# REMOTE SENSING APPLICATIONS IN FORESTRY

*A report of research performed under the auspices of the*

Forestry Remote Sensing Laboratory,
School of Forestry and Conservation
University of California
Berkeley, California

*A Coordination Task Carried Out in Cooperation with*

The Forest Service, U. S. Department of Agriculture

*For*

EARTH RESOURCES SURVEY PROGRAM
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

# REMOTE SENSING APPLICATIONS IN FORESTRY

MULTISTAGE, MULTIBAND AND SEQUENTIAL
IMAGERY TO IDENTIFY AND QUANTIFY
NON-FOREST VEGETATION RESOURCES

by



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ABSTRACT

This is the fourth annual progress report to assess the merits of aerial and space photography and multispectral scanner imagery for the interpretation and analyses of nonforest (shrubbery and herbaceous) native vegetation. The research for this reporting period was devoted primarily to analysis and recognition processing of multispectral scanner imagery for plant community classification in cooperation with the IROL at the University of Michigan. Also, interpretations of various film/filter/scale aerial photographs taken by NASA's RB57F were mostly completed. Data analyses and manuscript preparation of research on microdensitometry for plant community and component identification and remote estimates of biomass were completed.

Preprocessing of the scanner signals had to be done to eliminate a serious scan angle effect. This effect, defined as a third order polynomial, was believed to have been caused primarily by bidirectional reflectance of the target scenes and minimally by atmospheric attenuation of the target signal. Optimum channel selection, among the 12 channels of data available, identified six as providing the best information about 12 vegetation types and two nonvegetation categories. Final processing of the normalized data provided acceptable recognition results of generalized plant community types: Forested, grassland and hydrophyllic communities. Serious errors occurred with attempts to classify some of the specific community types within the grassland areas. Additional

analyses need to be done considering the convex mixtures concept of effects of different amounts of scene materials, i.e. live plant cover, exposed soil and plant litter cover, on apparent scene radiances to improve plant community classification.

Underexposure and nonuniform exposure of film/filter combinations not previously used at the Manitou test site and flown by the RB57F limited discrete interpretation regarding optimum combinations of film type/photoscale for plant community classification. In general, color infrared (2443 + 15 filter) was better than regular color for this purpose. A photoscale of 1:53,000 has the most value for refining multiple sampling techniques. Information gain using a 1:104,000 photoscale would be minimal for community classification and quantification, at least in areas similar to the Manitou test site.

Microdensitometry with color infrared aerial photography does show promise for automated discrimination of plant communities and components at photoscales ranging from 1:800 to 1:139,000. Identification accuracy should be improved using linear discriminate analyses of data from seasonal sequential photography.

Standing green crop biomass and its reciprocal, oven dry component, were significantly correlated to color infrared photo image density determined by microdensitometry. Image density of six classes of standing crop seeded big bluegrass was measured with a GAF microdensitometer using a green filter. The correlation coefficient between standing crop (y) and image density (x) was significant ($P = .01$) in all cases and greater than 0.80. The relationship was expressed as a simple linear function: $y = a + b(x)$.

## ACKNOWLEDGMENTS

This research is being performed under the Earth Resources Survey Program in Agriculture/Forestry under the sponsorship and financial assistance of the National Aeronautics and Space Administration, Contract No. R-09-038-002, This is the fourth annual progress report of a cooperative program with the Forest Service, U. S. Department of Agriculture. Research and administration direction are provided by the Rocky Mountain Forest and Range Experiment Station. Such direction has been accomplished in cooperation with the Remote Sensing Research Unit, Pacific Southwest Forest and Range Experiment Station, Berkeley, California. Professional salaries are being contributed by the Forest Service.

We are particulary grateful for the assistance of the Willow Run Laboratories at the University of Michigan for collecting and processing the optional mechanical line scanner data. Specifically, M.M. Spencer, F.J. Kreigler, F.J. Thompson and P.G. Hassell provided substantial contributions to this research.

Special appreciation is extended to P.O. Currie, M.J. Morris and O.C. Wallmo of the Rocky Mountain Station and to R.B. Gill, Research Biologist of the Colorado Game, Fish and Parks Division who contributed to this research.

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# MULTISTAGE, MULTIBAND AND SEQUENTIAL IMAGERY TO IDENTIFY AND QUANTIFY NONFOREST VEGETATION

by

Richard S. Driscoll

## INTRODUCTION

Nonforest vegetation, as used in this report, refers to native vegetation other than trees and includes exotic species used for special purposes. These special situations include vegetation improvements for food and cover for wildlife and domestic livestock or for protection of heavily used areas such as recreation sites. It does include that vegetation which occurs as understory in forested ecosystems. We are not especially concerned with the individual trees or tree stands except in relation to influences on understory species.

There are approximately 1.2 billion acres of land in the conterminous United States classed as forest and range ecosystems. These lands include the high mountain wilderness areas of the West as well as areas adjacent to highly populated metropolitan environments. This land area is shrinking through urban area expansion, the development of high-density recreation areas away from the metropolitan areas, and the development of completely new communities. Some of the area is fragile, such as the desert and high-mountain alpine and subalpine environments of the West. Much of the landscape is complex with highly variable topo-edaphic and consequent vegetation systems occurring over short distances. These conditions make it difficult to unlock the interrelationships of land use demands. Frequent decisions must be made not only for planning land use but also for determining the effects of different kinds of land use on the total ecosystem. Remote sensors, with their rapid data gathering capabilities, provide real-time information for these decisions. We need to identify the kinds of data various sensors can provide about native vegetation and how such data can be most effectively analyzed and interpreted to assist in land use planning, development and management.

This is the fourth annual progress report detailing research undertaken since October 1970. Earlier reports (Driscoll and Reppert 1968; Driscoll 1969; Driscoll and Francis 1970) summarized the importance of the problem regarding detection, identification and measurement of herbaceous and shrubby vegetation using aerial and space photographs of those resources. These reports detailed research results on use of color and color infrared aerial photographs for identifying individual plant species and communities. Also included were results on use of a multiple sampling procedure for plant community classification and quantification using space (Apollo 9) and supporting aircraft photographs. Preliminary results for estimating herbaceous standing crop using large-scale color infrared aerial photographs and microdensitometry were included in our 1970 Annual Report. These reports have identified some potential applications for use of aerial and space photographs for land use planning and management decisions although additional research is needed, especially in developing and testing sampling theory and techniques, before detailed operational procedures are defined.

Primary emphasis during the current reporting period has been on data analyses and summarization for manuscripts. The first part of this report describes multispectral processing and assessment of imagery taken July 29, 1970, by the University of Michigan's multispectral system. Also included in this section is an assessment of the photographic imagery taken on July 21, 1970, by the RB57F aircraft.

The second section of the report deals with other remote sensing research we have done that has been operationally financed partly by our NASA contract and partly by the Forest Service. This work includes: (1) Estimation of herbaceous standing crop with aerial photographs and microdensitometry, and (2) plant species and land classification with aerial photographs and microdensitometry.

The research described in both sections will coalesce to provide needed coefficients for understanding, through modeling, the structure and function of ecosystems using data from remote sensors.

## THE STUDY AREAS

Data for the multispectral scanner and RB57F tests were obtained from the Manitou test site (NASA Site 242) (Figure 1). This area is designated as one of three major test sites for our proposed ERTS-A and Skylab experiments in cooperation with the Forest Remote Sensing

Figure 1 The Manitou test site (Site 242). The Manitou Experimental Forest, a multidisciplinary research area maintained by the Rocky Mountain Forest and Range Experiment Station, is located specifically on either side of the drainageway between the two water bodies in the center of the photograph. The majority of our research is located in this area. This photo was made from IR color transparency from the NASA RB57F Mission 139; scale 1:104,000.

Project, Pacific Southwest Forest and Range Experiment Station. Current research at Manitou including our remote sensing work, is multidisciplinary among several Forest Service research projects. Consequently, information trade-off provides us with a significant amount of ground truth we would otherwise not be able to accumulate.

Information obtained for our other research was obtained at or near our Black Mesa, Kremmling and McCoy areas in addition to Manitou. Detailed descriptions of all study areas have been defined in the 1968 and 1969 annual reports.

## SECTION I

## MULTISPECTRAL AND HIGH FLIGHT (RB57F) EXPERIMENTS

### PROCEDURES

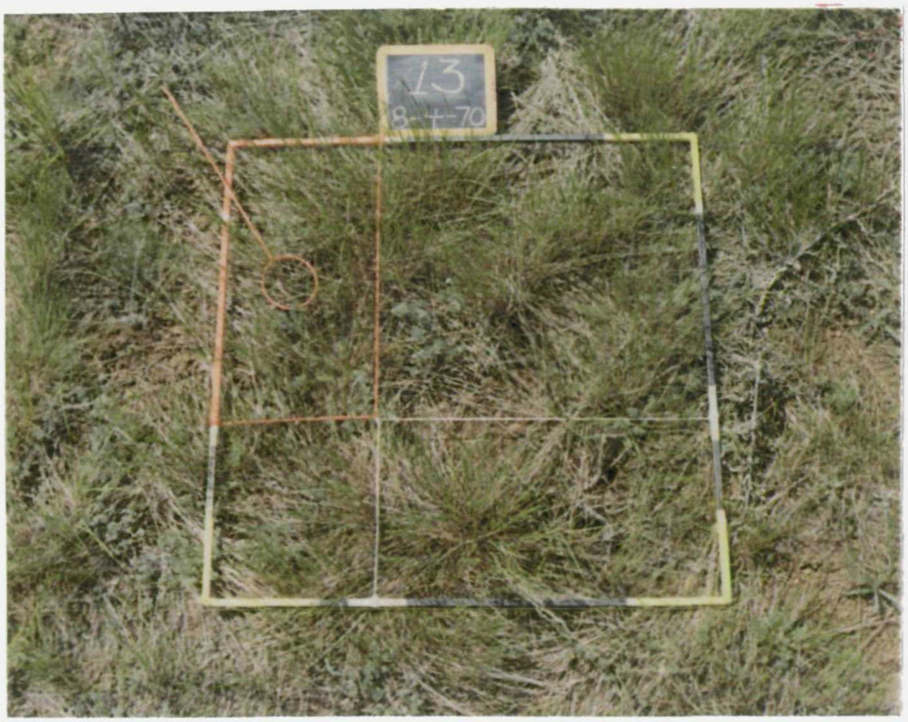
#### Ground Data

Ground truth for both of these experiments was obtained simultaneously since the objectives were similar, viz. discrimination of native plant communities. The specific objective of the multispectral experiment was to optimize multispectral channel data to determine the best channel or channels for discrimination among nine different herbaceous and shrubby plant communities and four different forested communities. The specific objective of the high flight experiment was to evaluate several film/filter combinations and photoscales not previously used in the Manitou area for detecting and identifying the same plant communities.

Immediately prior to the data missions, detailed mapping of the plant communities was completed. This mapping was based on current aspection of the plant communities and the relative composition of the communities regarding similarity of plant species components throughout the mapping unit. Medium-scale (1:8,000) color infrared mapping photographs flown approximately 6 weeks prior to the data missions were used in conjunction with detailed ground search. Each mapping unit represented a specific community type.

Plant species abundance was determined for each community type within 2 weeks of the missions. Abundance was based on a 5-point rating scheme ordered from very abundant to rare (Oosting 1956). At the same time, percent plant foliar cover, percent bare soil surface and percent plant litter cover of the soil surface of each of the plant communities were estimated. Such estimations were made by sampling with 3x3-foot sample plots (Figure 2) located by restricted random fashion throughout the community types. This plot size was related to the equivalent resolution element to be "seen" by the scanners at the lowest planned flight altitude for representation of the component mixtures of scene radiance. Plots 9 feet square were used at each sampling location to provide data directly related to the equivalent resolution element at the higher scanner flight altitude.

Considering the forested communities, ground cover sampling was restricted to land surface visible from above without interference from the tree canopy. All ground truth and sensor data were obtained at a time when most plant species were actively growing to offer the




<u>Figure 2</u> Ground plots measuring 3 feet on a side were used to estimate percent foliar cover, percent bare soil surface and percent plant litter cover of the soil surface for each of the plant communities used for multispectral recognition processing. This plot size represented the equivalent resolution element for the 1,000-foot flight altitude. Plots 9x9 feet at the same location were used to obtain ground data related to the equivalent resolution element at the 3,000-foot altitude.

best opportunity for discrimination considering a single data mission period. This decision was based on interpretation of seasonal aerial photographs taken during previous years as well as detailed phenological knowledge of the Manitou area based on previous research. The mapping units and a brief description of their characteristics are listed in Table 1. Also included are four nonvegetation categories which constituted inclusions within the mapping units but which could possibly be discriminated in the multispectral analyses.

In addition, near vertical ground photos were taken from a stepladder within a representative area of each plant community type using color film (35mm Kodacolor-X) and color infrared (70mm and 35mm Ektachrome Infrared, Type 8443). These photos were used in conjunction with aerial photos and quantitative ground data for selecting and defining training samples for processing the scanner imagery.

## Aerial Data

Multispectral (Mission M-19). All multispectral data collection was performed by the University of Michigan's multispectral scanning system on July 28 and 29, 1970. This system consisted of two double-ended optical mechanical scanners. Imagery requested included data records in 12 discrete spectrometer channels in the visible and near infrared, three intermediate infrared channels and two thermal bands (Table 2). Operating simultaneously with the scanner system were three aerial cameras: (1) K-17 loaded with Super 2 film with a K-2 Star filter;

Table 1. Generalized description of vegetation mapping units and landscape class inclusions

| Mapping Unit | Brief Description | % Soil Surface Cover: Plant Foliage | Plant Litter | Bare Soil |
|---|---|---|---|---|
| 1 | Recently logged ponderosa pine (*Pinus ponderosa*) forest; mountain muhly (*Muhlenbergia montana*) and Arizona fescue (*Festuca arizonica*) dominant herbaceous vegetation | 40.3 | 53.4 | 6.3 |
| 2 | Mature ponderosa pine forest, mountain muhly and pussytoes (*Antennaria* spp.) dominant herbaceous species | 29.1 | 54.6 | 16.3 |
| 3 | Dense natural ponderosa pine regeneration; crown closure nearly 80 percent; forest floor primarily pine needle litter | 8.0 | 91.0 | 1.0 |
| 4 | Dense planted ponderosa pine, crown closure nearly 80 percent, herbaceous understory primarily mountain muhly | 31.2 | 57.7 | 11.1 |
| 5 | Seeded crested wheatgrass (*Agropyron desertorum*) | 27.7 | 51.4 | 20.9 |
| 6 | Seeded big bluegrass (*Poa ampla*) | 19.2 | 72.4 | 8.4 |
| 7 | Native grasslands; no tree or shrub components; Arizona fescue and mountain muhly were generally the most conspicuous species; other herbaceous species more prominent locally; generally the community was a heterogeneous mixture of herbaceous species | 36.5 | 58.4 | 5.1 |
| 8 | Abandoned agricultural fields; land once tilled for crops on which native vegetation had re-established itself; community composition different from unit 7; primarily lacking in variety and abundance of perennial forbs | 41.9 | 49.1 | 9.0 |

Table 1. (continued)

| Mapping Unit | Brief Description | % Soil Surface Cover: Plant Foliage | Plant Litter | Bare Soil |
|---|---|---|---|---|
| 9 | Other seeded grasslands; old seedings of crested wheatgrass, big bluegrass, and Russian wildrye (*Elymus junceus*) which have been infested with native herbaceous species | 31.7 | 46.6 | 21.7 |
| 10 | Native grasslands excluded from cultural practices or livestock use for long periods of time ( ± 30 years) | 47.8 | 48.6 | 3.6 |
| 11 | Unclassified land: ecotonal situations or extremely heterogeneous vegetation or other land classes not fitting any other vegetation grouping | -- | -- | -- |
| 12 | Willow (*Salix* spp.) occurring along the flood plain of a stream. Herbaceous species occurring within the open areas between the shrub groups from either unit 14 or 15 | 98.0 | 1.0 | 1.0 |
| 13 | Open water -- streams and beaver ponds of various depths and turbulence | -- | -- | -- |
| 14 | Native bluegrass (*Poa praetensis*) meadows; species of sedge (*Carex* spp.) rush (*Juncus* spp.) and native clover (*Trifolium* spp.) ubiquitously scattered throughout the area. | 85.0 | 12.7 | 2.5 |
| 15 | Sedge/rush/bulrush (*Scirpus* spp.) meadows; normally occurring with standing water or seasonally ponded areas | 94.7 | 5.3 | 0 |
| 16 | Roads | | | |
| 17 | Bare soil (unstable gullies, alluvial fans) | -- | -- | -- |

Table 2. Spectral bands of data collection, Manitou Experimental Forest (M-19)

| Detector | Spectral Band-- 10 Percent Power Points (micrometers) |
|---|---|
| Spectrometer (channel) | |
| 1 | 0.398-0.431 |
| 2 | 0.423-0.456 |
| 3 | 0.446-0.475 |
| 4 | 0.458-0.487 |
| 5 | 0.478-0.508 |
| 6 | 0.492-0.536 |
| 7 | 0.514-0.558 |
| 8 | 0.538-0.593 |
| 9 | 0.566-0.638 |
| 10 | 0.604-0.700 |
| 11 | 0.656-0.775 |
| 12 | 0.725-0.920 |
| Near Infrared | |
| 1 | 1.0-1.4 |
| 2 | 1.5-1.8 |
| 3 | 2.0-2.6 |
| Thermal Infrared | |
| 1 | 4.5- 5.5 |
| 2 | 8.2-13.5 |

Pikes Peak on the south (lat. 38°55' N., long. 105°04' W.) to a point east of Deckers on the north (lat. 39°17' N., long. 105°08' W.), a distance of approximately 23 nautical miles. The Manitou Experimental Forest Headquarters site was located approximately midway along the flight line. The flight line was flown twice to assure complete coverage. Film/filter/scale combinations exposed are listed in Table 3. All cameras were set to obtain 60 percent forward overlap for stereoscopic coverage.

Prevailing weather during the mission schedule was generally clear with a few high, thin cirrus clouds along the flight line. Continuous fog occurred to the east of the area near Colorado Springs and the U. S. Air Force Academy. A slight cumulus build-up was occurring to the west of the flight line area.

Communications between the ground crew and the airplane were not available during the mission.

## RESULTS AND DISCUSSION

### Multispectral (M-19).

All processing of the multispectral data was done at the University of Michigan's Willow Run Laboratories under master contract NASA9-9784 and monitored by NASA, Manned Spacecraft Center, TF-8. Research Engineers M. M. Spencer and F. J. Kreigler were the prime data processors. In depth details of the processing procedures are documented in the report, "Analysis and recognition processing of multispectral scanner imagery of the Manitou Experimental Forest site in Colorado" by M. M. Spencer, September, 1971 (#31560-80-L).

Table 3. Film/filter/scale combinations exposed during Mission 139, NASA RB57F

| Camera | Lens Focal Length | Film | Filter | Film Format | Scale |
|---|---|---|---|---|---|
| Zeiss | 12 in. (300mm) | 2443 | W15 | 9 in. (230mm) | 1: 53,000 |
| RC-8 | 6 in. (150mm) | 2443 | W15 | 9 in. (230mm) | 1:104,000 |
| RC-8 | 6 in. (150mm) | SO-397 | 2E | 9 in. (230mm) | 1:104,000 |
| Hasselblad | $1\frac{1}{2}$ in. (40mm) | SO-117 | W15+CC30B | 2.75 in. (70mm) | 1:405,000 |
| Hasselblad | $1\frac{1}{2}$ in. (40mm) | SO-117 | W15 | 2.75 in. (70mm) | 1:405,000 |
| Hasselblad | $1\frac{1}{2}$ in. (40mm) | SO-168 | 2E | 2.75 in. (70mm) | 1:405,000 |
| Hasselblad | $1\frac{1}{2}$ in. (40mm) | 2402 | W25 | 2.75 in. (70mm) | 1:405,000 |
| Hasselblad | $1\frac{1}{2}$ in. (40mm) | 2402 | W58 | 2.75 in. (70mm) | 1:405,000 |
| Hasselblad | $1\frac{1}{2}$ in. (40mm) | 2424 | W89B | 2.75 in. (70mm) | 1:405,000 |

At this time, data from only one of the 32 data missions have been processed for multispectral recognition of native plant communities. These data were from flight line 1, flown at 3,000 feet above the terrain at 1000 hours local sun time on July 29, 1970 (Figure 3). This particular data mission was chosen for five primary reasons: (1) Video display of the preprocessed data from channel 10 (0.604 - 0.700 μm) indicated that this flight time and altitude might provide the best opportunity for the recognition processing, (2) cloud shadows noised the data at the 1200 and 1500 hours flight times, (3) the halo effect was particularly noticeable in the 1200 hours data and to some extent in the 1500 hours data, (4) environmental conditions prior to the early morning flight (heavy predawn rain) left target surfaces very wet and contributed to high relative humidity, both of which would contribute to abnormal radiance effects and (5) time and budgetary constraints precluded much additional data processing. In addition, most plant communities of interest were represented in this flight line and there was little variation in mean ground elevation (± 200 feet).

It became obvious in preprocessing review with the IROL engineers that some of our initial mapping units, to be used as recognition categories, were too generalized to provide a valid statistical recognition signature for any of the categories. These included mapping units 11, 13, 16 and 17 (Table 1). For example, category 11 (unclassified land) had no unifiable feature within the area and consequently statistical variation of training samples would result in a high order of misclassification.

Figure 3 Area within the rectangle includes the analyzed scanner coverage of a part of flight line 1 flown at 3,000 feet above the terrain (1000 hours local sun time; 7/29/70). Training sample areas for computer recognition can be located in this illustration by referring to Figure 6. (See Table 1 for a description of these units.) The photo was made from an IR color transparency from the NASA RB57F Mission 139; scale 1:53,000. At this photoscale, all recognition categories can be interpreted visually.

Consequently, this category was eliminated from recognition processing. Map unit 13 was also a heterogeneous unit for recognition purposes. It included relative shallow and deep water in various degrees of turbidity and included various amounts of hydrophyllic vegetation. This unit was also eliminated from recognition processing. Map unit 16 included both hard packed dirt and gravel roads as well as an asphalt road. This unit was reduced to only the asphalt road to provide orientation in the recognition map. Map unit 17 represented all kinds of bare soil areas; alluvial fans, bare gullies and naturally occurring bare soil areas. The decision was made to select training samples that could be identified in the support aerial photographs and let the remainder of the bare soil areas be classified by chance.

Another decision was made regarding mapping units 1 and 2. Both these units represented ponderosa pine forest but one unit (#1) had been recently logged and the other (#2) was unlogged. Major differences between these two areas were the amount and extent of tree foliage, the size and pattern of openings in the forest canopy and the vegetation composition of the forest floor within the openings in the forest canopy. To include each as an entity, samples for recognition signatures would have to include combined information from all these conditions. Consequently, the variance in spectral statistical signatures would be high, possibly leading to serious misclassification. Two alternatives were available: (1) Increase the sample size to reduce signature variance or (2) reclassify the map units (recognition categories) to a common denominator. We chose the latter alternative, in which a new unit or recognition category was defined with its spectral statistical signature characterized as dense ponderosa pine foliage, wherever it existed. The remaining areas, primarily openings in the tree crown canopy, could then possibly be classified as one of the grassland categories or not classified at all by the developed program. If the latter happened, it would indicate that these openings represented unique vegetational situations requiring specific spectral signature reference. The results of this reclassification are listed in Table 4.

A scan angle effect is present in all optical mechanical scanner data. This is to be expected since the view angle of the scanner mirror system for a discrete bit of data at an instant in time varies through the arc of the scanner field of view. Assuming that a target material had the same reflectance throughout the arc of the mirror system, the point of illumination is at the nadir, and the geometry of all components of the target material is perpendicular to the nadir, the scan angle effect would graphically illustrate a normal distribution curve. The apparent scene radiance for the target area for a scan line would be strongest at the point where the scanner view angle was simultaneously perpendicular to the

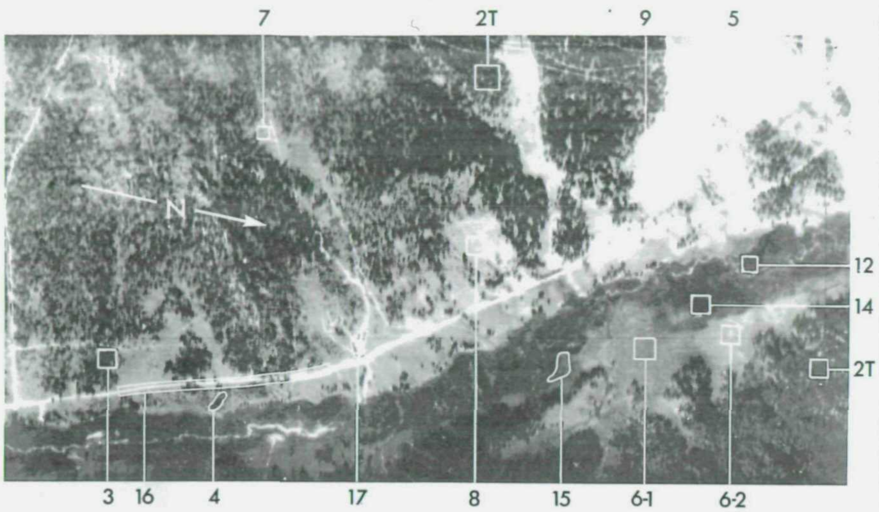
Table 4. Revised list of recognition categories

| Category No. (Map Unit) | Brief Description |
|---|---|
| 2T | Ponderosa pine forest |
| 3 | Dense natural ponderosa pine regeneration |
| 4 | Dense planted ponderosa pine regeneration |
| 5 | Seeded grassland (crested wheatgrass) |
| 6 | Seeded grassland (big bluegrass) |
| 7 | Native grasslands |
| 8 | Abandoned fields with native vegetation different from 7 |
| 9 | Other seeded rangeland |
| 10 | Other native rangelands, i.e., exclosures excluding livestock grazing or areas manipulated by cultural practices |
| 12 | Willow type vegetation |
| 14 | Native bluegrass meadows |
| 15 | Sedge/rush/bulrush meadows |
| 16 | Asphalt roads |
| 17 | Bare soil (alluvial fans, unstable gullies) |

categories 6, 7, 8 and 10, and categories 5 and 9. When linear dimensions such as fence lines or seeded area boundaries were evident, this was not so difficult. However, when such evidence was not apparent, or even when differences among community categories could be seen in the mapping photographs, the mental transcription from photograph to gray map location was difficult and possibly in error. (2) The second factor causing the wide variation of grassland signature values, one which may be more important to the problem of grassland community discrimination, is related to convex mixtures of amount and kind of herbage cover, plant litter and bare soil represented in the equivalent resolution element. Even though the data in Table 1 identify an amount of these three ground cover characteristics for each mapped unit or recognition category, considerable variation occurred among samples used to generate these statistics. For example, the range of vegetation cover in category 7 (native range) among the subsample units was 29 to 45 percent. This range on an individual plot basis, corresponding to the ground equivalent resolution element, was from 20 to 45 percent within an individual subsample unit. Although the ground sampling technique was adequate to describe the mapped units (recognition categories), especially when plant species composition was considered, serious apparent anomalous information occurred in the scanner data.

Unfortunately, the specific plot locations used to obtain these data were not positively located either on the ground or the mapping photographs. It might be possible to use data on hand from the various category subsample units to analyze the scanner data for effects of varying amounts of ground cover components, in order to determine the effects of these on apparent radiance. Additional research is needed, however, in which various mixtures of the ground cover components, in a natural condition, can be precisely located in the multispectral data and analyzed for the effects of these mixtures on apparent radiance.

Signature selection for the grassland categories was based on a method which used the probabilities of misclassification as criteria to determine similarity among units. With this routine, statistical parameters (mean, variance, covariance) for all channels were considered simultaneously for computing pairwise probabilities of misclassification. This term does not mean the distinction between the two possibilities of error in the normal procedure for testing statistical hypotheses. Rather, it involved testing many distributions by a likelihood ratio test in which each distribution was tested pairwise with all other distributions and the resulting Type II error from each test was summed. Thus, the distribution with the largest total of Type II errors was the distribution to represent a specific classification category. Figure 6 shows the locations of training areas selected by this process.




Legend

| | |
|---|---|
| 2T | Ponderosa pine forest |
| 3 | Dense natural ponderosa pine regeneration |
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| 5 | Seeded grassland (crested wheatgrass) |
| 6 | Seeded grassland (big bluegrass) |
| 7 | Native grasslands |
| 8 | Abandoned field with native vegetation different from 7 |
| 9 | Other seeded rangeland |
| 10 | Other native rangelands, i.e. exclosures excluding livestock grazing or areas manipulated by cultural practices |
| 12 | Willow type vegetation |
| 14 | Native bluegrass meadows |
| 15 | Sedge/rush/bulrush meadows |
| 16 | Asphalt roads |
| 17 | Bare soil (Alluvial fans, unstable gullies) |

Figure 6 Location of various components of the training area, identified by category (map unit) number.

Channel optimization for the classification problem was also based on the average probability of misclassification in which the six best channels were chosen on an ordered selection scheme. The process assumed that the signatures represented a Gaussian distribution of random variables, an assumption which thus far has been good for similar data examined (Heller, et al. 1970). A pairwise classification scheme was used in which, if there were M categories (recognition units), then there were M(M-1) probabilities of misclassification computed and averaged. For example, the probability of misclassification of each pair of materials was the probability of misclassifying material M2 as material M1. The end result, during which each entry was weighted, provided an average pairwise probability of misclassification and identified the best channel for classifying the categories previously defined. This ordered selection next combined the first channel with each of the remaining n-1 channels and picked the best combination of two channels. The process was continued until the best combination of channels was identified. The results of the ordered selection scheme, which was made in order to determine the spectral channels to use for the recognition processing, is shown in Table 5.

Six channels were selected for recognition processing. The channel selection procedure was stopped at this number because the addition of other channels indicated minimum improvement in recognition accuracy. For example, adding the effects of channel 6 indicated an increase in accuracy of classification by only approximately 11 percent. This was deemed acceptable for this problem (the classification of

Table 5. Spectral channels ordered for classification of eight herbaceous plant communities, three ponderosa pine forest communities, one shrub community, and two nonvegetated categories

| Spectrometer Channel No. | Spectral Band (μm) | APPM[1] | Percent Accuracy Increase |
|---|---|---|---|
| 10 | 0.604-0.700 | 0.0736 | |
| 12 | 0.725-0.920 | 0.0386 | 48 |
| 5 | 0.478-0.508 | 0.0290 | 25 |
| 9 | 0.566-0.638 | 0.0240 | 17 |
| 7 | 0.514-0.558 | 0.0209 | 13 |
| 6 | 0.492-0.536 | 0.0185 | 11 |

[1]Average pairwise probability of misclassification

plant communities) because a minimum level of accuracy for Agricultural Crop Census has been suggested at about 85 to 90 percent (Anderson 1971). However, one of the potential uses of pattern recognition using scanner data would be to monitor human-induced change in vegetation over time. These changes are frequently subtle but important and therefore would require something better than 10 to 15 percent accuracy. Problems related to accuracy improvement were previously discussed in relation to on-the-ground community classification and training set selection.

For the final recognition processing, the decision rule to classify each data point used a likelihood ratio test. This test was applied to each data point among all selected spectral channels. The test simultaneously compared the information content of each data point for category recognition and assigned the data point to a particular category when the following n-1 ratio tests were simultaneously satisfied:

$$\frac{f(M_i)}{f(M_j)} > 1$$

where:

$f(M_i)$ is the multivariate Gaussian probability density function for category $M_i$, and

$f(M_j)$ is the multivariate Gaussian probability density function for category $M_j$

The recognition processing results obtained from the digital computer are shown in Figure 7, a photograph of the color digital recognition map. This area represents a unit of terrain approximately

Figure 7  Color digital recognition map from six normalized data channels. The training area map (Figure 6) and IR color map (Figure 3) will aid in interpretation of the results. Most serious mixing of category recognition was between the big bluegrass seeding (Category 6), near top right corner of the map, and the three classes of native rangeland (Categories 7, 8 and 10).

2 miles long and 1 mile wide. The color/symbol coding which was used is listed in Table 6. The exact symbol coding is not recognizable in the photograph due to scale reduction from the original digital color map. However, if the reader makes a correspondence between color shades and the location of training areas (Figure 6), this will aid in interpreting the map.

Generalized plant communities were acceptably isolated. These included the forested areas (green), areas with hydrophyllic vegetation (black), and areas of upland herbaceous vegetation (red, blue and purple). This was not totally unexpected however, since others have reported similar results (Smedes, et al. 1971, Heller, et al. 1970). On-the-ground conditions of these units were very dissimilar and produced high contrast in apparent radiance signals.

However, problems existed in community classification by computer recognition processing for the upland herbaceous plant communities (categories 5-10). Even though intense preprocessing of the data was done, a large amount of misclassification occurred. For example, the bluegrass seeding in the northwest portion of the area was erroneously identified with the abandoned fields, with native vegetation, and with parts of category 7 (native range). Likewise, the native range and abandoned fields categories were mixed severely in some areas.

This does not mean that multispectral spectrometer data with the adjunct preprocessing techniques cannot be used for identifying and classifying specific plant community types within a generalized

Table 6. Color/symbol codes for digital color recognition map

| Category[1] | Unit | Green | Red | Blue | Black | Purple |
|---|---|---|---|---|---|---|
| | | Color | | | | |
| 2T | Ponderosa pine forest | ₳ | | | | |
| 3 | Natural pine regeneration | θ | | | | |
| 4 | Artificial pine regeneration | * | | | | |
| 5 | Crested wheatgrass seeding | | | ₳ | | |
| 6-1 | Seeded big bluegrass with sweetclover | | * | | | |
| 6-2 | Seeded big bluegrass with conglomerate forbs | | | * | | |
| 7 | Native range | | | | | 6 |
| 8 | Abandoned fields different from #7 | | ₳ | | | |
| 9 | Other seeded rangeland | | | = | | |
| 12 | Willow communities | | | | ₳ | |
| 14 | Native bluegrass meadows | | | | * | |
| 15 | Sedge/rush/bulrush meadows | = | | | | |
| 16 | Road (Asphalt) | | | | . | |
| 17 | Bare soil | | = | | | |
| Not Classified | | Blank spots in the map | | | | |

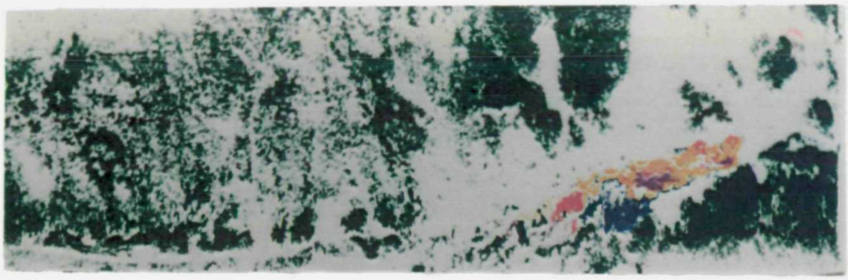
[1]Original categories 1 and 2 combined to ponderosa pine forest. Category 6 was separated into two units at high scan line numbers due to severe mixing with other categories, especially #9. 6-1 represents now big bluegrass seeding contaminated with yellow sweetclover (<u>Melilotus officinalis</u>); 6-2 represents big bluegrass seeding contaminated with numerous other herbaceous species. Category 6 at low scan line numbers and category 10 confounded with category 8 and additional research is needed to find out if these categories can be separated. Original categories 11 and 13 were not included in the processing.

herbaceous system. Rather it means we must be more discretely selective in choosing training sample areas representative of the community types selected. For example, the native range (category 7) areas identified by the recognition processing was correctly identified but not all native range areas were classified as native range. Those areas correctly identified consisted of plant communities with a composition primarily of vigorous stands of Arizona fescue and mountain muhly and little bare soil surface showing through the community canopy. Other areas not classified as native range but mixed with category 8 (abandoned fields) had considerably less herbaceous cover, less litter cover on the ground and more exposed bare soil surface. Similar conditions existed between the relatively pure big bluegrass seeding (low scan line numbers) and the more sparcely vegetated native range areas.

It may be that the relative radiance of herbaceous vegetation *per se* is not sufficiently contrasting to provide discrete separation. If this is the case, more consideration must be aligned to the combined relative amounts of vegetation cover, litter cover and bare soil surface which may provide the information needed for acceptable recognition processing. More research needs to be done on this aspect of the problem. This can be done with some of the spectral and corresponding ground truth data in hand. However, controlled experiments need to be initiated whereby the effective scanner ground resolution element can be isolated in the multispectral data with absolute information about the three ground cover characteristics. In addition, we need to know more about the ground scene radiance of various combinations of ground cover characteristics to determine the effects of these characteristics, together with community speciation, on effective scene radiance. This should be done using a field-going spectrometer calibrated to the band pass characteristics of the airborne multispectral scanner.

The normalized data from the six channels identified for digital processing were also processed through the Michigan Spectral Processing and Recognition Computer. The SPARC system accepts analog data and presents the results in analog form which is more easily interpreted than the digital map. Since the SPARC system can accept only data about eight recognition categories and we processed 14 recognition categories using six data channels, two separate operations were performed on the SPARC. The results of this processing are illustrated in Figure 8. The color codes are identified in Table 7. The relationships between the digital and analog processing in relation to known ground conditions were the same.

There is some confusion in interpreting the SPARC map as compared to the digital map. For example, on the SPARC map, seeded crested wheatgrass is identified as yellow and the other seeded grassland (category 9) is identified as dark green. Interpreting the digital map, point by point, shows some mixing of these two categories in the crested wheatgrass area, but the major portions of the data points in fact



(a)

(b)

Figure 8 Color recognition maps from SPARC processing using the six normalized data channels (channels 5, 6, 7, 9, 10, 12). Refer to Table 7 for the color coding of these maps.

Table 7. Color coding for SPARC recognition map for Figures 8(a) and 8(b)

| Figure 8(a) | | | Figure 8(b) | | |
|---|---|---|---|---|---|
| Category | Unit | Color | Category | Unit | Color |
| 2T, 3, 4 | All ponderosa pine | Green | 6-1 | Seeded big bluegrass with sweetclover | Dark Blue |
| 12 | Willow communities | Orange | 6-2 | Seeded big bluegrass with conglomerate forbs | Light Blue |
| 14 | Native bluegrass meadows | Purple | 12 | Willow communities | Orange |
| 6-1 | Seeded big bluegrass with sweetclover | Dark Blue | 9 | Other seeded rangeland | Dark Green |
| 15 | Sedge/rush/bulrush meadow | Red | 5 | Crested wheatgrass seeding | Yellow |
| | | | 8 | Abandoned fields with vegetation different from any of the above | Red |
| | | | 7 | Native rangeland | Purple |
| | | | 17 | Bare soil | Black |

represent the crested wheatgrass area. The SPARC readout identifies this area primarily as other seeded grassland. The reason for this crossover is not known now, but available evidence indicates that interpretation of the digital map may provide more discrete data about the individual plant community types. A similar relationship existed in SPARC classification of categories 6-2 and 7. Many small areas in the south of the SPARC map were classified as category 6-2 when they should have been category 7. The digital map again identified a mixing of these two categories in the area but the major portion of the data points were identified as native range (category 7).

The utility of developing a multispectral processing technique for native vegetation should be obvious. An important concern about management of native vegetation relates to changes in vegetation over time and determining what caused these changes. Since the multispectral scanner (and peripheral equipment) records and stores bits of information about a small piece of landscape, depending on the resolution capabilities of the scanner system, any change in that piece of landscape theoretically would be identified by a change in apparent radiance in subsequent scanner data. This assumes that discrete limits of the information stored, that is the mean relative radiance levels with variances that are discrete for specific plant communities, can be identified. The percentage of data points representing a kind of plant community can be computed (Table 8) and any change in these relative values can be determined using sequential imagery. This would then represent

Table 8. Percentage and number of digitized imagery points recognized according to category from the digital recognition processing

| Category | Percentage of Points | Number of Points |
|---|---|---|
| 2T | 19.8 | 45,099 |
| 3 | 13.3 | 30,294 |
| 4 | 9.6 | 21,866 |
| 5 | 2.0 | 4,555 |
| 6-1 | 4.7 | 10,705 |
| 6-2 | 5.0 | 11,389 |
| 7 | 9.2 | 20,955 |
| 8 | 13.4 | 30,521 |
| 9 | 2.9 | 6,605 |
| 12 | 2.6 | 5,922 |
| 14 | 1.0 | 2,278 |
| 15 | 1.2 | 2,733 |
| 16 | 1.2 | 2,733 |
| 17 | 0.6 | 1,367 |
| Not Recognized | 13.5 | 30,749 |
| Totals | 100.0 | 227,771 |

a change in area comprising a specific community type. Theoretically, this technique would provide more accurate information than photo interpretation only since interpreter error would be minimized. The concept needs substantial additional research, first to identify the minimum level of integrity with which the recognition processing can classify plant communities, and then (tested over time) to determine the repeatability of the technique.

High Flight (Mission 139)

The color photographs, both color infrared and normal color, were interpreted for plant community classification using the 1:8,000-scale color infrared photographs as "ground truth." The three black-and-white Hasselblad transparencies were to be used for multispectral combining. The hypothesis is that this technique would yield more information about community classification than would be obtained through independent use of color or black-and-white transparencies. Due to lack of ready access to a color combining system, this part of the experiment is not yet completed.

The three very small-scale (1:405,000) Hasselblad color photographs are illustrated in Figure 9. The color film (SO-168 with a 2E filter) was quite uniformly exposed although dark corners were evident. It had relatively good color balance in the lighter areas to provide for accurate color reproduction. However, it was generally underexposed which provided some difficulty for interpretation. The color infrared (SO-117 with a 15 filter) was slightly underexposed and nonuniform due apparently to the hotspot phenomenon.

The other color infrared film (SO-117 with a 15+CC30B filter) is sharp and clear, better than the other two films, but still with dark spots around the edges and in the corners, due possibly again to the hotspot phenomenon.

As might be expected, only generalized vegetation types could be positively identified using the very small-scale transparencies. This was especially true for the color (SO-168 with 2E filter). With this film type, only five primary mapping units were determinant (see Table 1 for descriptions). These included: (1) Recently logged ponderosa pine (unit 1); (2) mature ponderosa pine (unit 2); (3) meadow type vegetation (which includes mapping units 12, 14 and 15); (4) native or native/seeded grassland mixtures (units 7, 8, 9 and 10); and (5) seeded crested wheatgrass (unit 5). The seeded big bluegrass (unit 6) and ponderosa pine regeneration (units 3 and 4) could not be identified although film resolution in relation to unit size was of sufficient quality to potentially allow identification. The discrete ground differences did not resolve in the very small-scale color photographs.

Both color infrared films at the same very small scale proved to have more information content than the color film. In the timbered areas, some differences in understory vegetation were quite clearly discernible using 4X stereo viewing. This was especially true in the small drainageways where soils are slightly heavier, soil moisture was available longer to plants and where consequently, plant growth was more luxuriant than in associated areas. Also there were discernible differences among the meadow type communities that were not visible in the color transparencies. Larger areas of willow (unit 12) could be isolated by color differences by stereo interpretation. In some cases, the native bluegrass meadow (unit 14) and sedge/rush/bulrush (unit 15) could be discerned although commission errors were frequent. The native grassland communities as defined in this study could not be discriminated on this very small-scale photography. Comparing the two infrared color films, the SO-117 with a 15+CC30B filter may have a slight margin over the SO-117 with a 15 filter for community classification. This may have been due more to exposure variances than potential latent information, however.

Community classification and mapping with the very small-scale photographs is inadvisable except for generalized plant communities, i.e. forested areas, grassland areas and meadow areas. Although community differences were observed within these units, the mapping units would have to include community complexes due to the very small photographic scale. Larger-scale photographs are needed to determine in more detail the size and structure of the plant community inclusions.

Color (SO-397 with a 2E filter) and color infrared (2443 with a 15 filter) films were simultaneously exposed in RC-8 cameras at a scale of 1:104,000. The color film was underexposed, apparently because of hotspotting (Figure 10). The color infrared film (Figure 1) also had nonuniform exposure but in other respects, was generally good. Color contrast and balance were satisfactory especially in the immediate vicinity of the Experimental Forest area.

Figure 10 RC-8, 150mm color photography (SO-397 with 2E filter) taken at at a scale of 1:104,000. The exposure was nonuniform and most of the area was underexposed.

Even at this larger scale, as compared to the Hasselblad imagery, the color film had limited value for community classification except for discrimination among general community systems. The forest types, grassland types and meadow types, in general, were discernible but specific ecosystems within these units could not be consistently identified. Some of the seeded areas (map units 5 and 6) could be located by association but primarily by linear dimensions of fence lines creating systematic patterns. Interpretive commission errors (between the seeded areas and other grasslands) were high, based on color contrasts.

There was a significant information gain using the RC-8 color infrared photographs (scale 1:104,000) for community classification, especially the meadow type vegetation. The willow communities (unit 12), were easily interpreted; many of the areas for type locations of the native bluegrass meadows (unit 14) and sedge/rush/bulrush meadows (unit 15) were identified. The seeded pasture areas were interpreted primarily on the basis of linear dimensions of the fields. However, color differences of the crested wheatgrass seeding (unit 5) had sufficient color contrast so that this type, in fact, represented a unit class unlike all others in the photography. The seeded big bluegrass (unit 6) was so similar in color to much of the native range (unit 7) that interpretive commission and omission errors were high. A similar problem existed in recognition processing of the multispectral scanner imagery.

The 1:53,000-scale color infrared photographs (film Type 2443 with a 15 filter) will be of prime value for refining multistage sampling techniques (Figure 3). Although these photographs were not uniformly exposed, the color contrasts were good and details of the forested areas, grassland areas, urban developments and hydrologic features were distinct and clear. Considerable detail was interpretable within the forested areas, especially the recently logged area (unit 1). Although differences in type locations of herbaceous systems in this unit were very subtle in the photographs, areas where soil/water relations were more favorable to plant growth, at the time when the photographs were exposed, were identifiable. These were located primarily in drainage depressions.

The meadow type communities (units 12, 14 and 15) were easily interpreted at this photoscale. Although all three would probably be included as a single mapping unit using this scale of photography, the area of each could be accurately determined by point sampling or planimetry. This information would then be used in probability multistage sampling with smaller-scale photographs to determine the areal extent of the community systems.

Misinterpretation of the seeded grasslands versus native rangelands was still serious in the 1:53,000-scale photographs exposed at the one time (July 21) during the summer growing season. This time was chosen because it appeared to offer the best single time possibility of optimizing ground differences among the community types determined by phenological relationships. The single time hypothesis was also based on a potential operational procedure in which photo data gathering was presumed to be feasible only once during the year. Obviously, this cannot be done if an investigator is concerned about subtle but real differences among community types similar to those described for this study. Our previous work as well as that of other researchers has defined the need for multiseasonal photography for plant community classification and species identification. We hope to define how one might more succinctly overcome this problem, especially working with small-scale photographs and gross resolution imagery with our ERTS experiment; this will be done by working cooperatively with the Forest Service Forest Remote Sensing Project. We need additional small- and very small-scale photographs obtained seasonally before we can define how best to map and classify plant communities similar to those at the Manitou test site. On the basis of our data so far, color infrared photographs at photoscales around 1:50,000 will provide an intermediate sampling stage to classify and quantify community systems as we ground-identified them at Manitou. Photoscales at approximately 1:100,000 appear to provide minimum information gain before obtaining suborbital (1:400,000) or orbital (1:2+ million) data. This is not unlike results we obtained from our work with Apollo 9 information (Driscoll and Francis 1970).

## SECTION II

## REMOTE MEASURES OF HERBACEOUS STANDING CROP

### PROCEDURES

An ultimate analysis of aerial or space photographs would include a determination of the herbaceous standing crop in specified plant communities. This could be considered an end product for some management decisions. This information would be extremely useful for evaluating and monitoring changes in energy balances of the vegetational component of ecosystems which would be directly related to changes in productivity.

The details of this experiment were explained in a previous report (Driscoll and Francis 1970). Basically, ground truth consisted of simulating six levels of standing crop on 3x3-meter square plots by cutting, to equal herbage height, increments ranging from 0 to 100 percent herbage removal. The treatments were replicated four times in a big bluegrass seeding at the Manitou test site. Standing crop after herbage removal was estimated by double sampling with a heterodyne meter, an electronic device which senses mass within an array of probes (Neal and Neal, 1965).

Aerial photographs were flown at two scales -- 1:563 and 1:3,855 -- at the peak of the growing season in mid-August. This was done with the Forest Service Aero Commander using two 70mm Maurer cameras, one loaded with Anscochrome D-200 film and one with Type 8443 color infrared. All ground measurements were made within a week of the photo mission.

The color infrared photos were used in conjunction with a GAF microdensitometer (MDT) to provide image density differences among the various treatments. This film type was chosen because visual interpretation indicated that it provided more discriminatory evidence of differences among standing crop levels than color film. The MDT was programmed to scan with an effective circular aperture of $416\ \mu^2$ with a green filter (Wratten 93).

Scan lines were run perpendicularly to seeded drill rows to avoid possible measurements of only vegetation type or of nonvegetated areas between the drill rows (Figure 11). Nine random starts per imaged

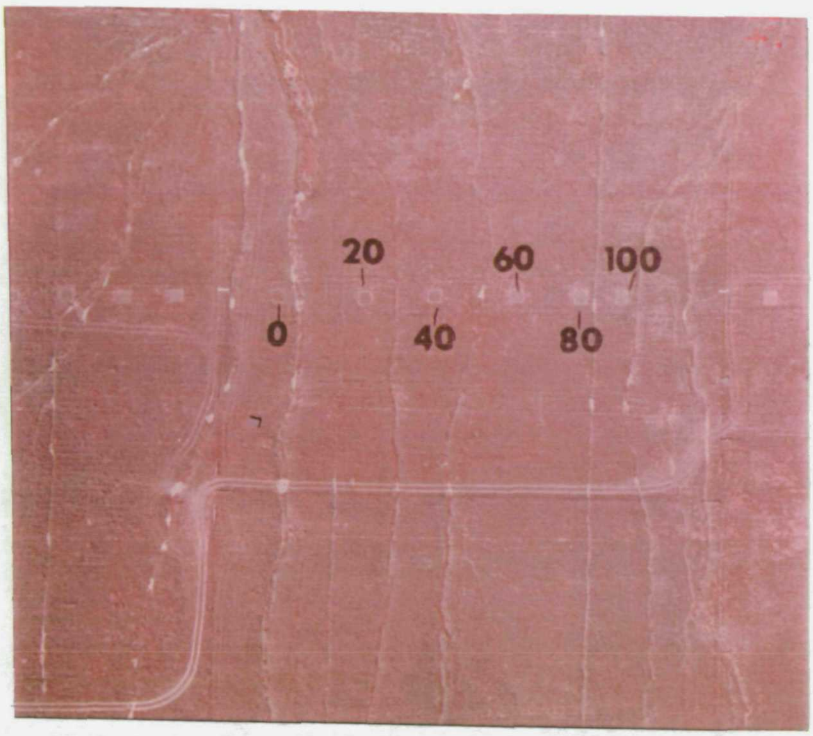



Figure 11 Visual and image optical density comparisons in a color infrared photography (1:3,855) of various levels of herbaceous standing crop in scale 1:2070 enlarged from a big bluegrass pasture indicate differences among levels of standing crop. The regression relationship between herbaceous green standing crop or its corresponding harvested dry weight to photo image density is explained by the linear function $y = a + b(x)$.

plots were used for the 1:563 photos; five were selected for the 1:3,855 photos. The data from the strip chart readouts were digitized by an Auto-trol digitizer.

## RESULTS AND DISCUSSION

The digitized data and image density data were analyzed by regression and correlation. Green standing herbage and corresponding harvested dry weight were each regressed as dependent variables (y) to the photo image density (x).

If a correlation coefficient (r) of 0.80 is established as an acceptable level of accuracy, the image density derived from both scales of photography provides a valid estimate of either green standing herbage or harvested dry weight (Table 9). In all cases, the correlation coefficient is high and significant ($P = 0.01$) indicating a strong relationship between image density values and amount of biomass. The "best" relationship occurs between image density and harvested dry weight ($r = 0.87$) using the 1:563 photoscale and can be expressed as a simple linear function:

$$y = a + b(x) \quad \text{where:}$$

y = standing crop production (dry weight)

a = -151.72

b = 62.61

x = image density

However, since a possible operational application of this technique may not allow dry weight determinations, the green standing crop/image

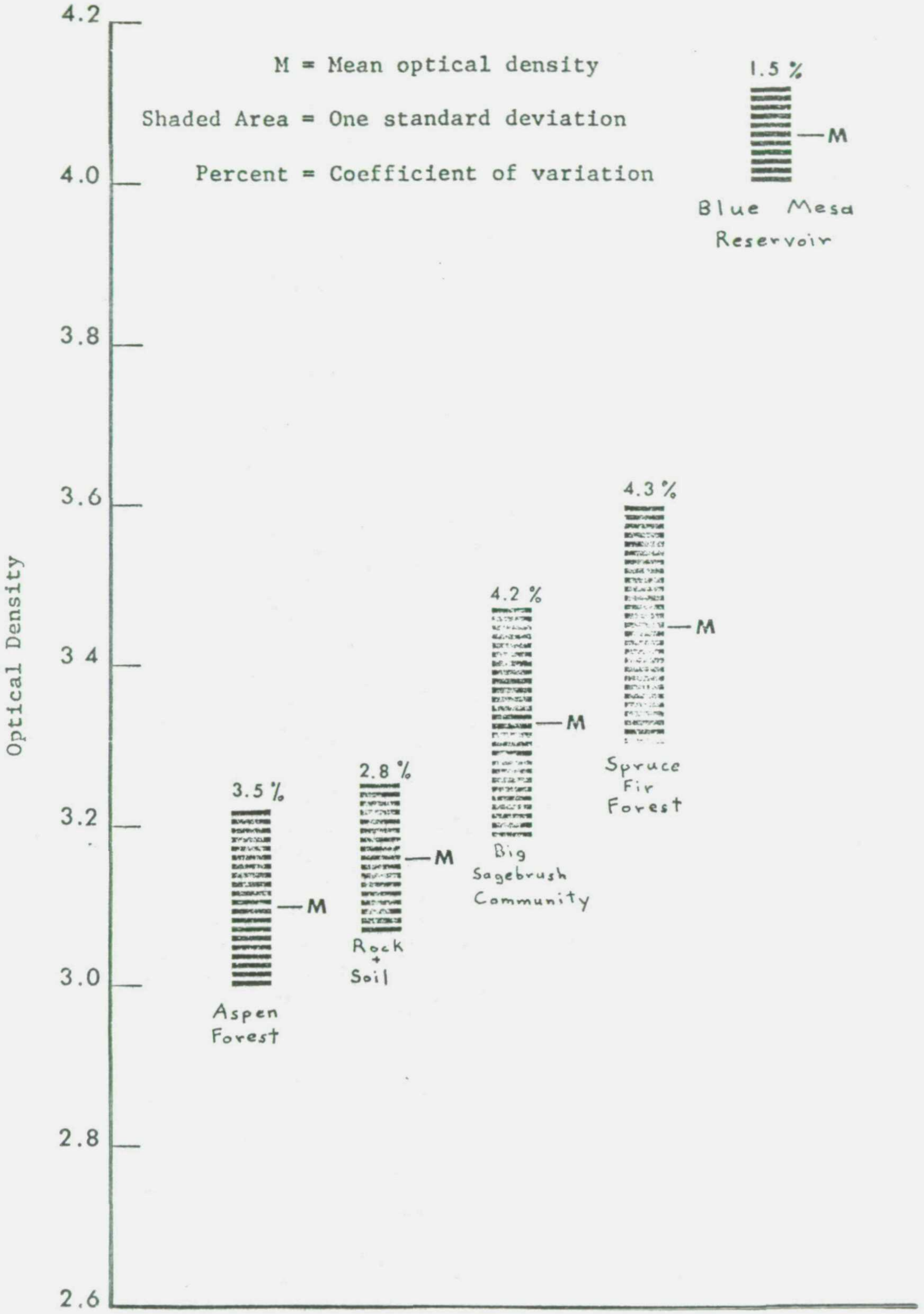



Figure 12 Optical film density through a green filter (Wratten 93) of three plant communities, rock and soil and Blue Mesa Reservoir, west of Gunnison, Colorado; 30 September 1968; scale 1:139,000, color infrared -- 8443.

larger coefficients of variation. This would be expected especially for a spruce-fir forest because it is a very heterogeneous plant community while the water body is homogeneous.

The images of four plant communities at Manitou were compared for optical density. Mean optical density for the two grassland communities (3.09 and 3.25) were similar but were discretely less than the two forest communities (3.66 and 3.73) (Figure 13). The coefficient of variation in density values was less for the grasslands, (2.9 percent and 0.6 percent), especially the seeded area, than the pine forest communities. The density variation of the big bluegrass area was sufficiently narrow that mean optical density separated it from native grassland at one standard deviation. The coefficient of variation in mean optical density for the ponderosa pine forest (5.7 percent and 6.4 percent) was greater than the two forest types at the Blue Mesa Reservoir location (Figure 12). This is because the pine forest is usually a more heterogeneous plant community than the spruce-fir or aspen forest. A pine forest often has natural and cleared openings and more sun and shadow contrast which results in a greater range in density values.

Large Scale

Three microdensitometry trials were made to separate, by optical density, plant communities and components on large-scale photography. At Manitou, considering the four cultural treatments, the results were not encouraging (Figure 14). The range in mean density values among all treatments was only 0.11 value points (2.71 for untreated

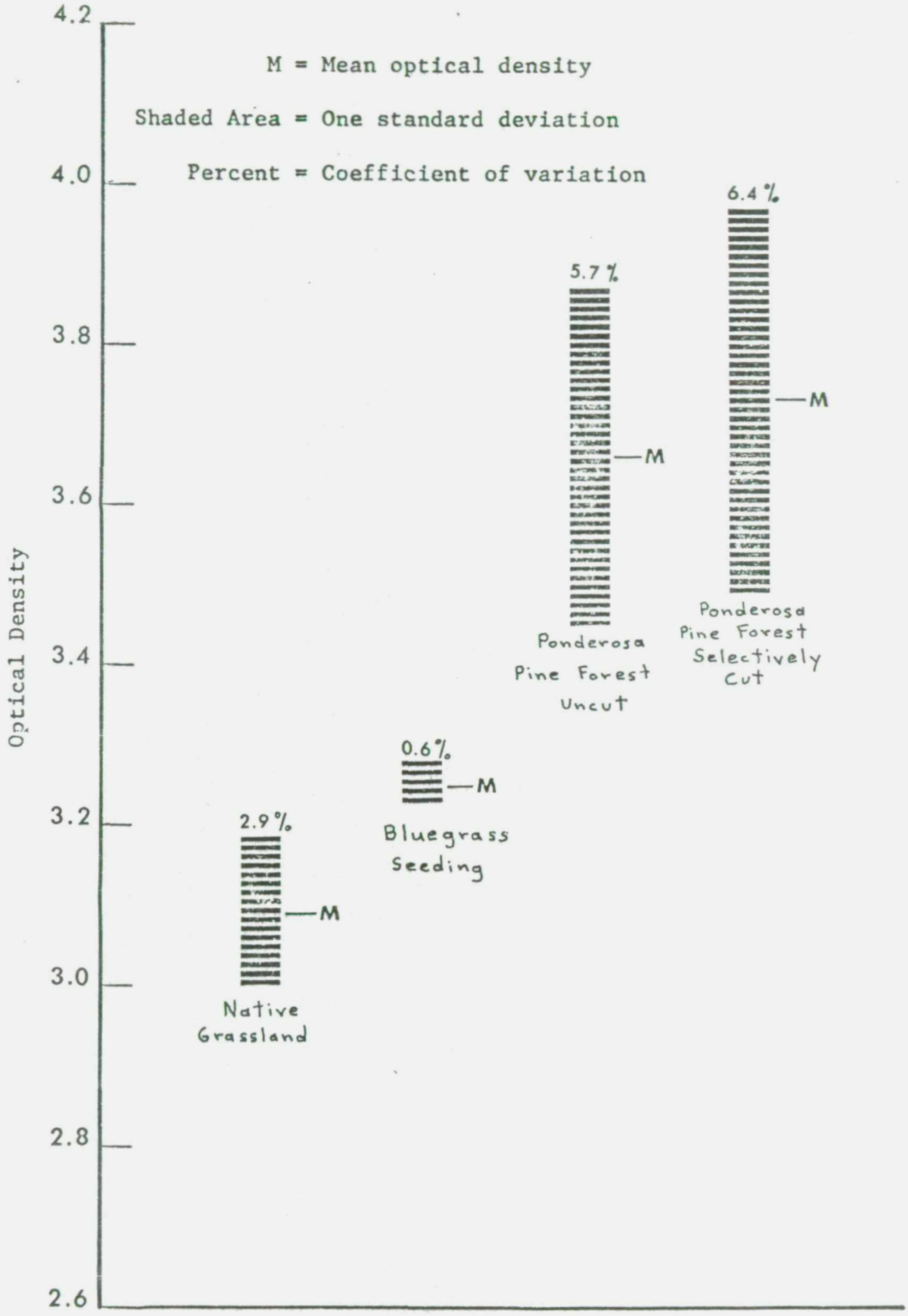



Figure 13 Optical film density through a green filter (Wratten 93) of two grassland communities and two forest communities. Manitou Experimental Forest, Colorado; 1 October 1968; scale 1:135,000; color infrared -- 8443.

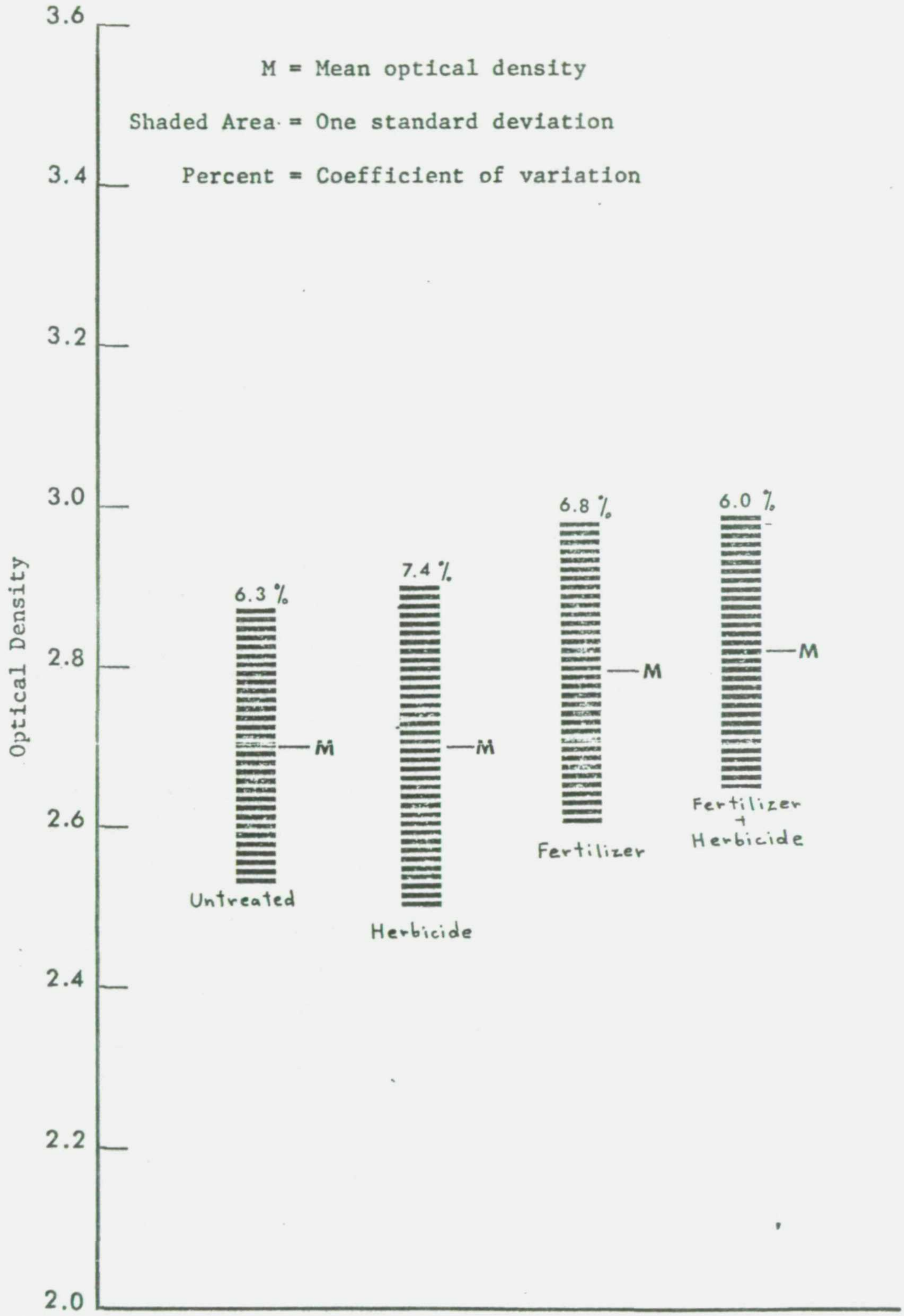



Figure 14  Optical film density through a green filter (Wratten 93) of four cultural treatments. Native grassland community, Manitou Experimental Forest, Colorado; 8 August 1968; scale 1:2,700; color infrared -- 8443.

areas to 2.82 for an area treated with fertilizer on herbicides). Coefficients of variation varied from 6.3 percent to 7.4 percent. Therefore, treatment effects could not be discriminated at one standard deviation (0.20) by image density although visual differences were apparent in the photographs. Apparently these visible differences had little effect on optical density.

A second trial was made with large-scale color infrared photographs at Black Mesa to determine if optical densities of photographic images of two range sites were different (Figure 15). Results showed a higher density value for the more productive site (3.20) as compared to the less productive site (2.95). However, considerable variation in density values (coefficients of variation were 10.3 percent and 7.5 percent respectively) caused severe overlap in optical density at one standard deviation and therefore, the sites could not be discriminated.

A third trial with large-scale photography was made of two tree species, four shrub species, and bare soil at the McCoy test site to determine how well individual species and bare soil could be separated by image optical density. Mean image density values varied from 2.50 for soild to 3.68 for mountain mahogany (Figure 16). The soil value at one standard deviation was sufficiently different from all six plant species to provide confident identification. This was due both to low mean density and a low standard deviation (0.02) and coefficient of variation (0.8 percent) which indicated a homogeneous community component. The two species of sagebrush (mean densities of 2.77 and 2.80) separated very

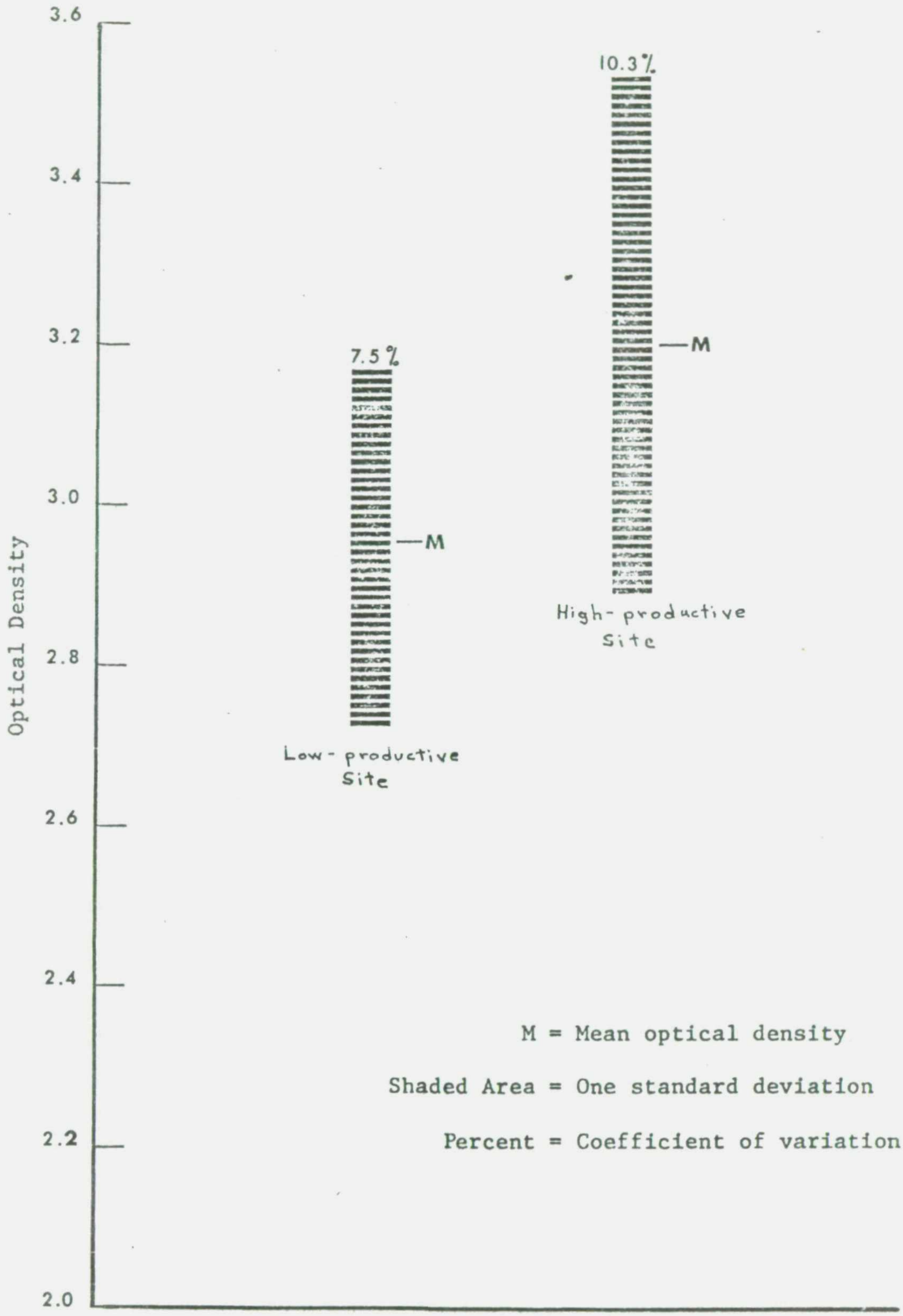



Figure 15 Optical film density through a green filter (Wratten 93) of two grassland sites. Black Mesa Colorado, 7 August 1968, scale 1:800, color infrared -- 8443.

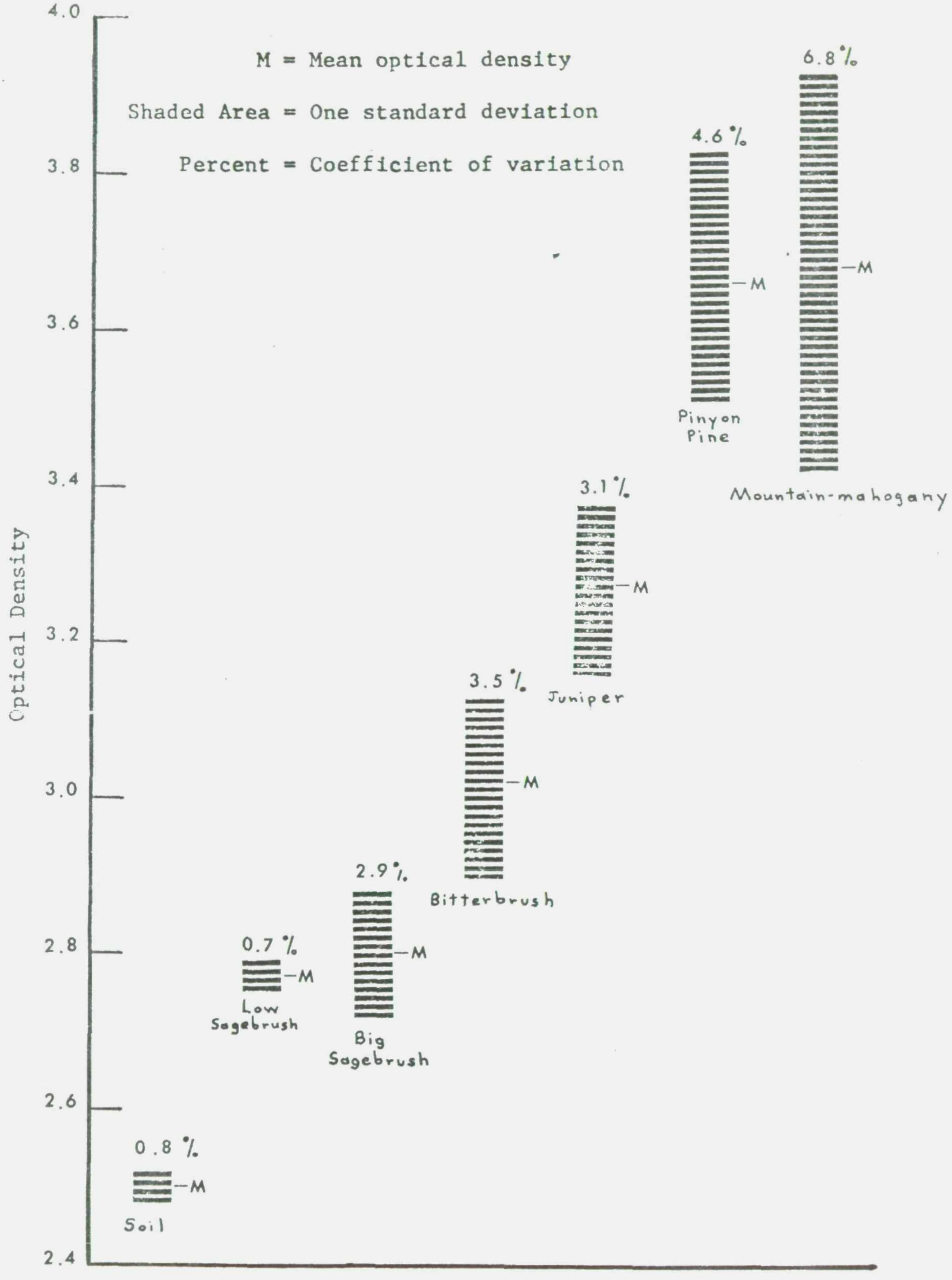



Figure 16 Optical film density through a green filter (Wratten 93) of two trees, four shrub species, and soil. McCoy, Colorado, 6 August 1968, scale 1:1,100, color infrared -- 8443.

well from the four other species (mean optical densities of 3.17 or more), but not from each other. However, by image color and shape these two species are easy to correctly identify nearly 100 percent of the time (Driscoll and Francis 1970).

Based on optical transmission as a measure of density of film images examined in this study, the microdensitometer separated some, but not all, plant communities and their components identified by manual photo interpretation. Independently considering all five test locations -- a total of 27 optical density tests -- seven complete separations at one standard deviation occurred at three locations (Figures 12, 13 and 16). In addition, 10 partial separations occurred at the same three locations. Partial separation occurred when a plant community or component separated from some, but not all of the others at a particular location.

Minimum opportunity for target separation based on optical density occurred most often within a single plant community even though site variability or treatment effects were visible to a photo interpreter (Figures 13, 14 and 15). These phenomena are unexplained at this time.

One of the most obvious characteristics that aids in optical density separation is related to homogeneity of the plant community or component. This was obvious as identified by density values of the water body (Figure 12), bluegrass seeding (Figure 13) and soil (Figure 16) as compared to other plant communities in the photographic imagery.

Aldrich (1971) reported mean optical density values for 11 land classifications from 2.44 (plowed field) to 3.87 (pine forest) -- a range of 1.43. His microdensitometer tests (with a red filter) were with very small-scale (1:2,430,000) Apollo 9 color infrared film exposed in early spring. Comparing his test with our two very small-scale tests (Blue Mesa Reservoir -- 1:139,00, and Manitou -- 1:135,000) where nine plant communities and components were examined, mean optical density ranged from 3.09 (native grassland, October 1) to 4.06 (a reservoir, September 30) -- a range of 0.97. For the six tree and shrub species and soil at McCoy (scale 1:1,100) the range in mean optical density was 1.18; from 2.50 (soil) to 3.68 (mountain mahogany). This indicates that there is value for using microdensitometry for automated interpretation on very small- as well as very large-scale photographs.

Plant community or component size is not an important element in density discrimination assuming appropriate scale of photography. This research identified both success and failure for both community components such as individual small shrubs and generalized vegetation types. Optical density separation may be acceptable on large-scale or small-scale photography depending on the particular optical film densities being measured in a given mosaic of landscape features.

These results are encouraging, but additional research is needed to more positively identify seasonal and photoscale effects on image optical density. In some of the cases of poor optical density separation, acceptable discrimination by manual photo interpretation is possible (Driscoll and Francis 1970). This suggests that bringing other spectral characters into a system could be a way of assembling an efficient remote inventory and monitoring system utilizing more than optical film density alone.

Steiner (1970), working with 11 crop classification in Switzerland suggested a two-dimensional system utilizing time as well as the spectral dimension (in this case optical density on large-scale panchromatic aerial photographs). This concept could be useful and increase the likelihood of correct differentiation between wildland plant communities as well as individual plant species.

Steiner measured optical density of the 11 crops from photographs obtained at 10-day intervals from early April into August. Naturally the crop communities were more homogeneous and therefore easier to separate than most of our wildland plant communities (the average optical density standard deviation for crops was 0.04). The data matrix was subjected to a linear discriminate analysis. The result was 100 percent correct crop classification.

Steiner pointed out that such repeated observations would be especially suitable from an orbiting survey satellite. A broad outline for automation of crop surveys from an orbiting satellite was also given. This would have application for wildplant communities which are of interest. Anderson (1971) suggests that such a system should have a minimum level of accuracy of about 85 to 90 percent which is comparable to the current land use enumeration for the Census of Agriculture.

How addition of the time dimension could conceivably aid in plant community separation is identified in Figure 12. At the late September date the yellowing aspen forest community, although separate from the spruce-fir forest, is undifferentiated from the rock-soil component

| Channel No. | Spectral Band (μm) |
|---|---|
| 5 | 0.478-0.508 |
| 9 | 0.566-0.638 |
| 7 | 0.514-0.558 |
| 6 | 0.492-0.536 |

4. The recognition processing results provided acceptable discrimination of generalized plant communities. These included: (1) ponderosa pine forested areas, (2) upland herbaceous vegetation, (3) hydrophyllic herbaceous vegetation.

5. Serious problems still exist in classification of plant community systems within the generalized herbaceous community type. Seeded crested wheatgrass was satisfactorily classified. However, seeded big bluegrass was mixed seriously with native range which was in turn confused in the computer processing for abandoned fields with native vegetation significantly different from native range.

6. Additional processing needs to be done to attempt to segregate the misclassified vegetation systems. This would involve more discrete selection of representative training samples. It would also involve new research in which the relative radiance of mixtures of vegetation, bare soild, and plant litter cover on the soil were considered as classificatory evidence of community types.

High Flight (Mission 139)

1. Generally, photographs generated from this mission were good in all respects except exposure. In all cases, the imagery was slightly underexposed and was not uniform throughout any single frame. This was possibly due to hotspot phenomena.

2. Color infrared photographs (Type 2443 with a Wratten 15 filter or SO-117 with a Wratten 15 filter) provided more information about plant community identification than color film (SO-397 or SO-168 each with a 2E filter) at all photoscales (1:53,000, 1:104,000 and 1:405,000). The addition of a CC30B to the SO-117+15 for very small-scale photographs (1:405,000) added no significant interpretive qualities.

3. The 1:53,000 color infrared photographs were valuable for refining multistage sampling for plant community extent and composition. We have not yet completed this aspect of our research.

4. These conclusions are based on only one high-flight mission. They need to be tested against other data obtained at different seasons of the year and integrated into a discriminate function analytical procedure to optimize native plant community classification.

Remote Measures of Herbaceous Standing Crop

1. Image optical density measured with a microdensitometer was highly correlated with either green herbaceous standing crop of seeded big bluegrass or its corresponding oven dry weight using color infrared (Type 8443 + Wratten 12 filter) positive transparencies at photoscales of 1:563 or 1:3,855.

2. The relationship can be expressed as a simple linear function ($y = a + b(x)$). In all cases the correlation coefficient ($r$) was highly significant ($P = 0.01$) and greater than 0.80.

3. These results identify how the system can be used to remotely determine herbage production of a seeded grass stand. We now need to test the system for native herbaceous communities considering both

season of photography and different scales. This would provide a way for synoptic sampling of standing crop at any specific point in time.

Microdensitometry for Plant Communities and Components

1. Varied results were obtained when using the microdensitometer for automatic classification of plant communities and components. In general, the greater the homogeneity of the image of interest, the greater the possibility of automated interpretation by microdensitometry.

2. Seeded grasslands, bare soil or rock areas, and generalized plant communities identify acceptably well by optical density measurements through a green (Wratten 93) filter on small-scale (1:135,000 - 1:139,000) color infrared (Type 8443 with Wratten 12) transparencies obtained in the fall.

3. Individual species, range sites, or site treatment effects were not identified at an acceptable level of accuracy using the imagery available.

4. By taking advantage of the seasonal aspects of plant communities in relation to changing image characteristics and using linear discriminate analyses, one might find it possible to develop an analytical system using microdensitometry to obtain near 100 percent correct community classification.

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# APPENDIX I

The following is a list of Forest Service, U. S. Department of Agriculture, personnel who contributed to this study and represent a major salary contribution to it:

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In addition, the COLORADO GAME, FISH AND PARKS DIVISION, specifically R. B. Gill, Research Biologist, contributed to this research.