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-I (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 km^2 (5400 sq mi; *fig. 11*). Included within the area is the NASA/Manitou Test Site, No. 242. This nonurban, nonagricultural 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

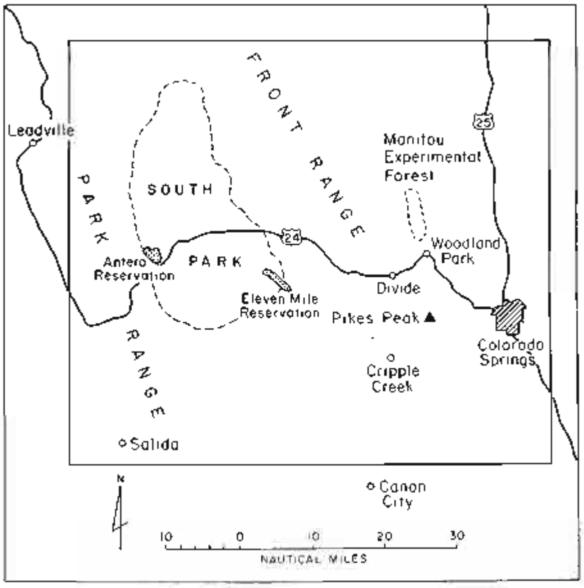


Figure 11—The mountainous central Colorado study area includes two intensive test sites, South Park and the Manitou Experimental Forest. Colorado Springs is near the southeast corner of the area.

(*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:

IV - Region	*III - Series*
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 underflight photographs. To prepare a base vegetation map from Forest Service type-maps, Series level (ECOCLASS) 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 combining 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 m^2 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:

	Number of cells
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 km^2 (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 km^2 (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 site*[1]

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—Conifers*[1] *and Grassland—Manitou, Colorado, test site*[2]

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		79.1		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.

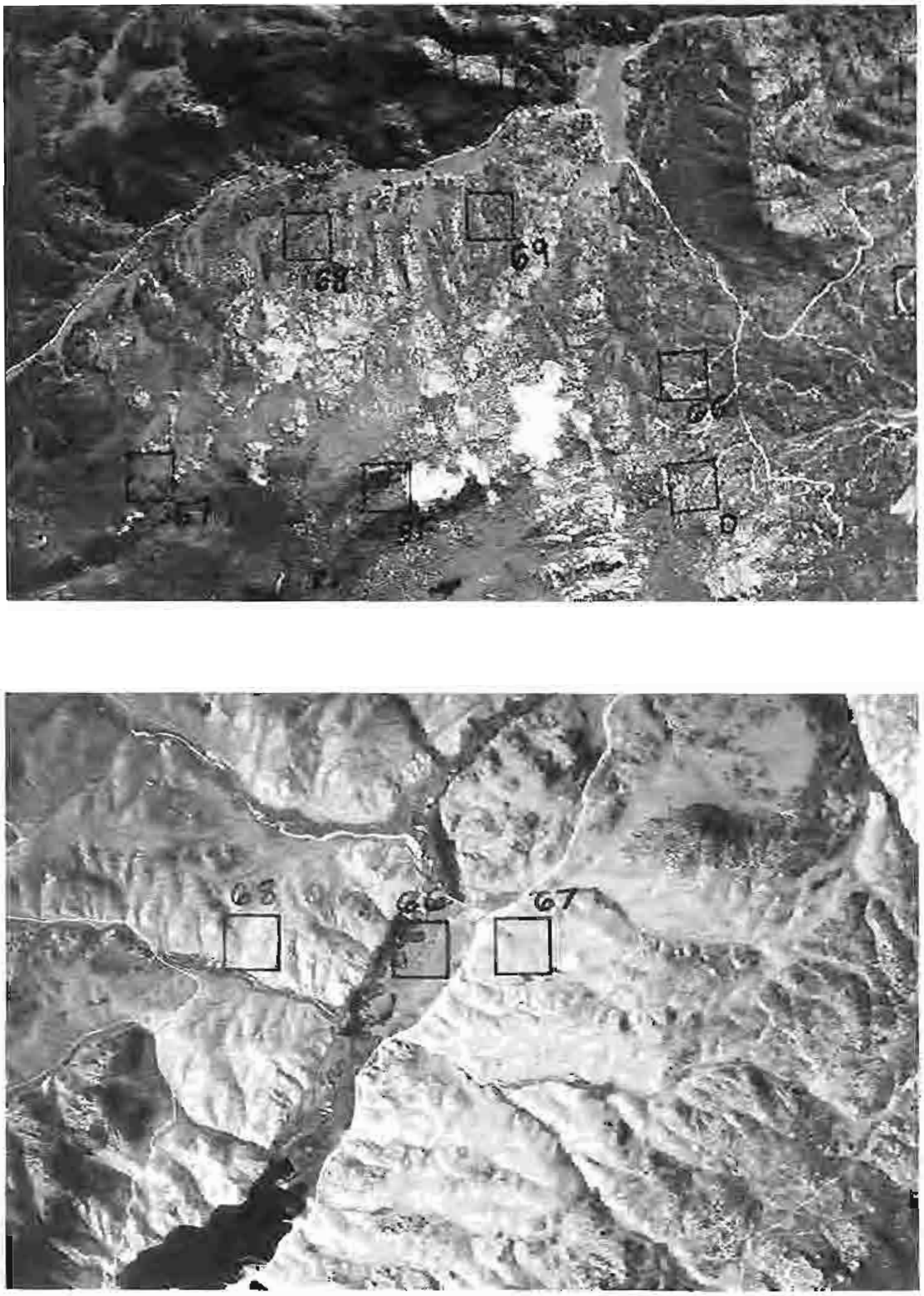


Figure 14—Aircraft support photography (CIR, 1:50,000) was used with acetate overlays showing sample training cells (labeled) and test cells (numbered) for visual classification of native plant communities. In the August photo (*above*), note the Deciduous/Conifer (Aspen/Ponderosa Pine) mixing in cell 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.

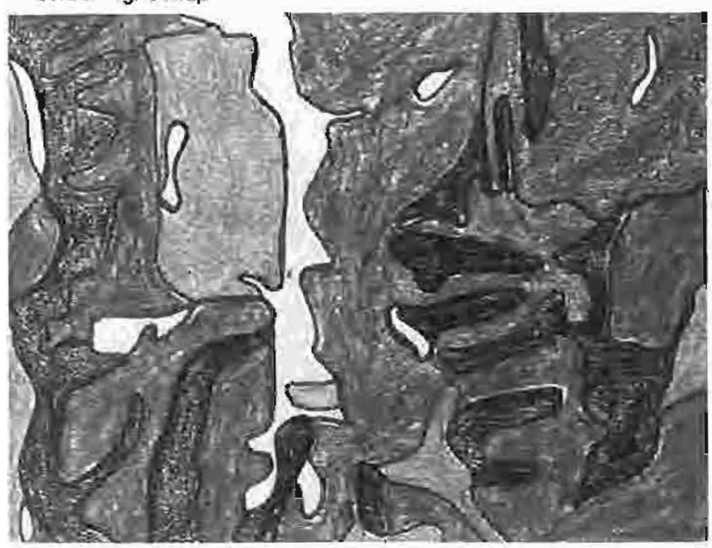
The Deciduous (Aspen) class was not successfully mapped from either the underflight or the Skylab photos (*table 14*), because of stand sizes and class mixing between Deciduous and Conifer. No Deciduous class areas were mapped from the lower-resolution Skylab photos.

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 Shortgrass Series classes could not be distinguished well enough in the Skylab photos to be mapped separately. Therefore, they were combined into a single

Base map

Underflight map



Skylab map

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

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 (12,611 ha)	31,163		31,163	
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 (12,611 ha)	31,163		31,163	

[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

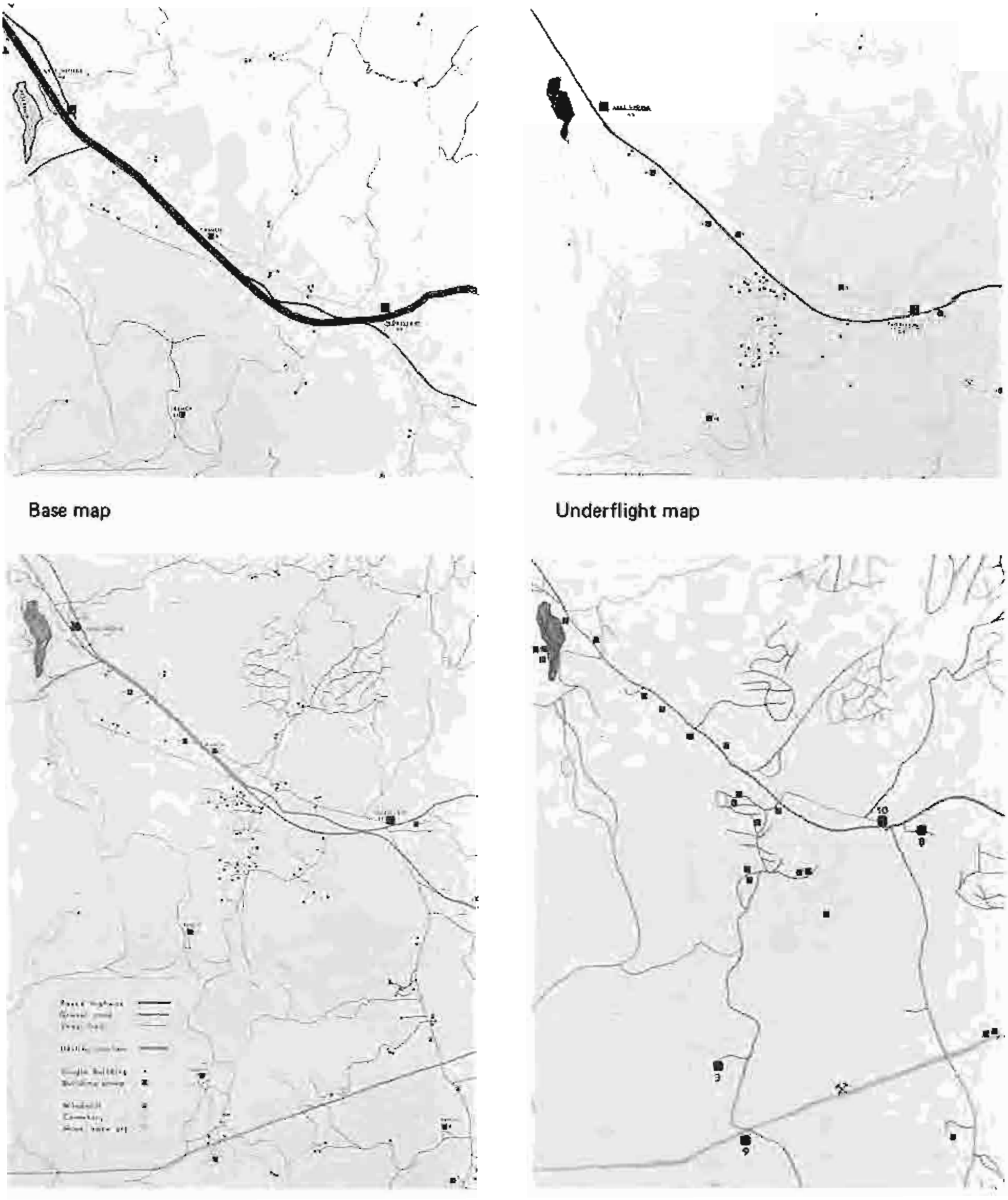


Figure 16--Cultural features were mapped by visual interpretation at 1:24,000 from an area of 156 km² (61 sq mi) within the Manitou site. The photo-revised map was compiled using the 1956 USGS quadrangle and the 1973 aircraft photos. The buildings grouped near the reservoir (*upper left*) in the Skylab 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:

	Correlation coefficients	
	Eleven Mile	*Antero*
Technique and class:		
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

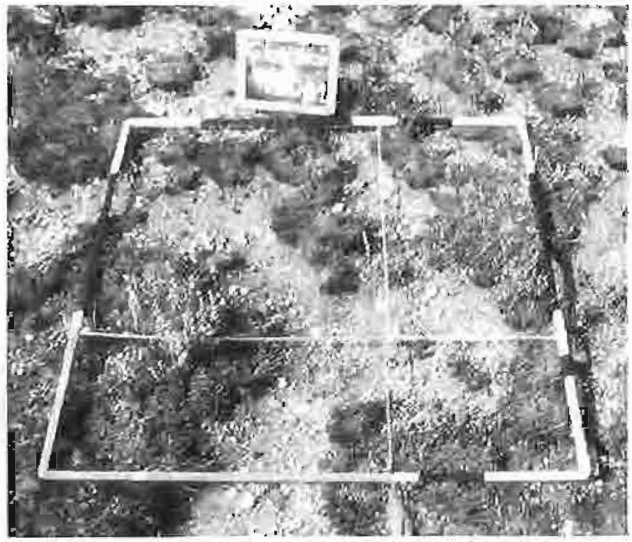
* Significant at 0.05 level.

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 matte-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 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.



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).

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 vignetted 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 ($p \geqslant 0.95$) 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 density*[1] *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	3.32	3.86	4.08	2.06	3.90
vs.					
Conifer	3.45**	3.94	3.88**	2.23	3.63**
Deciduous	3.32	3.86	4.08	2.06	3.90
vs.					
Grassland	3.01**	3.42**	3.36**	1.79*	3.21**
Conifer	3.45	3.94	3.88	2.23	3.63
vs.					
Grassland	3.01**	3.42**	3.36**	1.79**	3.21**
Series:					
Mountain Bunchgrass	2.98	3.47	3.38	1.86	3.15
vs.					
Shortgrass	2.99	3.42	3.21**	1.75**	3.13
Mountain Bunchgrass	2.98	3.47	3.38	1.86	3.15
vs.					
Shortgrass	2.99	3.42	3.21**	1.75**	3.13
Mountain Bunchgrass	2.98	3.47	3.38	1.86	3.15
vs.					
Wet Meadow	3.12**	3.38	3.77**	1.81	3.63**
Shortgrass	2.99	3.42	3.21	1.75	3.13
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 separable 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 June Color	Skylab S190A June CIR	Skylab S190A August Color	Skylab S190A August CIR	Skylab S190B, August, color
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 Bunch-grass	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

[1] Color 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.

[2] Distribution, 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.