuracy of plot overlays on the very small-scale imagery. Time of year and poor film quality also influenced results. That is, vegetation was in an early stage of growth providing little infrared reflectance, and the film was of very poor quality, with a strong blue color saturation predominating.

Within the tree Series classes, only Ponderosa Pine could be separated from all other tree classes at any time; this distinction occurred on late-season S190A

and S190B color photos (table 16). Ponderosa Pine could be consistently separated from the other three Conifer classes regardless of date, film type, or scale. Douglas-fir was separated from the other three classes in both the early-season CIR and late-season color S190A photos (table 16). But as can be seen, Douglas-fir was not consistently separated from the other classes by any one film type and season combination.

Aspen and the Conifer classes could not be separated with any consistency, and the differences were date, film-type, and scale dependent (table 16). For example, Aspen could be separated from Lodgepole Pine in the early-season but not in the late-season S190A color and CIR photos. Aspen was also separable from Spruce/Fir in both the early- and late-season CIR photos and in the early-season color photos. Ponderosa Pine and Aspen could be separated on the late-season S190A and S190B color photos; however, they could not be separated on early-season S190A color and CIR photos.

It is not completely understood why these inconsistencies occurred; however, we believe that the stage of phenological development and Series class mixing are both major factors. For example, Lodgepole Pine and Aspen frequently grow together on the same site. The two classes could be separated on early-season color and CIR S190A photos, but they could not be separated in the S190A late-season photos. Leaf development in the early-season Aspen was only 1/2 to 2/3 complete, and this allowed better discrimination (increased optical density) from Lodgepole Pine. Later season Aspen with mature leaves was not sepa-

rable from Lodgepole Pine, however, because their reflectance (optical density) was similar. In another example, Lodgepole Pine could not be separated from Spruce/Fir because of class mixing and overlapping of the physiographic range of the two classes; both classes also had similar optical densities. Most inconsistencies in Conifer class separation are caused when the species grow in the same area and have very similar optical film densities. Where the Conifer classes were separable, this could be partly attributed to differences in crown cover and the homogeneity of the stands.

Applications

Areal plant community mapping on an extensive basis appears to be highly successful at the Region level. Intensive plant community mapping at the Series level appears to be applicable if the land manager recognizes the constraints imposed by mountainous terrain and the necessity to form community complexes in some areas to allow for interpretation difficulties caused by a natural mixing of dominant species and by terrain slope and aspect.

Plant community mapping can be done on rangeland and forested areas as well as grasslands and shrublands where trees are not dominant or are absent. This type of information can be useful to update existing vegetation maps, most of which are over 10 years old and are outdated by changes in management schemes or land use patterns and by catastrophic events.

Extensive cultural feature mapping and monitoring can also be accomplished using Skylab-type photo-

Table 16—Significance of differences in mean optical density between plant community classes, Forest, Series level, Manitou, Colorado, test site

Forest Series Class	Skylab S190A				Skylab S190B, August, color
	June		August		
	Color	CIR	Color	CIR	
Aspen vs. Douglas-fir	**	ns	ns	*	*
Aspen vs. Lodgepole Pine	**	**	ns	ns	*
Aspen vs. Ponderosa Pine	ns	ns	**	ns	**
Aspen vs. Spruce/Fir	**	**	ns	*	ns
Douglas-fir vs. Lodgepole Pine	ns	*	*	ns	ns
Douglas-fir vs. Ponderosa Pine	**	*	**	**	**
Douglas-fir vs. Spruce/Fir	ns	*	**	ns	ns
Lodgepole Pine vs. Ponderosa Pine	**	**	**	**	**
Lodgepole Pine vs. Spruce/Fir	ns	ns	ns	ns	ns
Ponderosa Pine vs. Spruce/Fir	**	**	**	**	**

* Difference significant at $p = 0.95$.

** Difference significant at $p = 0.99$.

ns = no significant difference.

graphic products. Depending on the mapping objectives, cultural mapping, however, can require supplementary aircraft photography at larger scales. For instance, an aircraft photographic scale of 1:100,000 proved highly successful for most of the cultural features mapped in this study. Mapping features requires either larger scale photos or inference by a skilled interpreter trained in ecological principles. One example of the potential application of cultural feature mapping is a dirt road system being developed within the Manitou area for access to a mountain home development. The roads, about 6.1 m (20 ft) wide, were discernible on the S190B color photos. Such mapping shows a land manager the size and extent of developing areas—information not now readily available for large tracts of land, but required for total land management.

In areas where vegetation has not been mapped or has been mapped only superficially, Skylab-type photographs can be useful as a first level of stratification for both mapping and multistage sampling of

natural vegetation resources. Stratification was especially successful with vegetation units that display a high scene contrast—such as wet meadows within a grassland system—provided those units do not occur in narrow stringers as ecotones and are large enough to be resolved on Skylab-type photographic products.

Skylab-type photographs, coupled with aircraft underflights, can provide a base for multistage sampling schemes in order to stratify and quantify specific plant community systems through the estimation of plant community parameters. Ground data must be used as a final stage. In this study, large-scale (1:600) aircraft photos and ground measurements were used to sample areas delineated on high-altitude aircraft and Skylab photographs to estimate foliar cover of plants and shrubs. Success appears to depend on the diversity of plant communities in relation to the parameters measured.

Descriptive and dichotomous keys (table 17) may also be an aid to the land manager using aircraft and Skylab-type photographic products. These keys can

Table 17—Descriptive key of plant community characteristics imaged on early-season (June) 1:400,000-scale CIR aircraft photos (image characteristics determined from training sample cells used for visual interpretation)

Plant community	Color ¹	Aspect	Crown or foliar cover density	Distribution ²	Texture	Height and resolution ²
Forest:						
Aspen	Very red (11) or deep red (13)	All; drainages	60 to 90 percent; med. to high	Uniform to clumped; often in stringers	Even or rough	Only rarely apparent unless clumped
Douglas-fir	Very deep red (14) or deep red brown (41)	Generally north, east	50 to 80 percent; med. to high	Generally uniform when pure	Even or mottled	Not apparent—a uniform mass
Lodgepole	Deep red brown (41) or dark gray olive (111)	All; in saddles	70 to 90 percent; med. to high	Generally uniform when pure	Smooth or slightly mottled	Not apparent
Ponderosa Pine	Dark olive brown (96) or deep red brown (41)	All; but usually not north	10 to 60 percent; low to med.	Random, not uniform	Slightly mottled	Rarely apparent
Spruce/Fir	Deep red brown (41) or dark red brown (44)	All; commonly north	50 to 90 percent; med. to high	Generally uniform	Slightly mottled	Not apparent
Grassland:						
Mountain Bunchgrass	Very light bluish green (162)	All slopes to nearly flat	30 to 70 percent; low to med.	Varies with terrain; uniform	Smooth	Not apparent
Shortgrass	Pale purple pink (252) or blue white (189)	Flat	10 to 50 percent; low to med.	Uniform if pure	Smooth to mottled	Not apparent
Wet Meadow	Deep red (13) or dark pink (6)	Flat or drainages	30 to 70 percent; low to high	Uniform; near water	Smooth or broken	Not apparent

¹Color notation based on National Bureau of Standards System (NBS 1955). Overlap in colors is result of natural mixing of species and terrain slope and aspect.

²Distribution, height, and resolution of the dominant plant species within the sample cell are described as they appear to the photointerpreter.

be compiled at various levels of classification to characterize the appearance of plant communities. The keys can be used in stratification of plant community units to measure area and to determine boundaries for sampling with very large scale aircraft photos to quantify foliar cover by individual species. Keys can be effective if the user is aware of their constraints within mountainous terrain—especially with smaller

scale photographs which provide synoptic landscape views. Descriptive characteristics, especially image color signature and texture, are affected by terrain slope and aspect (shadows), degree of plant species mixing, ecotones, and general “condition” of the plant community or species. It must also be recognized that image characteristics represent both plant and soil components.

FOREST STRESS DETECTION

Ponderosa Pine Mortality from Mountain Pine Beetle

Frederick P. Weber

The detection of stress in our Nation's wildlands and forests is a large multiagency task for which several million dollars are spent each year in aerial and ground surveys. Stress detection in the National Forest System as well as on State and private lands usually means the detection of insect or disease damage and the evaluation of impact by a count of the number of killed or damaged trees. Only when damage caused by forest pests can be detected early in the development of the pest buildup, can rapid and effective remedial action be taken. Early and reliable detection methods are required where damage or threat of damage extends over large areas and many ownerships.

This part of the Skylab research program was designed to assess the usefulness and comparative effectiveness of data products from three separate systems of the Earth Resources Experiment Package. Data analyses were made to determine the benefits of high spatial resolution (S190B) compared with improved spectral discrimination (S190A and S192), and automatic classification (S192) compared with manual interpretation (S190A and S190B). We established the experimental hypothesis that Skylab could not be used to detect stress in forests, and then attempted to disprove it. The Black Hills National Forest and surrounding lands were chosen as the site of the investigation.

The mountain pine beetle (*Dendroctonus ponderosae* Hopk.) is a threat to ponderosa pine (*Pinus ponderosa* Laws.) throughout the central Rocky Mountain region, and the Black Hills in particular. Aircraft have been used since the mid-1920's to detect and appraise damage caused by the mountain pine beetle. The first remote sensing research to improve aerial detection and appraisal of mountain pine beetle damage in the Black Hills was established in 1952 (Heller and others 1959). During an epidemic outbreak of the mountain pine beetle in the northern Black Hills in 1963-64, the Forest Service Remote Sensing Research Work Unit took aerial color photographs at a scale of 1:7920 over the northern Black Hills. The resulting high-resolution color transparencies were used to train forest resource managers to locate infestation spots and to count dead trees. In 1965 the unit began 8 years of stress detection

research. This work provided invaluable experience in the requirements for insect damage detection and evaluation of impact on resources. Detailed studies established guidelines for aerial photography and also identified complex physiological and environmental relationships affecting interpretation of multispectral data (Weber 1969; Weber and Polcyn 1972; Weber and others 1973).

Beginning in 1972, a LANDSAT-1 (ERTS-1) experiment was conducted in the Black Hills to determine the potential usefulness of low-resolution satellite systems to detect and monitor forest stress and map vegetation cover types. The results of the experiment (Weber and others 1975) indicated that LANDSAT-1 imagery can provide information for broad area planning but cannot provide specific unit estimates of cover-type acreages. The level of classification for which satisfactory accuracies were obtained has questionable utility for the land planner and resource manager. We speculated that the best quantitative application for LANDSAT-1 data was in providing the first broad level of stratification of land use and cover-type classes—acres of deciduous vegetation, acres of coniferous vegetation, etc. Stress detection was a failure in spite of our best efforts. Neither computer-assisted processing of digital tapes nor interpretation of LANDSAT-1 data in photographic form with special optical viewers was a successful technique for detecting stress.

The Skylab studies were designed to evaluate products of a different satellite data-collection system, with possible advantages over the LANDSAT-1 System.

Study Area

The Black Hills test site (fig. 19) is an area of 10,200 km² (3938 sq mi) in western South Dakota and eastern Wyoming. The focus of the site is an elliptical dome extending over 0.75 million hectares (1.85 million acres). The most important tree species, providing more than 95 percent of the total commercial sawtimber volume, is ponderosa pine. Geologically, the Black Hills National Forest portion of the test site is an exposed crystalline core surrounded by sedimentary formations. The central formation, at an



Figure 19—The Black Hills National Forest test site is outlined on this simulated color infrared composite photograph taken with the S190A multispectral camera system on June 9, 1973. Shown within the test site are intensive-study sub-blocks 1 and 2 as well as sub-block 4 in the Bear Lodge Mountains.

elevation between 1200 and 2150 m (4000 and 7000 ft), is highly dissected, with large areas of exposed soil and surface rock. Surrounding the central core are sedimentary formations of Paleozoic limestone. The topography here is gently rolling, especially in the northwestern Black Hills, where the limestone forms a plateau generally above 1800 m (5900 ft). The eastern part of the Black Hills contains the same formations but generally at lower elevations. The radial-dendritic drainage pattern of the permanent east-flowing streams in this area is strongly evident on

satellite imagery. Immediately outside the ponderosa pine zone, which surrounds the Black Hills, is a circular valley formed from reddish Triassic and Permian soft shale and sandstone. The "red valley," as it is called locally, is highly visible on Skylab SL-2 photography.

Our primary investigation area covers 653 km² (252 sq mi) surrounding the gold-mining town of Lead, South Dakota. Two sub-blocks were chosen within the area—Savoy, with an area of 3949 ha (9759 acres), and Englewood, with an area of 4142

ha (10,235 acres). During the SL-3 mission in September 1973, a third sub-block, Warren Peaks, was established outside the primary area in the Bear Lodge Mountains of eastern Wyoming, northwest of the Black Hills. The Warren Peaks sub-block, though never surveyed on the ground, was studied through aerial reconnaissance surveys and newly acquired aerial color photography. The area of this sub-block was 4144 ha (10,240 acres).

In the LANDSAT-1 study (Weber and others 1975) the mountain pine beetle infestation spots on the two intensive study sites were identified on September 1972 aerial photographs (CIR, 1:32,000). The Englewood sub-block contains many moderate- and small-sized mountain pine beetle infestations and is important as a transitional area where little beetle activity is noticeable during endemic conditions. This area is first affected, however, during an expanding bark beetle population, and thus is a good barometer area for an impending epidemic outbreak. The Savoy sub-block is on the west side of the primary study area. Traditionally it contains a full spectrum of mountain pine beetle activity. Here it is common to have high beetle populations, and large volumes of timber are killed annually. In contrast to the Englewood area, the Savoy sub-block has been an area of perpetual activity for the last 13 years and contains the critical mass of the bark beetle population. Beetle populations have remained constantly high in the area, and it is apparently a source of beetles which aggravates the control problem in two surrounding National Forest management areas. The Savoy sub-block contains the largest infestations, which we hoped to detect and map on Skylab imagery. The Warren Peaks sub-block was added to the study because the SL-3 mission did not satisfactorily photograph the Black Hills test site during the best period for forest stress detection. Although the mountain pine beetle does not cause serious damage in the Bear Lodge Mountains, the Warren Peaks area contains numerous dead ponderosa pine, both singly and in small groups. During September 1973, reconnaissance surveys revealed several moderate-sized infestations, showing 25 or more trees per group, west of Warren Peaks.

Classification System

Interpretation of all Black Hills test site imagery—photographic transparencies, color composites, or computer-compatible tape data—is based on the hierarchical classification of Black Hills ecosystem cover types (table 18). This hierarchy was devised specifi-

Table 18—Black Hills National Forest classification hierarchy for remote sensing imagery¹

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

¹ Classes used in computer-assisted mapping are underscored.

² Included rock outcrop for computer mapping.

cally for use with aircraft or satellite imagery and is suitable for the entire Black Hills test site. The nine predominant cover-type classes underscored in the table were used as a basis for mapping the sub-blocks in the test site. For analysis using computer-assisted techniques, a somewhat modified classification system was required, as follows:

<u>Savoy</u>	<u>Englewood</u>
Transition-sunlit	Wet pasture
Bare soil-rock	Dry pasture
Bare soil-sand	Type 1 conifers-sunlit
Type 1 conifers-sunlit	Type 1 conifers-shaded
Type 1 conifers-shaded	Type 2 conifers-sunlit
Type 2 conifers-sunlit	Transition-sunlit
Hardwoods-sunlit	
Dead pine	

Although the major Level III categories in table 18 remained intact, variations in sunlight caused pri-

marily by topography had to be accounted for.

A system for classifying mountain pine beetle infestations by size was also devised. Before evaluating the earth resources satellite data, the Remote Sensing Research Work Unit had classified infestations into photo strata based on the number of trees identified in an infestation spot. For microscale photography and satellite imagery, however, spot size in meters was a more useful measure, as follows:

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

In the sub-blocks, however, only those spots greater than 50 m (165 ft) in the longest dimension were classified.

Skylab Data

September was identified in the original research proposal and data requests as the only satisfactory time (SL-3 mission) to collect data for our studies. Extensive cloud cover obscured the Black Hills on the September 13, 1973 pass, and EREP sensors were not activated on the September 18 pass. We elected, however, to go ahead with our research program on a restricted basis with available data.

An excellent and complete data set was received from the SL-2 overpass of the Black Hills test site on June 9, 1973. Although the imagery was of exceptional quality, June is perhaps the worst possible time of year to detect forest stress resulting from mountain pine beetle damage. Any dead trees in the site had lost most of their discolored foliage during the winter.

Although western South Dakota was obscured by cloud cover during the September 13 pass, there was one good frame of S190B color photography with only a wisp of clouds over the Bear Lodge Mountains, and one poorly exposed frame of color and color infrared (S190A) photography. The S190A frame covered the westernmost piece of the Black Hills test site but was badly underexposed and most of the test site was obscured by clouds. In addition, the S190A frame covered the Bear Lodge Mountains but, again, was poorly exposed over the forest. A special processing effort by the photographic laboratories at Johnson Space Center improved the interpretability of the multispectral images.

Table 19—Tree mortality caused by mountain pine beetle for the years 1972 and 1973,¹ sub-blocks 1, 2, and 4,² Black Hills, S. Dakota, test site

Infestation size class (meters)	Total number of dead trees				
	Englewood (1)		Savoy (2)		Warren Peaks (4)
	1972	1973	1972	1973	
Less than 10	—	148	—	276	236
10 to 25	2,702	2,653	2,552	6,811	399
26 to 50	1,198	1,207	252	3,060	308
51 to 100	1,079	435	—	870	445
101 to 300	715	845	—	325	582
More than 300	—	1,050	—	—	—
Total	5,694	6,338	2,804	11,342	1,970
Ratio, 1972/73	1.11/1		4.04/1		

¹ No data available for Warren Peaks, 1972.

² Area of sub block 1: 3,949.2 ha (9,758.6 acres), 2: 4,142.0 ha (10,235.1 acres), 4: 4,187.2 ha (10,342 acres).

On January 18, 1974, the SL-4 mission passed over the northern tip of the Black Hills test site and obtained coverage of the Savoy and Englewood sub-blocks with the multispectral camera. Although the test area was clear of clouds, the ground was snow covered. As a result, the forest vegetation was underexposed on both the color and color infrared S190A film. The test site was not covered by the S190B nor S192 systems.

Ground Truth

The trend and spread of the mountain pine beetle in the northern Black Hills, which included the Englewood and Savoy sub-blocks, was monitored with 1:32,000 scale color infrared (CIR) aerial photography. These photographs were taken in late August or in early September 1972 and 1973 by the Remote Sensing Research Work Unit. The infestations were delineated and recorded by spot size to test detection by satellite and aircraft sensors (table 19). Other yearly surveys were conducted by the Forest Service Rocky Mountain Region.⁴ These annual surveys provided estimates of bark beetle damage for the entire Black Hills National Forest and were useful in this study.

Forest Service resource photographs for the Bear Lodge Mountains (at a scale of 1:15,840) were used to establish ground truth in the Warren Peaks sub-

⁴ Information on file, U.S. Forest Service, Rocky Mountain Region, Division of Timber Management, Denver, Colorado.

block. We were fortunate that these photographs were in color and taken near the date of the SL-3 photography of the Bear Lodge Mountains.

Tree mortality counts within the Englewood and Savoy sub-blocks for 1972 and 1973 are shown in *table 19*. These data cover the period of the Skylab experiment, but could be used only in part to serve as ground truth. Trees identified as dead on the August 1973 CIR photography had not yet begun to exhibit discoloration at the time of the June 1973 SL-2 mission, and as stated earlier, coverage in the later SL-3 and SL-4 missions was inadequate. Mortality counts for the Warren Peaks sub-block (*table 19*) were obtained from the August 1973 color 1:15,840 resource photography.

An expanding epidemic is evident from a comparison of the mortality totals in the table. Whereas the Savoy sub-block had high mortality counts for both 1972 and 1973, a threefold increase in mortality is seen in the Englewood sub-block from 1972 to 1973. The mortality counts in the Englewood sub-block for 1973 are conservative—many faded trees were removed by salvage logging during July and August 1973 before the photographs were taken.

Infestations varied greatly between the Savoy and Englewood sub-blocks. In the Savoy sub-block there was considerable aggregation of smaller prior infestations into several very large infestation centers in both 1972 and 1973. By contrast, most of the numerous infestation spots in the Englewood sub-block were less than 50 m (165 ft) in size in 1972. With an expanding epidemic in this area, the 1973 resource photography revealed considerable aggregation of smaller spots and the creation of many infestations over 50 m (*table 19*).

From the CIR photography for 1972, 439 sample points representing each of nine cover-type classes shown in *table 19* were selected from the entire test site for the Skylab photointerpretation test. Sample point choice was based on the availability of the sample area for ground check, distribution of the samples throughout the study area, and distinctiveness of the sample point with respect to the surrounding landscape. A map was prepared in the form of an acetate overlay showing the sample points as microdots.

To evaluate the maps created from S192 data tapes by computer-assisted mapping, the type map drawn for the LANDSAT-1 study (Weber and others 1975), using the nine cover-type classes (*table 18*), was used. The type maps were drawn on acetate overlays, from interpretation of 1:32,000 scale CIR resource photographs.

Procedures

Photointerpretation

Before interpretation began, all sub-block boundaries were marked on the Skylab photographs. Three methods were used to detect, count, and map bark-beetle-killed trees on the Skylab products. First, photographs were examined on a Richards MIM 3 light table using a Bausch and Lomb 240 Zoom stereomicroscope. Stereo and zoom optics were changed to provide four separate viewing magnifications. All photo products were viewed in ascending order of scale (1:500,000, 1:100,000, 1:25,000) to reduce the possibility of interpreter bias.

Next, the same Skylab products were viewed in the same way as before except that stereo optics were replaced with monocular optics. The same four viewing scales were used.

Finally, a Variscan rear-projection viewer was used to scan the image at a magnification ratio of 12:1. As areas of interest were identified, the magnification ratio was changed to 29.5:1, which provided the largest interpretation scale. Resultant viewing scales ranged from 1:237,500 to 1:16,000.

Multispectral Scanner Data Analysis

The Skylab S192 multispectral scanner data was analyzed by the University of Kansas Space Technology Center. Only five of the thirteen bands of electromagnetic energy were used, as follows:

Band:	Electromagnetic wavelength range (μm)	Description
3	0.52 to 0.56	Blue-green
6	0.68 to 0.76	Red
8	0.98 to 1.08	Infrared
12	2.10 to 2.35	Infrared
13	10.20 to 12.50	Thermal infrared

These were the bands found to be most useful for stress detection and vegetation mapping when all 13 channels of data were previewed on the Johnson Space Center interactive computer processing system.

The Skylab scanner data, when plotted, follows a circular arc, not a straight line. This geometric distortion occurs because the scanner is pointed at an angle of 5.53° from the vertical. Normally, the resulting conical scan data could be processed by computer without too much difficulty, but when the conical data is displayed on a TV monitor as a straight line, the distortion introduced hinders the location and identification of landmarks and ground truth from

aerial photographs and maps. Therefore, geometric distortions were removed and the scan line data straightened in this analysis by a computer procedure developed at Kansas University.

Line-straightened data for the Savoy and Englewood sub-blocks were processed by the KANDIDATS (Kansas Digital Image Data System) interactive digital multi-image pattern recognition system. This system uses nonparametric statistics, the Bayes decision rule, and the table look-up approach to classification. Categories to be recognized by the system are those listed earlier in this report under "Classification System."

Further information regarding the KANDIDATS processing system can be obtained from the University of Kansas Space Technology Center, Lawrence, Kansas, or the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Results and Discussion

Photointerpretation

From cursory examination of all Skylab photographic products received, we significantly reduced the actual number of frames to be subjected to quantitative interpretation. Monocular and Variscan interpretations were performed only on three S190B color photos from SL-2 and one from SL-3. Stereoscopic interpretations were performed on the three S190B color photos from SL-2. The remainder of the photographic products examined did not reveal evidence of dead trees, forest stress, or bark beetle infestations.

Positive results with S190 photographic products were understood simply as identification of mountain pine beetle infestation spots and not as ability to count individual dead trees. Results are given as a count of infestation spots within sub-block study areas. Furthermore, in the preliminary examination, no infestation spots could be identified on color or color infrared products from the multispectral camera system. Therefore, all identifications were made on normal-color products from the earth terrain camera (S190B).

A comparison of results for the Savoy study area (table 20) revealed the benefit of stereoscopic viewing, both in terms of high number of identified infestations and fewer commission errors. All of the correct identifications were made from a group of 40 infestations larger than 50 m (164 ft longest dimension) and shown on the ground truth map. In all interpretation attempts, all nine infestations on the

ground truth map that were larger than 100 m (328 ft) were located.

Identification within the Englewood study area showed similar results (table 20). All correct identifications within the Englewood study area were made from a group of 26 infestations in the ground truth; they were larger than 26 m (85 ft) but less than 50 m (164 ft).

The optimum viewing scale, using either monocular or stereo optics on the Zoom 240 microscope, was about 1:75,000 (fig. 20). This scale combined satisfactory magnification with reasonably sharp image definition. It is important to note that identification of the dead ponderosa pine in the S190B color film was primarily by the bright reddish-orange color rather than by recognition of any textural difference from the healthy pine. The sparsity of the dead foliage remaining on the trees at the time of the June 9, 1973 pass, 10 months after the time when the dead and dying trees first became visible, undoubtedly prevented much more spectacular results. Furthermore, the low sun angle during the SL-2 pass early in the morning, made interpretation difficult. In the steep terrain of the Black Hills, most infestations on west- and north-facing slopes were in shadow and were not visible.

The comparison of monocular and stereoscopic viewing revealed a definite interpreter preference for stereo. The most tangible benefit of stereo viewing was a lesser tendency to make commission errors in the interpretation of dead tree groups. Most of the commission errors resulted from calling patches of bare soil or exposed forest floor (in sunlight) infestation spots.

Results of interpretation with the Variscan viewer

Table 20—Accuracy of infestation count on Skylab S190B photos by monocular and stereoscopic viewing, for two sub-blocks, Black Hills, S. Dak. test site

Sub-block and viewing scale	Number of infestations			
	Monocular		Stereo	
	Counted	Correct	Counted	Correct
Savoy:				
1:500,000	0	0	4	4
1:100,000	13	12	17	17
1:50,000	18	12	12	12
1:25,000	1	1	3	3
Englewood:				
1:500,000	0	0	1	1
1:100,000	19	14	19	18
1:50,000	22	13	14	14
1:25,000	8	5	4	4



- a Infestation area c Mine tailings e Recreation housing area
b Spearfish Canyon d Hardwood forest

Figure 20—Interpretation of photos at a scale of 1:75,000 was determined to be most effective for resource evaluation, including the detection of dead ponderosa pine. Photo SL2-81-157 was generally considered to represent the best possible imagery with the earth terrain camera, but its resolution of 15+ meters was not good enough to resolve individual trees or small groups of dead trees, such as would be counted in a standing dead timber inventory. Photo scale is approximately 1:100,000.

indicated this technique was inferior to microscopic viewing of transparencies on a good-quality light table. For example, with the Variscan, 1:80,000 was best; at this scale, eight correct identifications were made in the Savoy sub-block and one in the Englewood sub-block.

From our experience with photos from the SL-2 mission, we concluded that it was unfortunate that during the SL-3 mission (1) stereo S190B color coverage was *not* obtained for the Bear Lodge Mountains, and (2) opportunity was not taken to image the Black Hills test site on the September 18, 1973, pass when the entire area was clear of clouds. With monocular viewing of the earth terrain camera photo of the Warren Peaks area (September 13, 1973), the following results were obtained:

Scale:	Number of infestations	
	<u>Counted</u>	<u>Correct</u>
1:500,000	1	1
1:100,000	6	5
1:50,000	5	5
1:25,000	0	0

Close examination of the photo revealed that although large portions of the Bear Lodge Mountains were free of clouds, there were several cumulus clouds in the Warren Peaks area. Also, a thin layer of cirrus clouds covered most of the study area. Although this layer did not obscure the area, it served to absorb red/orange reflected light, detracting from successful identification of dead and dying trees. This phenomenon was most apparent on several frames of

the multispectral camera facility. All the infestation spots identified were larger than 100 m (328 ft, longest dimension) and were oriented on sun-exposed slopes. Three additional spots greater than 100 m (328 ft) were not located in the S190B photography because of their placement on relatively steep north- and northwest-facing slopes.

Multispectral Scanner Data Analysis

The results of this experiment were disappointing. Poor results can be attributed to four factors: (1) quality of the multispectral data (June 9, 1973) was unsatisfactory, (2) data were not collected during the peak of spectral response of beetle-killed trees (September), (3) several channels of data normally used in forest classification were not usable, and (4) the five bands of usable data could not be accurately registered with one another. Ponderosa pine trees killed by the mountain pine beetle were not detected and therefore they were not classified by KANDIDATS processing. The misregistration of MSS bands was probably the primary reason why the relatively small beetle infestations could not be detected.

Using the June 9, 1973 multispectral scanner data and the KANDIDATS processing system, many procedural variations of the spectral bands and variations were attempted to improve and smooth the data. Various combinations of the spectral bands and variations in the table look-up threshold values were tried in an effort to optimize classification results. All attempts, however, were fruitless. The best classification was in the Englewood sub-block. For instance, with training data and paired MSS bands 3 and 6 and 8 and 12 (see "Procedures") in coordination, the best average misclassification rate for all classes was 12 percent. The poorest misclassification rate was 20 percent for wet meadow. Using test data, the poorest classification was for conifer type 2 with 35 percent misclassified. The average misclassification rate for all test data was 15 percent. Other combinations of MSS data bands and table look-up threshold values resulted in higher misclassification rates.

Attempts to improve classification by trying different data smoothing procedures, band pair combinations, table look-up decision rules, and modified ground truth sets were not very rewarding. In one set of experiments, over-all classification accuracy was improved by removing the dead-tree category, combining all conifer categories, and improving the training set for the transition category. The results were better, but because of misregistration, there remained an unavoidable trade-off between interpreting hardwoods as bare soil and rock or interpreting bare soil

and rock as hardwoods. An attempt was made to resolve the conflict between hardwoods and bare soil and rock, by modifying the probabilities of classification based on ground observations—the probabilities were used as weighting factors to improve classification. Results of these different combinations of techniques and processing parameters are quite variable, but the best classification showed only about 70 percent of the 439 sample points correctly identified.

Applications

Of all the Skylab data products, color photography obtained in stereoscopic coverage with the S190B earth terrain camera was best for the location and appraisal of dead ponderosa pine killed by mountain pine beetle. For greatest usefulness, orbital coverage, like aircraft photography, should be obtained in late August or early September during the peak of difference in spectral reflectance between healthy and dying trees. In steep terrain like the Black Hills, where infestations occur independent of slope or aspect, satellite photography obtained in late summer should be planned for midday exposure when the higher sun angles occur. Comparisons of S190B color photography (ground resolution approx. 15 to 20 m or 49 to 66 ft) and higher resolution photographic systems (such as that of the U-2 high-flight aircraft), indicate that satellite photography with a resolution of 1 to 2 m (3.27 to 6.54 ft) ground-resolved distance would be ideal for detection and impact appraisal of stress in forests. Photographic emulsions could be either high-resolution color or color infrared, although the former is preferred.

Although photography from the multispectral camera (S190A) was of no use for stress detection in the Black Hills, both the multiband capability and large area coverage were useful to forest planners and resource managers. They preferred a 28.5X enlargement (1:100,000 scale) of the color infrared band from the multispectral camera system. As a working tool, the CIR print was used to aid in updating existing type-maps, in nonsystem road inventory, and in planning timber sales. All the resource managers and forest planners canvassed in the Black Hills agreed that such a print, received once each year, would be effective in carrying out their work. Interpretative aids to enhance the utility of the photograph would be easy to develop, and include such items as a template overlay showing administrative boundary locations, a geographic coordinate grid overlay, and ownership boundaries. Although no effort was made to create type-maps with Skylab photo products,

they were used successfully to check the type at point locations—as resource managers frequently use photography.

The results of the University of Kansas computer-assisted analysis of S192 multispectral scanner data of the Black Hills showed only limited utility for resource analysis. We recognize that the S192 system was an experimental package, perhaps best thought of as a prototype of a future shuttle scanner. Even so, the scanner performance and resulting image product did not measure up to expectation. Although the gross classification results were reasonable (about 80 percent for most classes), many significant land use classes could not be identified and others had unacceptable errors in point-by-point classification. The pursuit of optimum computer-assisted classification was exhaustive, but the rewards were minimal. A direct comparison of LANDSAT (ERTS) MSS and S192 MSS imagery for the same study blocks was not performed. It is assumed from earlier studies, however, that the classification results would have been similar. Because of the poor quality of band 13 data (thermal IR) the question of whether the benefits of moderate-resolution thermal imagery from space adds significantly to either (1) the detection of stress in forests or (2) the multispectral classification of land use. Analysis of only the two good-quality bands of MSS data was not adequate for our purposes. Detection and classification accuracy suffered because of (1) misregistration of data between bands, (2) inadequate spatial resolution of MSS imagery, and (3) too few bands of usable MSS data for a full and complete analysis.

During the 2½ years since the Skylab launch, we have had the opportunity to test EREP data for several useful applications that are not connected

with the Black Hills study objective:

1. Enlargements of S190B color and CIR photography have been used on the east coast of the United States to obtain baseline data from sample locations approved for the national Forestry Incentives Program (FIP). Location and examination of FIP sites has in many instances provided information, otherwise unavailable, on the condition of practice sites before the program was begun. Although S190B resolution was adequate for some examinations, it was inadequate for others. Again, resolution of 1 to 2 m with CIR film would have been ideal.

2. Stereoscopic enlargements of color photos from the earth terrain camera of standing dead Engelmann spruce (*Picea engelmannii* Parry) in the Jemez Mountains northwest of Los Alamos, New Mexico, proved useful for forest managers. Because no other resource photography was available, the Skylab photography was used for planning sales of large areas of standing dead timber, accessible from existing roads.

3. Black Hills National Forest planners and resource managers used 1:100,000 enlargements of CIR photos from the multispectral camera system. The photos were used for updating cover type maps, for nonsystems road inventory, and for planning timber sale layout. All users agreed that continued availability and use of the satellite photos would produce new and cost-effective applications. For greatest utility, new space photos should be available once a year, or at least once each 3 years. Furthermore, almost all requirements for remote sensing data could be met with space-acquired CIR photography having a resolution of 1 to 2 m ground-resolved distance. User preference was for a stereo pair covering a minimum of 240,000 ha (592,800 acres).

MEASUREMENT OF FOREST TERRAIN REFLECTANCE

Determination of Solar and Atmospheric Effects on Satellite Imagery

Robert W. Dana

A practical method of correcting satellite radiance data to account for changes in solar irradiance and atmospheric effects is a continuing need. Such a method would be useful for a number of reasons: to permit the comparison of spectral signatures of different targets at different sites; to allow accurate measures of spectral variations caused by temporal changes in vegetation and water quality; and to improve techniques for extending spectral signatures from one area to another in computer-aided classification of satellite imagery.

One approach to the problem of obtaining normalization coefficients to correct for solar and atmospheric effects is to study the sensor's response to targets of known reflectance. In the simplest description, the satellite-acquired radiance (N_s) is assumed proportional to terrain reflectance (ρ), with a multiplicative coefficient representing the product of total irradiance and atmospheric transmittance. The radiance data also include an additive term representing the path radiance (N_p) of upward scattered radiation. Specifically, the equation takes this form, assuming the reflector is Lambertian:

$$N_s = \frac{H\tau}{\pi} \rho + N_p \quad (1)$$

in which H = irradiance and τ = beam transmittance.

Reflectance values of two or more areas that vary greatly in brightness when plotted against their corresponding satellite radiance values yield a first-order measure of atmospheric effects at the time of the satellite overflight.

The reflectance measurement technique has an advantage over some other methods in that the data acquisition need not be temporally coincident with the satellite overflight. This technique does not probe the atmosphere but studies the reflection properties of the terrain. During some seasonal periods, terrain reflectance probably does not vary over time. Therefore, the reflectance data might be acceptable if acquired within a week or two of the satellite overflight. An important consideration would be the stability of important target aspects such as plant

phenology, soil moisture, and water turbidity. Of course, it is advisable to work under the same solar irradiation conditions that the satellite sensor experiences (same time of day and similar cloud and haze conditions)—particularly if the targets are non-Lambertian.

This paper reports results of the analysis of one set of Skylab (EREP) photos and one scene of ERTS-1 (LANDSAT-1) multispectral scanner data, offers some conclusions about this experiment, and suggests some possible applications of this type of radiance measurement. All data show a high correlation between satellite radiance and aircraft reflectance, with reasonable values of path radiance resulting from the calculations.

The investigation of solar and atmospheric effects stems from earlier attempts to use near-ground-level radiometric measurements as aids in analyzing satellite imagery (Heller and others 1975). For similar targets, large differences in LANDSAT-1-measured radiance values were noted between different dates of coverage. LANDSAT-1 radiance values also differed by as much as 30 percent from ground-measured values. These examples, combined with past evidence of haze effects in aerial photography, led us to search for a method of accounting for variations in solar irradiance and atmospheric interference.

The prospect of using existing complex atmospheric modeling techniques with their detailed computational procedures did not appeal to us. They would require too much software development and costly wavelength-by-wavelength computations to derive meaningful atmospheric coefficients. Also, accurate modeling probably requires some kind of in situ radiometric measurement. With satellite-matched reflectance measurements, we hoped to devise a simpler means of finding two coefficients that could linearly transform satellite data.

Instead of tower-mounted instrumentation as used in the LANDSAT-1 study, a low-flying aircraft was used in this study to collect reflectance. Thus we avoided two problems—the difficulty of maintaining an unattended field site in an often harsh environ-

ment, and the difficulty of relating a few small tower sites to the large satellite study area. One tower instrument viewed only a small portion of one LANDSAT picture element, whereas a low-flying aircraft could have adequately sampled dozens of targets easily resolved by LANDSAT.

Study Area

The possibility of acquiring Skylab coverage on more than one date for the Black Hills, South Dakota, and the Atlanta, Georgia, sites gave us hope of demonstrating the use of atmospheric corrections to data in these two areas. One possible application was measurement of temporal changes in vegetative spectral signatures. Another application was signature extension from one sub-block to another in computer-aided classification work.

The aircraft system for terrain reflectance measurement was flown over the Savoy and Englewood sub-blocks in the Black Hills study area on July 27, 1973. A mission was also flown over two study blocks of approximately 4050 hectares (10,000 acres) near Carrollton, Georgia (in the original Atlanta study area) on January 13, 1975. Because Skylab imagery did not prove to be available for our underflight coverage, no attempts were made to compute atmospheric effects on Skylab data for these two sites. The Black Hills flight data, however, were analyzed and compared with LANDSAT-1 data.

During the final days of the Skylab program we were able to obtain coverage for a secondary site in northern California. With only a day's notice, a test site was selected 15 km (24 miles) west of Redding, California (fig 21). It was a narrow strip along Skylab track 63 extending from a point 8 km (5 miles) northwest of Whiskeytown Reservoir to the airport on the southeast edge of Redding—a distance of 35 km (22 miles).

The western end of the test area is moderately steep terrain with wooded slopes of mixed ponderosa and digger pine (*Pinus sabiniana* Dougl.), California black oak (*Quercus kelloggii*), and canyon live oak (*Quercus chrysolepis* Liebm.). Patches of manzanita (*Arctostaphylos* sp.) and other chaparral species are also present. The central portion and eastern end of the strip are predominantly mixed oak, chaparral, and pastureland, with some rural homesites.

A few fallow fields and fields of winter crops were noted at the time of the Skylab coverage. The waters of Whiskeytown Reservoir and the Sacramento River appeared relatively turbid during the overpass.

Instrumentation

The instrumentation for gathering the necessary data was installed in a twin-engine Aero Commander 500B aircraft modified for aerial photography. The equipment consisted primarily of a radiometer, irradiance meter, highspeed recorder, vidicon (video) camera, video tape unit, and wide bandpass filter sets (fig. 22). Power for most components was provided by a stabilized (frequency and voltage) inverter rated at 500 watts, running off the 28-volt d.c. aircraft supply.

Reflectance was measured by an upward-pointing irradiance meter and a downward-pointing radiometer. The silicon diode detectors were filtered to match the bandwidths of LANDSAT-1 multispectral scanner and Skylab S190 sensors. The reflectance was derived from the aircraft radiance N_a using equation 2, in which the altitude is assumed to be low enough to minimize the effects of atmospheric path:

$$\rho = \frac{\pi N_a}{H} \quad (2)$$

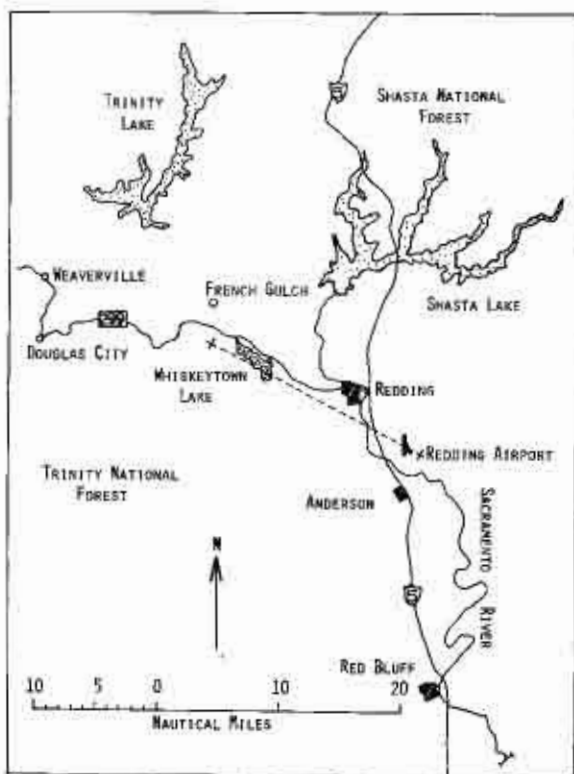


Figure 21—The test site for measurement of forest terrain reflectance was a strip 35 km (22 miles) long between Redding Airport and Whiskeytown Reservoir.



Figure 22—Equipment for aircraft target measurement of terrain reflectance included (left to right) video tape recorder, strip chart recorder, radiometer, static inverter, irradiance meter with input probe and filter chamber, TV monitors, vidicon camera, and radiometer input probe on aerial camera mount.

When H or N_a are known at the time of satellite overflight, equations 1 and 2 can be used to find the beam transmittance:

$$\tau = \frac{\pi(N_s - N_p)}{H\rho} = \frac{N_s - N_p}{N_a} \quad (3)$$

The Skylab S190A photos to be compared with the reflectance data were scanned by a digital microdensitometer. Programs were written to convert the microdensity values to diffuse density and subsequently to effective film exposure at the film plane.

Radiometer

The radiometer employed for measurement of terrain radiance is an Optronic Laboratories Model 700F with digital and analog output. It amplifies the signal from a silicon photodiode in a photovoltaic current-to-voltage mode and provides six decades of linear amplitude. The full-scale value of the most sensitive range is about 1×10^{-8} A or about 3×10^{-8} W of light energy on a silicon detector. It is more sensitive than necessary for this experiment because our normal operation was about 1 microamp.

The radiometer was custom built for low noise and high frequency response. For a square-wave input at the 1 microamp level, the total of the rise and fall times and the transient effect of any underdamping conditions in the output wave is less than 1 millisecond. Therefore, this instrument is responsive enough for measurements at aircraft speeds up to 45 meters per second (100 mi/h).

The input optical probe was constructed from a machined aluminum block linking a 135-mm camera lens and a planar-diffused junction silicon diode, which is masked by a 6-mm diameter aperture. The resultant field of view (FOV) is 44 milliradians or a full angle of 2.6° . At the designed experimental altitude of 300 m, the ground resolution is 13 m. Light filtration is accomplished with 50-mm filters mounted on the front of the lens.

Irradiance Meter

Total irradiance at aircraft altitude was measured with an electronics package designed and built in our laboratory. It essentially matches the performance characteristics of the unit used for gathering radiance data. Light from a diffuser mounted in the top surface of the aircraft was carried by a fiber optics light

ment, and the difficulty of relating a few small tower sites to the large satellite study area. One tower instrument viewed only a small portion of one LANDSAT picture element, whereas a low-flying aircraft could have adequately sampled dozens of targets easily resolved by LANDSAT.

Study Area

The possibility of acquiring Skylab coverage on more than one date for the Black Hills, South Dakota, and the Atlanta, Georgia, sites gave us hope of demonstrating the use of atmospheric corrections to data in these two areas. One possible application was measurement of temporal changes in vegetative spectral signatures. Another application was signature extension from one sub-block to another in computer-aided classification work.

The aircraft system for terrain reflectance measurement was flown over the Savoy and Englewood sub-blocks in the Black Hills study area on July 27, 1973. A mission was also flown over two study blocks of approximately 4050 hectares (10,000 acres) near Carrollton, Georgia (in the original Atlanta study area) on January 13, 1975. Because Skylab imagery did not prove to be available for our underflight coverage, no attempts were made to compute atmospheric effects on Skylab data for these two sites. The Black Hills flight data, however, were analyzed and compared with LANDSAT-1 data.

During the final days of the Skylab program we were able to obtain coverage for a secondary site in northern California. With only a day's notice, a test site was selected 15 km (24 miles) west of Redding, California (fig 21). It was a narrow strip along Skylab track 63 extending from a point 8 km (5 miles) northwest of Whiskeytown Reservoir to the airport on the southeast edge of Redding—a distance of 35 km (22 miles).

The western end of the test area is moderately steep terrain with wooded slopes of mixed ponderosa and digger pine (*Pinus sabiniana* Dougl.), California black oak (*Quercus kelloggii*), and canyon live oak (*Quercus chrysolepis* Liebm.). Patches of manzanita (*Arctostaphylos* sp.) and other chaparral species are also present. The central portion and eastern end of the strip are predominantly mixed oak, chaparral, and pastureland, with some rural homesites.

A few fallow fields and fields of winter crops were noted at the time of the Skylab coverage. The waters of Whiskeytown Reservoir and the Sacramento River appeared relatively turbid during the overpass.

Instrumentation

The instrumentation for gathering the necessary data was installed in a twin-engine Aero Commander 500B aircraft modified for aerial photography. The equipment consisted primarily of a radiometer, irradiance meter, highspeed recorder, vidicon (video) camera, video tape unit, and wide bandpass filter sets (fig. 22). Power for most components was provided by a stabilized (frequency and voltage) inverter rated at 500 watts, running off the 28-volt d.c. aircraft supply.

Reflectance was measured by an upward-pointing irradiance meter and a downward-pointing radiometer. The silicon diode detectors were filtered to match the bandwidths of LANDSAT-1 multispectral scanner and Skylab S190 sensors. The reflectance was derived from the aircraft radiance N_a using equation 2, in which the altitude is assumed to be low enough to minimize the effects of atmospheric path:

$$\rho = \frac{\pi N_a}{H} \quad (2)$$

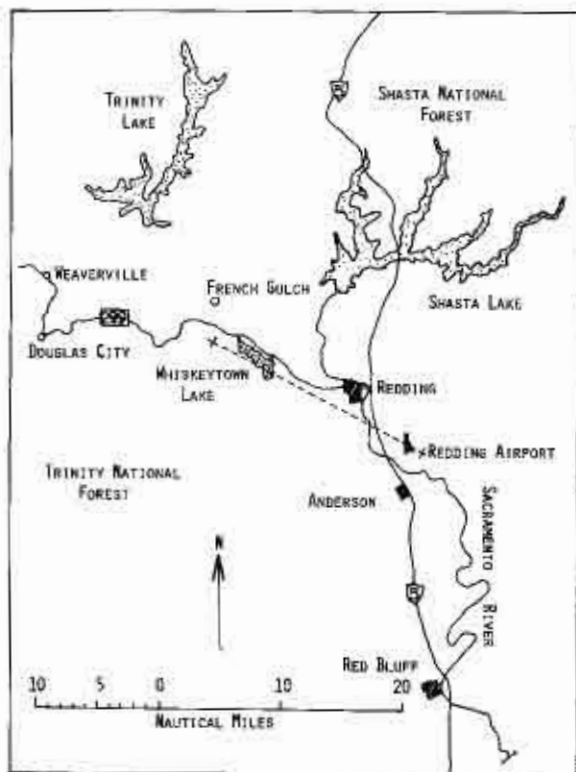


Figure 21—The test site for measurement of forest terrain reflectance was a strip 35 km (22 miles) long between Redding Airport and Whiskeytown Reservoir.



Figure 22—Equipment for aircraft target measurement of terrain reflectance included (left to right) video tape recorder, strip chart recorder, radiometer, static inverter, irradiance meter with input probe and filter chamber, TV monitors, vidicon camera, and radiometer input probe on aerial camera mount.

When H or N_a are known at the time of satellite overflight, equations 1 and 2 can be used to find the beam transmittance:

$$\tau = \frac{\pi(N_s - N_p)}{H\rho} = \frac{N_s - N_p}{N_a} \quad (3)$$

The Skylab S190A photos to be compared with the reflectance data were scanned by a digital microdensitometer. Programs were written to convert the microdensity values to diffuse density and subsequently to effective film exposure at the film plane.

Radiometer

The radiometer employed for measurement of terrain radiance is an Optronic Laboratories Model 700F with digital and analog output. It amplifies the signal from a silicon photodiode in a photovoltaic current-to-voltage mode and provides six decades of linear amplitude. The full-scale value of the most sensitive range is about $1 \times 10^{-8} \text{ A}$ or about $3 \times 10^{-8} \text{ W}$ of light energy on a silicon detector. It is more sensitive than necessary for this experiment because our normal operation was about 1 microamp.

The radiometer was custom built for low noise and high frequency response. For a square-wave input at the 1 microamp level, the total of the rise and fall times and the transient effect of any underdamping conditions in the output wave is less than 1 millisecond. Therefore, this instrument is responsive enough for measurements at aircraft speeds up to 45 meters per second (100 mi/h).

The input optical probe was constructed from a machined aluminum block linking a 135-mm camera lens and a planar-diffused junction silicon diode, which is masked by a 6-mm diameter aperture. The resultant field of view (FOV) is 44 milliradians or a full angle of 2.6° . At the designed experimental altitude of 300 m, the ground resolution is 13 m. Light filtration is accomplished with 50-mm filters mounted on the front of the lens.

Irradiance Meter

Total irradiance at aircraft altitude was measured with an electronics package designed and built in our laboratory. It essentially matches the performance characteristics of the unit used for gathering radiance data. Light from a diffuser mounted in the top surface of the aircraft was carried by a fiber optics light

guide to a filter and detector chamber. An identical optical assembly was constructed to use in laboratory calibrations. Necessary cosine correction of the data for low sun angle effects was accomplished by a laboratory goniometric technique. (Details of the technique for cosine correction for the irradiance probe are available on request; see Introduction.) This correction is in the order of +10 percent for a zenith angle of 60°.

Data Recorder

The radiance and irradiance data were recorded on a Brush Mark 222 portable chart recorder. This battery- or a.c.-powered recorder accommodates two independent channels of analog data at a fast rate. Full response for a moderate amplitude takes less than 14 milliseconds, which means that the ground track being sensed has moved only about 0.6 m or less than 5 percent of the diameter of the spot being measured.

Video Equipment

To locate precisely the flight path corresponding to a narrow FOV radiance measurement, support imagery showing the surrounding terrain is required. A vidicon camera with magnetic tape recording was chosen for its capability of real-time measurement. The cameraman can see in a monitor the picture being recorded and replay the tape immediately after completing a flight line to be certain he has flown the right area and recorded the necessary imagery.

In addition to its real-time capability, the vidicon camera can approximate the spectral response of the radiometer and irradiance meter by use of filters and a silicon diode array pickup tube in the camera. The silicon target in an RCA model 4532 tube had a spectral sensitivity curve similar to the curve of the photodiodes used in the radiometer and irradiance meter (fig. 23). The silicon vidicon camera is so sensitive in the absolute sense that normal operation in the plane required a lens opening of $f/11$ and a neutral-density filter of 10 percent transmittance in combination with the bandpass filter.

The vidicon camera was vertically mounted on a mapping camera mount with the boresighted radiometer secured to the camera housing. Two small closed-circuit TV monitors were used—one in the front of the aircraft to aid the pilots in navigating along the flight line, and the other in the rear for the instrument operators.

The video signal was recorded on a commercial-quality half-inch tape recorder (VTR). Although the image resolution with this device is limited to about

300 TV lines per picture height (the camera itself is capable of 700), this low-cost recorder does allow playback of useful pictures. Analysis can be conducted at normal speed, variable slow speeds, or at a stop-action setting.

The VTR employed in this study had two available audio channels. One channel was used for house-keeping data introduced by a microphone. On the other channel, a timing signal was introduced by an audio pulse generator, which synchronously excited an event marker on the chart recorder. This provided time-base synchronization of the VTR with the chart recorder.

Filter Sets

In matching the Skylab S190A bands, we were limited by the time and funds available. We attempted to match the spectral responses of the four bands that utilized black-and-white film. Three sets of filters were required—one each for the irradiance meter, radiometer, and vidicon imager. We selected off-the-shelf absorption glass filters in stock thicknesses to meet the time and cost constraints. For each spectral band a cut-on filter was combined with a glass filter for absorption of long wavelengths. The filter sets and their thicknesses, in millimeters, were:

- A. Hoya Y-50 (2.5) and Schott BG-18 (1.0)
- B. Hoya R-60 (2.5), and Hoya HA-30 (3.0), and Schott BG-20 (2.0)
- C. Hoya R-70 (2.5) and Hoya HA-30 (3.0)
- D. Hoya IR-80 (2.5) and Hoya B-370 (2.5)

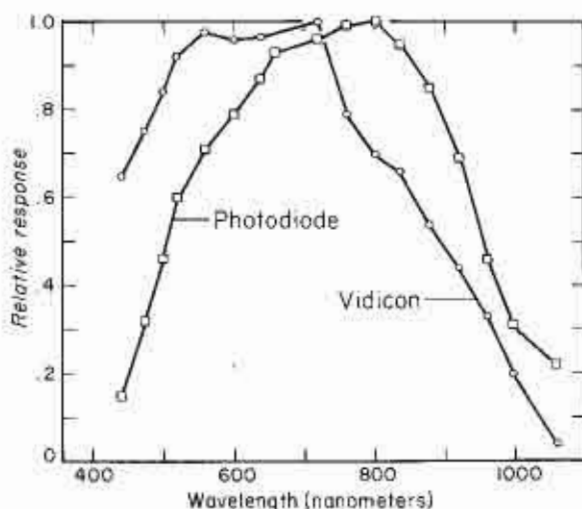


Figure 23—The spectral response of the silicon vidicon is similar to that of the photodiode. Each curve was separately normalized to its highest value.

The spectral responses of the vidicon and photodiodes were combined with filter transmittance data to arrive at curves of system spectral response. The spectral response of the S190A camera stations employing black-and-white film was also computed (computation available on request). The film spectral sensitometry data were taken into account, as well as spectral transmittances of all optical components in the system. The bandwidths are summarized in terms of the locations of the half-power points where the response reaches 50 percent of the peak value (table 21).

Although mismatches between the Skylab cameras and the radiometric instruments are apparent, they may not cause large errors in wideband measurements of terrain reflectance. The most important difference occurs between filter set B and station 5, where the radiometer and vidicon pick up excess energy from the strong infrared reflection band of live vegetation, beginning at about 700 nanometers (nm). This condition would result in a higher reflectance value from some aircraft measurements than that to which the satellite camera responds.

Skylab Data

For the northern California site we requested and received photographic data from mission SL-4, pass 93 (January 27, 1974), ground track 6. The data included duplicate films for S190A, magazines 73 through 78, and S190B, magazine 94. The western 40 percent of the aircraft flight path over which we obtained reflectance data was cloudfree on the S190A photos. The S190B camera was turned on too late to include any of the test site.

All camera stations of the S190A package were operable except station 5. The critical frame (number 214) was blank for this red band. The green band (station 6) and the normal-color band (station 4)

were well exposed, but the three infrared-sensitive bands (stations 1, 2, and 3) were slightly underexposed.

High-resolution images from stations 6 and 4 supported meaningful microdensitometer scanning increments as small as 8 microns (fig. 24). The black-and-white infrared images of stations 1 and 2 were very granular and did not merit scanning increments smaller than 32 microns. Features smaller than 100 m (327 ft) across were rarely detected by eye on the infrared images.

Procedures for Data Analyses

The experiment produced two kinds of data to be reduced and analyzed. The first consisted of aircraft radiance and irradiance data, recorded on a strip chart; these data had to be reduced to average target reflectance values for specific areas on the ground. Conventional manual and computer-aided techniques were used. The second kind of data was Skylab imagery, which required the conversion of photographic density to apparent radiance values. A new computer technique was developed utilizing sensitometric data provided by the Photographic Technology Division of NASA/JSC. Data gathered earlier during the study of the LANDSAT-1 satellite was also analyzed, as described below under "Results and Discussion."

Aircraft Radiance and Irradiance Data

Before analyzing the radiance data, we reviewed the video tapes of the flights and plotted the flight paths on available maps and aerial photo coverage. To find the large-scale video paths on 1:2,900,000-scale space photos, it was often necessary to transfer the paths to a medium scale, such as 1:15,000 resource photography. Thus, it was possible to determine

Table 21-Relation of spectral response bandwidths for Skylab camera stations and Forest Service instruments, using filter sets with either silicon vidicon or Pln 10-DB diffused silicon photodiode

Camera station/ filter set	Bandwidth			
	Skylab		USFS instruments	
	Design	Actual	Photodiode	Vidicon
<i>Half-power points, nanometers</i>				
Station 1/filter C	700 to 800	713 to 814	689 to 779	690 to 780
Station 2/filter D	800 to 900	805 to 882	810 to 956	805 to 965
Station 5/filter B	600 to 700	601 to 695	605 to 723	605 to 720
Station 6/filter A	500 to 600	517 to 594	497 to 622	495 to 615



Figure 24—Microdensitometer scanning at 8-micron increments was feasible for the northern California site imaged by S190A camera station 6.

which parts of the radiance data stream represent relatively homogeneous areas that are resolvable on the satellite imagery.

The strip chart data were sampled with a digitizer at intervals equaling approximately 20 m on the ground. The ratios of radiance to irradiance were calculated by computer to generate a data stream of reflectance values. Calibration coefficients for the radiometer, irradiance meter, and chart recorder were derived in our laboratory near the time of the aircraft flights by using a light source with calibration trace-

able to a National Bureau of Standards source. We selected portions of the data stream that transected 6 to 13 homogeneous areas of interest on the photos, and computed mean values of reflectance.

Skylab Photographic Data

The satellite radiance data were derived from digital microdensitometer (MDT) scans made on duplicate photos of the test site, using a Photometric Data Systems Model 1010 unit. The NASA sensitometric data is given in terms of macroscale diffuse density. Cross-calibration scales between microdensity and diffuse density differ considerably for variations in film properties, MDT numerical aperture, and general internal optical design (Weiss 1973; Schmitt and Altman 1970). Hence it was necessary to calibrate microdensity against the diffuse density scale by using calibrated samples of copy films provided by JSC. Working in diffuse density units, we chose not to use the intermediate steps dealing with the original film sensitometry, but to compare measured duplicate densities with those produced by the exposure values applied to the original film. The system response curve was obtained by polynomial modeling techniques described by Dana (1973).

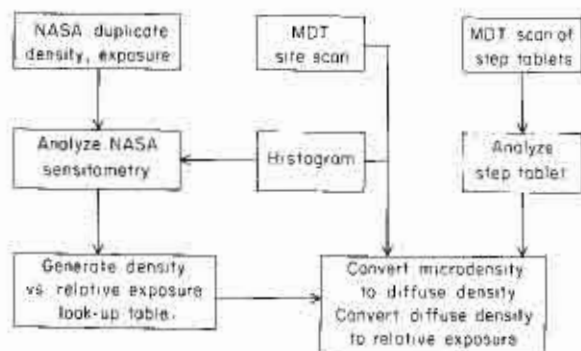


Figure 25—The density calibration program had three parallel paths, as shown.

The analysis and data flow proceeded generally in three parallel paths (fig. 25). From the microdensitometer scan of the test site, a histogram was generated in the first path to establish the range of density values which must be calibrated. This data tape was then ready for the final processing step. In the second path a separate tape containing the JSC step-tablet scans was analyzed by a program called RNSTAB. A least-squares fit of the microdensity M (in digital counts) to diffuse density D produced a second-order equation with a standard error always less than 0.01 diffuse density units for the three copy films used. (A linear form was tried, but it produced standard errors of about 0.04.) Conversion to diffuse density could then be made with an equation of the form

$$D = C_2 M^2 + C_1 M + C_0 \quad (4)$$

in which C_2 , C_1 , and C_0 are modeling coefficients.

In a third path, modeling of the photographic system response generally resulted in an equation for duplicate density that was third order in $\log_{10}$ of relative exposure. Some of the narrower ranges of density could be fit to a second-order curve. From these equations, look-up tables were generated to do the actual conversion.

The look-up table, the coefficients of the density conversion equations from RNSTAB, and the site-scan tape were put into a program named XCAL, which derives and prints out a relative exposure value for each microdensity value. Another program, DENCAL, combines the functions of RNSTAB and XCAL, utilizing the look-up table and both MDT input tapes in one computer run. DENCAL writes an exposure tape, as well as a printout, but does not have the flexibility of selecting different combinations of scanning runs from the MDT tapes as do RNSTAB and XCAL.

Once the relative exposure printout was obtained, the data corresponding to particular image blocks were identified and mean values computed for each. The absolute exposure E at the film plane was computed by using additional data provided by NASA. A conversion to equivalent radiance N in engineering units (Jenson 1968) was made by the equation

$$N = \frac{4F^2}{\pi t T} E \quad (5)$$

in which F = camera lens f-number, t = integrated exposure time, and T = total transmittance of camera lens, filter, and window.

Results and Discussion

For the Whiskeytown Reservoir site covered by Skylab photos, the distributions of reflectance (measured on the same day) were recorded and satellite radiance values were computed (fig. 26). The green band results indicate the possibility of two distinct populations of reflectance—one around 0.04 and another around 0.14. Possibly a high linear correlation is forced on the data, but exclusion of the two high points yields a difference in path radiance of only 3 percent from linear regression. The slope of the new regression line would be 11 percent less. How the reflectance data should be used for classification depends on the distribution of radiance and reflectance values in the training and test areas. Multimodal data might present problems.

Camera station 5 (red band) malfunctioned momentarily over the Whiskeytown area and the photo in that band was not taken. But it was possible to compute the relative exposure values from red-filtered densitometer scans of the normal-color film (SO-356) from camera station 4. Since the red-sensitive layer in color film is not exclusively sensitive to the red wavelengths, we did not try to convert exposure to absolute radiance. Nevertheless, reflectance and exposure were closely correlated in the red region (fig. 26), as they were in the other wavelength regions.

Further evidence of the linear relationship between reflectance and satellite radiance came from a test flight in the Black Hills on August 27, 1973 (fig. 26). Because of anomalies in calibration data, reflectance is shown here in normalized form. The satellite radiance values were from LANDSAT-1 image 1028-17121 of the same area taken on August 20, 1972. No LANDSAT data from August to September 1973 were usable because of cloud cover. Average radiance values were computed from the system-corrected computer tapes and converted from digital counts to engineering units using conversion data from appropriate NASA publications (NASA 1972; Thomas 1973).

All correlation coefficients exceeded 0.94, suggesting that the radiance equation 1 is valid (table 22). The path radiance values are all within the range of those reported by Rogers and others (1973) for four different LANDSAT images. We do not understand why camera station 2 recorded more path radiance than camera station 1, as station 2 represents longer wavelengths and has a narrower bandwidth. One possible source of error is the large factor (roughly 1.5 to 2.3) used in the NASA sensitometry pro-

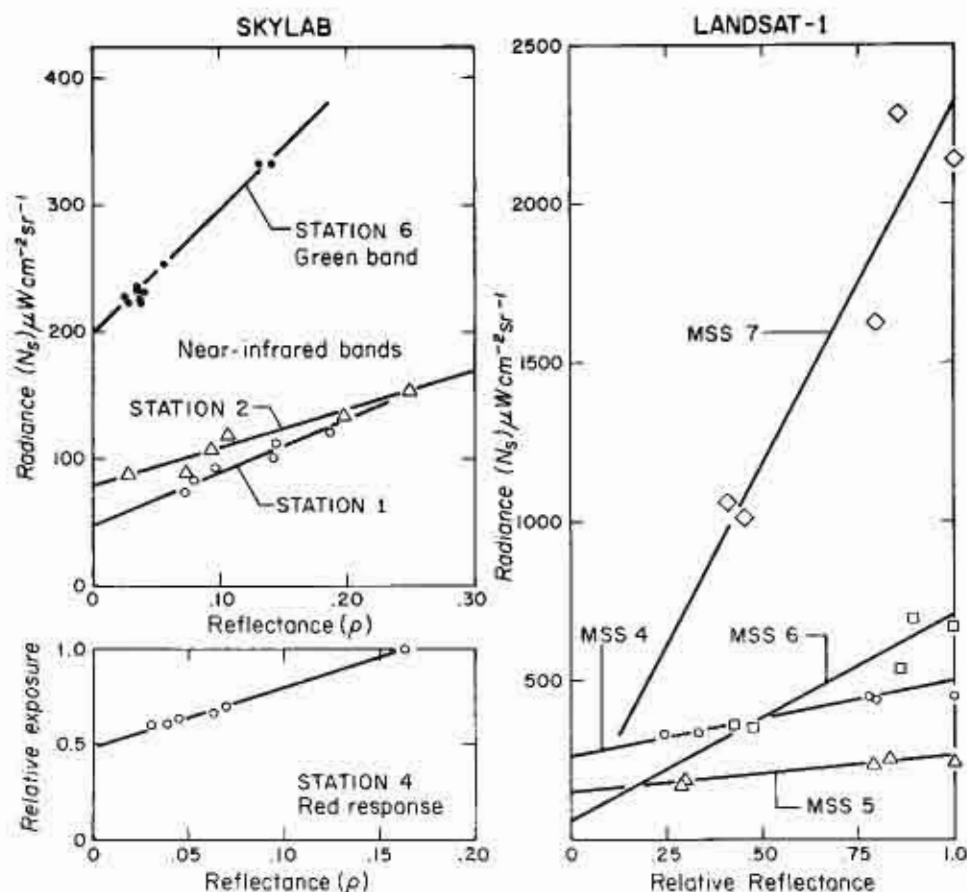


Figure 26—Relationships between radiance and reflectance are graphed here for Skylab and ERTS for various bands. For Skylab camera station 5, because no photo was available, relative exposure and reflectance for the red response of the normal-color film of camera station 4 were calculated. For LANDSAT multispectral scanner data, reflectance in each band was separately normalized to its highest value.

Table 22—Path radiance values and correlation coefficients derived from analysis of the relation between satellite radiance and terrain reflectance

Space platform, sensor, camera station or band, and bandwidth (nm)	Path radiance	Correlation coefficient
	$\mu W \text{ cm}^{-2} \text{ sr}^{-1}$	
Skylab S190A:		
6-517 to 594	196	.98
4 ¹	—	.99
1-713 to 814	51	.96
2-805 to 882	78	.97
LANDSAT-1, multispectral scanner:		
4-494 to 598	289	.98
5-604 to 700	153	.96
6-693 to 799	77	.95
7-808 to 987	76	.94

¹ Relative exposure of red response.

cedure to correct for a wider band Kodak Wratten 89 filter used in the sensitometer rather than the actual flight filters. We also found other unexplained discrepancies in comparing ground-measured radiance data with values from S190A film density, amounting to as much as 40 percent.⁵ The matter deserves further study.

The space photos indicated semitransparent cirrus or cirrostratus clouds in the vicinity of the test site. Also, a very light and variable cirroform veil was noted about 1 hour after the Skylab overflight when the aircraft flight was performed. Therefore, undetected ice crystals or other aerosols might have contributed to the anomaly in near-infrared path radiance.

⁵ National Aeronautics and Space Administration. 1974. *Skylab program, sensor performance report, vol. 1 (S190A)*, MSC-05528. NASA L. B. Johnson Space Center, p. 5-8p to 5-8q.

Despite the increasing cirrus veil, the appearance of strong shadows in the forest at the time of the aircraft flight suggested that the reflectance data would be valid for a clear sky. However, only the radiance and irradiance data acquired early in the flight for the green band could be considered valid for beam transmittance calculations using equation 3. The result was 0.86 ± 0.05 .

Applications

This reflectance measurement technique shows much promise as a means of obtaining valid values of the path radiance components of satellite imagery and probably of high-altitude aircraft imagery. Although this method may not be the least expensive one, it may be a valuable adjunct to computational methods or to methods using ground-based instrumentation requiring measurements coincident to the satellite overpass. Plans are underway to compare the aircraft reflectance method with the groundbased method developed by Rogers and Peacock (Rogers and others 1973). This comparison should at least help determine the relationship of the slope of the regression line to total irradiance and beam transmittance.

Several variables affecting the aircraft measurement technique need to be investigated. Most of them concern the question of how closely the flight conditions must match those at the time of satellite overflight. These variables include solar zenith angle, viewing angle, time of day, aircraft altitude, and spectral effects.

Equation 1, which is concerned with spectral effects, is strictly valid only at individual wavelengths

or for narrow bandwidths. The factors τ , H , ρ , and N_p are all spectrally dependent. Since the broadband measurements are actually integrals over wavelength, the results should be checked against measurements made with spectroradiometers (Hulstrom 1974).

Possible applications of linear atmospheric transformation in computer classification have been discussed in the literature (Rogers and others 1973; Potter 1974; Kan 1972). The objective is to extend spectral signatures from a classified scene or data set to a similar unclassified set when the main differences are due to solar and atmospheric effects. Rewriting equation 1 we have

$$N_i = a_i \rho_i + b_i \quad (6)$$

in which the subscript i refers to the wavelength band. Knowing the correct coefficients a_i and b_i , one could convert the radiance sets N_i to reflectance sets ρ_i before classification. Also, new sets of radiance data N'_i (with coefficients a'_i and b'_i) could be converted to the scale of previous sets by the equation

$$N_i = \frac{a_i}{a'_i} N'_i + \frac{a_i}{a'_i} b'_i + b_i \quad (7)$$

In a supervised classification scheme requiring training sets, one could transform the discriminant function used in the analysis of the old data set to the scale of the new data set. This method should require the least amount of computation. For example, using a Gaussian linear classifier implies the transformation of the mean vector and the covariance matrix to new functions that are applicable to the new data set.

LITERATURE CITED

- Aldrich, R. C.
1971. Space photos for land use and forestry. *Photogramm. Eng.* 37(4):389-401, illus.
- Aldrich, R. C., N. X. Norick, and W. J. Greentree.
1975. Forest Inventory: Land use classification and forest disturbance monitoring. In *Evaluation of ERTS-1 data for forest and rangeland surveys*. USDA Forest Serv. Res. Paper PSW-112, 67 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
- Canfield, R. H.
1942. Sampling ranges by the line-interception method. Res. Rep. 4. 28 p. USDA Forest Serv., Southwest Forest and Range Exp. Stn., Tucson, Ariz.
- Dana, R. W.
1973. Digital sensitometry of color infrared film as an aid to pattern recognition studies. In *Remote Sensing of Earth Resour.*, 2:435-452. Space Inst., Univ. of Tennessee, Tullahoma, Tenn.
- Daubenmire, R. F.
1952. Forest vegetation of northern Idaho and adjacent Washington and its bearing on concepts of vegetation classification. *Ecol. Monogr.* 22:301-330.
- Draeger, W. C., L. R. Pettinger, and A. S. Benson.
1971. The use of small scale aerial photography in a regional agricultural survey. In *Proc. Seventh Int. Symp. on Remote Sensing of Environ.* Univ. of Mich., Ann Arbor, 2:1205-1217.
- Driscoll, R. S.
1969. Aerial color and color infrared photography—some applications and problems for grazing resource inventories. In *Proc. Aerial Color Photogr. in Plant Sci.* Aerial Color Photogr. Workshop, Univ. of Florida, Gainesville, p. 140-149.
- Driscoll, R. S., and R. E. Francis.
1972. Multistage, multiband, and sequential imagery to identify and quantify non-forest vegetation resources. Final report Earth Resour. Surv. Program, NASA Office Space Sci. and Appl., 49 p.
- Driscoll, R. S., and R. E. Francis.
1975. Range Inventory: Classification of plant communities. In *Evaluation of ERTS-1 data for forest and rangeland surveys*. USDA Forest Serv. Res. Paper PSW-112, 67 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
- Heller, R. C., Tech. Coord.
1975. Evaluation of ERTS-1 data for forest and rangeland surveys. USDA Forest Serv. Res. Paper PSW-112, 67 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
- Heller, R. C., J. L. Bean, and F. B. Knight.
1959. Aerial surveys of Black Hills beetle infestations. Stn. Paper 46, 8 p. Rocky Mountain Forest and Range Exp. Stn., Fort Collins, Colo.
- Hildebrandt, G.
1973. Use of earth satellites for supranational inventories of forest and agricultural areas. *Raumfahrtforschung*, 17:164-168.
- Hulstrom, R. L.
1974. Spectral measurements and analyses of atmospheric effects on remote sensor data. *Proc. of the Soc. of Photo-optical Instrum. Eng. Semin. on Scanners and Imagery Syst. for Earth Observ.* [San Diego, Calif., August 10-20, 1974], 51:90-109.
- Jensen, N.
1968. Optical photographic reconnaissance systems, p. 73-76. John Wiley and Sons: New York and London.
- Kan, E. P. F.
1972. Effects of atmospheric correction on classification. Lockheed Electron. Co., Inc., Houston Aerospace Syst. Div., Houston. Publ. LEC Number TM642-620. 9 p.
- Kuusela, L., and S. Poso.
1972. Multi-stage acquisition of forest information from space and aircraft imagery and ground sampling. In *Space Research III. Proc. of the Fifteenth Plenary Meet.* 1:113-117.
- Langley, P. G., R. C. Aldrich, and R. C. Heller.
1969. Multistage sampling of forest resources by using space photography. In *Second Annu. Earth Resour. Aircr. Program Status Rev. Vol. 2, Agric./For. and Sens. Studies*. NASA Manned Spacecr. Cent., Houston. p. 19-2 to 19-21.
- Munsell Color Company.
1920-1960. *Munsell book of color*. Munsell Color Co. Baltimore.
- National Aeronautics and Space Administration, Goddard Space Flight Center.
1972. Data users handbook: NASA Earth Resources Technology Satellite. Doc. No. 71SD4249. NASA Goddard Space Flight Center, Greenbelt, Md. p. G-14.
- National Bureau of Standards.
1955. The ISCC-NBS method of designating color and a dictionary of color names. U.S. Dep. of Comm., NBS, Circular 553.
- Nichols, J. D., M. Gialdini, and S. Jaakkola.
1973. A timber inventory based upon manual and automated analysis of ERTS-1 and supporting aircraft data using multistage probability sampling. Vol. 1: Tech. Presentations, Sec. A. Third Earth Resour. Tech. Satellite-1 Symp. NASA Goddard Space Flight Center, Greenbelt, Md. p. 145-157.
- Personnel of the Remote Sensing Research Work Unit.
1972. Monitoring forest land from high altitude and from space. Final report for Earth Resour. Surv. Program, NASA Office of Space Sci. and Appl., 192 p., illus.
- Peterken, G. R.
1970. Guide to check sheet for IBP [International Biological Program] areas; including a classification of vegetation for general purposes by F. R. Fosberg. IBP Handb. 4. Blackwell Sci. Publ., Oxford. 133 p.
- Pfister, R. D., and J. C. Corliss, Co-chairmen.
1973. *ECOCCLASS—a method for classifying ecosystems*. USDA Forest Service Ecosystems Task Force. Rep. on file at Forestry Sci. Lab., Intermountain Forest and Range Exp. Stn., Missoula, Mont. 52 p.

- Potter, J. F.
1974. Haze and sun angle effects on automatic classification of satellite data-simulation and correction. *Proc. Soc. Photo-optical Instrum. Eng. Semin. on Scanners and Imagery Syst. for Earth Obs.* [San Diego, Calif., August 19-20, 1974], 51:73-83.
- Rogers, R. H., K. Peacock, and N. J. Shah.
1973. A technique for correcting ERTS data for solar and atmospheric effects. *Proc. of Third ERTS Symp.*, Washington, D.C. vol. 1, sec. B, p. 1787-1804.
- Schmitt, H. C., Jr., and J. H. Altman.
1970. Method of measuring diffuse RMS granularity. *Appl. Optics*. 9(4):871-874.
- Thomas, V. L.
1973. Generation and physical characteristics of the ERTS MSS system corrected computer compatible tapes. Publ. No. X-563-73-206. NASA Goddard Space Flight Center, Greenbelt, Md. p. E-1 to E-4.
- U.S. Forest Service.
1974. *Forest Service Handbook: Inform (FSH 1309.13)*. U.S. Forest Serv., Washington, D.C., Chap. 20 [148 p.].
- U.S. Forest Service.
1968. *Forest Survey Manual for the Southeast*. Southeastern Forest Exp. Stn., Asheville, N.C. [317 p.].
- Weber, F. P.
1969. Remote Sensing implications of water deficit and energy relationships for ponderosa pine attacked by bark beetle and associated disease organisms. Ph. D. thesis, Univ. of Mich., Ann Arbor. 143 p.
- Weber, F. P., R. C. Aldrich, F. G. Sadowski, and F. J. Thomson.
1973. Land use classification in the southeastern forest region by multispectral scanning and computerized mapping. *In Proc. Eighth Int. Symp. on Remote Sensing of Environ.*, Univ. of Mich., Environ. Res. Inst. of Mich., Ann Arbor. 1:351-373.
- Weber, F. P., and F. C. Polcyn.
1972. Remote sensing to detect stress in forests. *Photogramm. Eng.* 38(2):163-175.
- Weber, F. P., E. H. Roberts, and T. H. Waite.
1975. Forest stress detection. *In Evaluation of ERTS-1 data for forest and rangeland surveys*. USDA Forest Serv. Res. Paper PSW-112, 67 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
- Weiss, J. P.
1973. Densitometry. *In SPSE Handb. of Photogr. Sci. and Eng.* p. 829-877. John Wiley & Sons: New York and London.

Aldrich, Robert C., *technical coordinator*

1976. **Evaluation of Skylab (EREP) data for forest and rangeland surveys.**

USDA Forest Serv. Res. Paper PSW-113, 74 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Data products from the Skylab Earth Resources Experiment Package were examined monocularly or stereoscopically using a variety of magnifying interpretation devices. Land use, forest types, physiographic sites, and plant communities, as well as forest stress, were interpreted and mapped at sites in Georgia, South Dakota, and Colorado. Microdensitometric techniques and computer-assisted data analysis and sampling procedures were developed and tested against ground truth. Results indicate that only Skylab S190B color photographs are good for classification of forest and nonforest land (90 to 95 percent correct). Both visual and microdensitometer techniques can separate range plant communities at the Region level (ECOCCLASS system) with over 90 percent accuracy. Only mountain pine beetle infestations more than 26 m (85 ft) long could be detected. In a study near Redding, California, radiance from Skylab S190B and LANDSAT sensors was found linearly correlated with terrain reflectance.

Oxford: U629.19[+587.7+44]

Retrieval Terms: Skylab; Earth Resources Experiment Package; photointerpretation; microdensitometric analysis; remote sensors; forest classification; range inventory; plant communities; forest stress.

Aldrich, Robert C., *technical coordinator*

1976. **Evaluation of Skylab (EREP) data for forest and rangeland surveys.**

USDA Forest Serv. Res. Paper PSW-113, 74 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Data products from the Skylab Earth Resources Experiment Package were examined monocularly or stereoscopically using a variety of magnifying interpretation devices. Land use, forest types, physiographic sites, and plant communities, as well as forest stress, were interpreted and mapped at sites in Georgia, South Dakota, and Colorado. Microdensitometric techniques and computer-assisted data analysis and sampling procedures were developed and tested against ground truth. Results indicate that only Skylab S190B color photographs are good for classification of forest and nonforest land (90 to 95 percent correct). Both visual and microdensitometer techniques can separate range plant communities at the Region level (ECOCCLASS system) with over 90 percent accuracy. Only mountain pine beetle infestations more than 26 m (85 ft) long could be detected. In a study near Redding, California, radiance from Skylab S190B and LANDSAT sensors was found linearly correlated with terrain reflectance.

Oxford: U629.19[+587.7+44]

Retrieval Terms: Skylab; Earth Resources Experiment Package; photointerpretation; microdensitometric analysis; remote sensors; forest classification; range inventory; plant communities; forest stress.

Aldrich, Robert C., *technical coordinator*

1976. **Evaluation of Skylab (EREP) data for forest and rangeland surveys.** USDA

Forest Serv. Res. Paper PSW-113, 74 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Data products from the Skylab Earth Resources Experiment Package were examined monocularly or stereoscopically using a variety of magnifying interpretation devices. Land use, forest types, physiographic sites, and plant communities, as well as forest stress, were interpreted and mapped at sites in Georgia, South Dakota, and Colorado. Microdensitometric techniques and computer-assisted data analysis and sampling procedures were developed and tested against ground truth. Results indicate that only Skylab S190B color photographs are good for classification of forest and nonforest land (90 to 95 percent correct). Both visual and microdensitometer techniques can separate range plant communities at the Region level (ECOCCLASS system) with over 90 percent accuracy. Only mountain pine beetle infestations more than 26 m (85 ft) long could be detected. In a study near Redding, California, radiance from Skylab S190B and LANDSAT sensors was found linearly correlated with terrain reflectance.

Oxford: U629.19[+587.7+44]

Retrieval Terms: Skylab; Earth Resources Experiment Package; photointerpretation; microdensitometric analysis; remote sensors; forest classification; range inventory; plant communities; forest stress.

Aldrich, Robert C., *technical coordinator*

1976. **Evaluation of Skylab (EREP) data for forest and rangeland surveys.** USDA

Forest Serv. Res. Paper PSW-113, 74 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Data products from the Skylab Earth Resources Experiment Package were examined monocularly or stereoscopically using a variety of magnifying interpretation devices. Land use, forest types, physiographic sites, and plant communities, as well as forest stress, were interpreted and mapped at sites in Georgia, South Dakota, and Colorado. Microdensitometric techniques and computer-assisted data analysis and sampling procedures were developed and tested against ground truth. Results indicate that only Skylab S190B color photographs are good for classification of forest and nonforest land (90 to 95 percent correct). Both visual and microdensitometer techniques can separate range plant communities at the Region level (ECOCCLASS system) with over 90 percent accuracy. Only mountain pine beetle infestations more than 26 m (85 ft) long could be detected. In a study near Redding, California, radiance from Skylab S190B and LANDSAT sensors was found linearly correlated with terrain reflectance.

Oxford: U629.19[+587.7+44]

Retrieval Terms: Skylab; Earth Resources Experiment Package; photointerpretation; microdensitometric analysis; remote sensors; forest classification; range inventory; plant communities; forest stress.