MULTISPECTRAL SCANNER IMAGERY FOR PLANT COMMUNITY CLASSIFICATION[1/]

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ABSTRACT

Optimum channel selection among 12 channels of multispectral scanner imagery identified six as providing the best information for computerized classification of 11 plant communities and two nonvegetation classes. Intensive preprocessing of the spectral data was required to eliminate bidirectional reflectance effects of the spectral imagery caused by scanner view angle and varying geometry of the plant canopy. Generalized plant community types—forest, grassland, and hydrophytic systems—were acceptably classified based on ecological analysis. Serious, but soluble, errors occurred with attempts to classify specific community types within the grassland system. However, special clustering analyses provided for improved classification of specific grassland communities.

INTRODUCTION

Multispectral remote sensing coupled with automatic data processing may be the future land management technique for classifying and monitoring changes in nonagricultural vegetation. The research reported in this paper represents some of the most significant results obtained from an experiment designed to test the hypothesis that multispectral scanner data will identify specific plant communities determined by ecological analyses.

The study area for this research was located within the Manitou Experimental Forest in Colorado. The vegetation was typical of the lower Montane Zone along the eastern slope of the Rockies; open-to-dense stands of ponderosa pine were interspersed with meadows and grassland parks.

Multispectral scanner data were obtained with The University of Michigan's optical-mechanical multispectral scanner. The data were obtained at 1000 hrs on July 29, 1970 at a flight altitude of 915 meters (3,000 ft) above the ground datum of 2,350 meters (7,700 ft).

Recognition processing of the multispectral scanner data was performed by both a general purpose digital computer and a special purpose analog recognition computer (SPARC). Channel selection among 12 channels of multispectral scanner data identified six as providing the best information for computerized classification of 11 plant communities and two nonvegetation classes.

The recognition processing results provided acceptable discrimination of generalized plant communities. These included:

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(1) Ponderosa pine forested areas.

(2) Upland herbaceous vegetation, such as crested wheatgrass seeding, seeded big bluegrass with sweet clover and seeded big bluegrass with a conglomerate of forbs.

(3) Hydrophytic herbaceous vegetation such as willow, native bluegrass and sedge/rush/bulrush meadows.

The two nonvegetation categories, asphalt roads and bare soil, were acceptably classified.

Not all portions of the specific community types identified by ground survey were classified through computer processing as belonging to their appropriate grassland systems. This problem occurred whenever the proportion of bare soil and plant litter together exceeded the proportion of healthy vegetation foliar cover. Because of the variable foliar cover within some of the specific grassland community types, an analysis was made to determine representative training areas for the recognition processing. A clustering technique of the multi-variate distributions was used and is described. This technique uses the probability of misclassification as the criteria to determine spectral similarity and separability between specific community types with variable ground cover.

The multispectral scanner data was preprocessed using an empirical technique in order to eliminate a pronounced scan angle effect which would have hindered the recognition processing. This scan angle effect could be attributed to the bidirectional reflectance properties of the materials in the scene. The atmospheric effects were deemed negligible because of the clear atmospheric condition (visibility in excess of 160 km.) and the low flight altitude of 915 meters.

DATA ACQUISITION

The Study Area

The study area for this research is located approximately 25 airline miles (40 kilometers) northwest of Colorado Springs, Colorado, and is within the Manitou Experimental Forest, a research unit of the Rocky Mountain Forest and Range Experiment Station. The elevational range was from 7,600-7,800 feet (2317-2378 meters) and included gently rolling terrain. The Forest is a 16,000-acre (39,536 hectare) area within the ponderosa pine-bunchgrass type and is devoted to multi-disciplinary wildland research. The vegetation is typical of much of the lower Montane Zone along the eastern slope of the Rockies; open-to-dense stands of ponderosa pine (*Pinus ponderosa* laws.) are interspersed with meadows and grassland parks.

The specific test site included an area approximately 7.28 square kilometers (2.81 square miles) with a mean ground datum of 2,350 meters (7,700 feet) (Fig. 1). Within the area there were three general kinds of vegetation: (1) ponderosa pine forest of various stand classes, (2) upland grasslands which included native and seeded herbaceous stands, and (3) hydrophytic communities, including both herbaceous and shrubby systems.

Aerial Data

All multispectral data collection was performed by The University of Michigan's multispectral scanning system. This system consisted of two double-ended optical mechanical scanners. Imagery included data records in 12 discrete spectrometer channels in the visible and near infrared regions of the spectrum (Table I).

The scanner was flown at approximately 915 meters (3,000 feet) above ground datum at 1000 hours, Mountain Standard Time, on July 29, 1970. This flight altitude was selected because the apparent resolution of the system (3 milliradians) subtended an apparent ground resolution data cell of 9 x 9 feet at the nadir of the scanner system. The "plot" size represented a sufficiently large enough ground area to include representative component mixtures (vegetation, bare soil surface, and plant litter cover on the soil surface) of the plant community systems subsequently defined for recognition processing. The time of year was selected because previous work with visual interpretation of aerial photographs and ground research indicated that plant communities at the Manitou Experimental Forest were more readily discernible at that time than as compared to other periods. The mid-morning time was selected to avoid highly probable cloud build-up later in the day.

Weather at the time of the overflight was clear with visibility in excess of 160 kilometers (100 miles). Target surfaces were dry except for bare soil which was damp due to heavy rainfall the previous day. The mission was flown on a 330° azimuth.

Ground Data

Detailed mapping of plant communities was completed immediately prior to the scanner mission. This was based on current aspection of the plant communities and the relative composition of the communities regarding similarity of plant species components. Medium scale (1:8000) color infrared mapping photographs flown approximately 6 weeks prior to the scanner mission were used in conjunction with detailed ground search. At this photo scale, each mapping unit represented a specific community type. The mapping units, which corresponded to recognition categories of the scanner data, and a brief description of their characteristics are listed in Table II. Also included were two nonvegetative categories which were inclusions in the vegetative units.

Plant species abundance was determined for each community type within 2 weeks of the mission. 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 (the sum of the three equalling 100 percent viewed vertically) was estimated. This was done by sampling with 9- by 9-foot sample plots (Fig. 2) which were located by restricted random fashion throughout each community type. Ground cover sampling in the forest communities was restricted to land surface visible from above without interference from the tree canopy.

DIGITAL PROCESSING OF MULTISPECTRAL DATA

Preprocessing

The multispectral scanner data was preprocessed using an empirical technique in order to eliminate a pronounced scan angle effect which would hinder the recognition processing. This technique was developed and proved successful in a previous study (Smedes et al, 1971).

The transformation which was used on the data to correct for the scan angle effect is a function of scan angle and spectral channel, but is independent of the various materials in the scanner imagery. From the analysis of the data, if the scan angle correction is determined as being strictly multiplicative in nature, the transformation is performed on each scan line of data by dividing by a function of scan angle which is associated with each spectral channel. If the scan angle correction is determined as being both additive and multiplicative, the transformation is performed on each scan line of data by first subtracting by one function of scan angle and then dividing by another function of scan angle.

In order to determine the nature of the transformation, there must be at least two materials having a fairly good distribution of training areas in the scan line direction. For these two materials, the statistical signatures for all training areas are extracted directly from the multispectral scanner data. The mean value as obtained from the signature for each training area is graphically related to the average value of the scan angle for that training area. This procedure is followed for each material and for all the spectral channels. A smooth curve is drawn through the plotted points for each of the materials. These curves are then normalized with respect to the data at the same scan angle from each curve. If the two normalized curves are the same function, then this function is used to perform a multiplicative transformation. When the two normalized curves are not the same function, then a function of scan angle is calculated and subtracted from each of the smooth curves. The resulting curves will then normalize to the same function. The subtractive function and the normalized scan angle function based on one of the new curves would be the two appropriate functions to use in the transformation.

In this multispectral scanner data, there were two materials which could be used; one of the materials was the ponderosa pine forest which was designated as recognition category 2T, and the other material was in the grassland categories designated as category 7 (native rangeland). For this latter category there were much fewer training areas with more limited distribution in the scan line direction than for category 2T.

The statistical mean values for all signatures from categories 2T and 7 were used. Figure 3 shows the data points plotted for spectral channel 5 (0.478 - 0.508 μm). The smooth curves which have been drawn in Figure 3 indicate the scan angle function for each of the two materials, 2T and 7 where the lower curve is for category 2T and the upper curve is for category 7.

Figure 4 shows the results of the transformation on spectral channel 5. The mean values for the signatures from the training area as extracted from the transformed data for categories 2T and 7 are plotted in Figure 4. The two horizontal lines now correspond to each of the mean values for each of the categories, 2T and 7, in this spectral channel. The mean values of each of the training areas for category 2T lie within ±0.1 volts of the mean values of 1.02 for the entire category

2T. With the mean value of 1.78 for category 7, most of the means from the training areas are well within ±0.1 volts.

Information about the seeded big bluegrass category (6) is also illustrated for both the original (Fig. 3) and transformed (Fig. 4) data from channel 5. The apparent radiance levels of the bluegrass seedings at the low scan line point numbers were very similar to that of the native range. Ground measurements at the time of the scanner overflight indicated a relative similarity of these two categories for amount of herbaceous foliage cover, plant litter and bare soil. The bluegrass seeding had 25% foliage cover, 64% plant litter and 11% bare soil and the native range area had 34% foliage cover, 53% litter, and 13% bare soil.

The bluegrass seeding at the high scan line point numbers did show apparent spectral differences as compared to the native range. In fact, there was an apparent intra-category dissimilarity which was detected in the data plots of the original (Fig. 3) and transformed (Fig. 4) data. The data for category 6 which appeared at the high scan line point numbers were obtained from two different training areas. One of the areas of the big seeded bluegrass was contaminated with yellow sweetclover (Melilotus officianalis (L.) Lam.) while the other area was contaminated with a conglomerate mixture of forbs. The fact that known differences existed between the training areas of category 6 made it unadvisable to have this category influencing the nature of the transformation. This also emphasizes the importance of accounting for species mixtures within and among herbaceous communities as well as the relative proportions of scene contribution due to foliar cover, plant litter and bare soil.

Signature Selection

The selection of a signature to represent some of the categories (Table II) was relatively simple using the preprocessed spectrometer data. Even though a category might have several training areas, the statistical signatures for each of the areas were so similar that it was arbitrary as to which was to be used. For some of the categories then, one training area was chosen and its statistical signatures used to represent its category. For category 2T, statistical signatures were extracted from the two training areas and combined into one signature to represent that category. The upland grassland categories (units 5 through 9 in Table II) were not handled in this straightforward manner because the signatures from several of the training areas were not similar in all cases. This was because of the variable ground cover within some of the grassland systems and specific community types. An analysis was made to determine the representative training area using a clustering technique which is described along with the results on the signature selections made for the upland grassland categories.

Clustering of Multi-Variate Distributions

The clustering technique was used to determine

(1) Spectral similarity and separability between specific community types and those grassland systems with variable ground cover.

(2) The best training area to represent the various similarity groupings.

The probability of misclassification was used as the criteria for each step of the clustering technique. With this criteria, all the statistical parameters (i.e., mean, variance and covariance) for all the spectral channels were considered simultaneously in computing the pairwise probabilities of misclassification.

For the first step, a signature was placed in a similarity group when the average pairwise probability of misclassification with respect to each of the signatures within the grouping had a high value. A signature was not placed in this similarity group if the average pairwise probability of misclassification with respect to each of these signatures was low. The lowest average probability of misclassification which was acceptable was approximately 0.1.

In the second step, a signature was chosen which was most likely to be confused with all the other signatures within its similarity group. Again, the probabilities of misclassification computed on a pairwise basis was used as the criteria but in a different manner than was used in the previous step. Actually the term "probabilities of misclassification" does not include the distinction between the two possibilities of error in the procedure for testing hypotheses. This distinction must now be made in order to explain the second step of this technique.

In following a procedure for testing hypotheses such as is used in the likelihood ratio test, if the hypothesis is true but the test rejects the hypothesis, an error known as a Type I error is made. If the hypothesis is false but the test accepts the hypothesis, an error known as a Type II error is made. The probability of misclassification associated with the Type II error will be used as the criteria for choosing the signature to represent the category.

In testing many statistical signatures by the likelihood ratio test, each signature was tested pairwise with all the other signatures and the resulting Type II error from each test was summed. A sum of Type II errors was obtained for each signature tested. The signature having the largest sum of Type II errors was the signature used to represent the similarity grouping. This two step clustering technique was first used on the signatures of the training areas within the upland grassland categories.

The results are that:

(1) At least one similarity group existed in each of the categories.

(2) Category 6, big bluegrass seeding had three similarity groupings.

(3) In all the categories, there were signatures which did not qualify as being represented by any of the similarity groupings within a category.

(4) A representative signature was chosen for each of the similarity groupings.

The clustering technique was applied again collectively to the group which contained the representative signatures and the signatures not represented within their category (items 3 and 4 above). The results finalized the set of signatures which were used in the recognition processing for the upland grassland categories.

The results were:

(1) Three categories, 5, 6, and 9, remained pure, i.e., none of the signatures from the other categories were similar to these. However, category 6 had two similarity groups.

(2) Categories 7 and 8 became the unpure categories, i.e., all the signatures not represented within their categories were similar to one or the other of these categories.

It was obvious after this analysis that neither categories 7 or 8 represent the categories as they were originally defined (see Table II). All training areas which contained any type of vegetation cover as long as the area had a low proportion of foliage cover would be similar to either categories 7 or 8. The separation between categories 7 and 8 was based mainly on the relative proportions of dead plant litter and bare soil. According to this analysis, some of the training areas of native rangelands were more similar to the similarity grouping of category 8 than to their own category.

More specific details of this procedure have been discussed by Spencer (1971). The relative location of training sets selected for final recognition processing are shown in Figure 5.

<u>Channel Selection</u>

The choice of which channels to use in the recognition processing was determined by an ordered selection scheme. The channel selection was started by picking the best channel out of the group of N channels where N was the total number of channels available. The selection was continued by combining the first channel choice with each of the remaining N-1 channels and picking the best combination of two channels. This ordered selection was continued until the best combination of six channels was obtained.

The criteria for the best channel was that the lowest average probability of misclassification was obtained for this channel with respect to the other N-1 channels. The total number of probabilities of misclassification that was computed was based on the number of materials being considered and tested on a pairwise basis. If there were M materials then there were M(M-1) probabilities of misclassification computed and averaged. Since, for each pair of materials tested, two probabilities of misclassification were computed; the probability of picking material M_1 given material M_2, and the probability of picking material M_2 given material M_1.

The results of using the ordered selection scheme to determine the spectral channels to be used in the recognition processing is shown in Table III. Six channels were selected for final processing. The channel selection scheme was stopped at this number because addition of data from other channels indicated minimum improvement in recognition accuracy. For example, adding the last channel indicated, channel 6, provided for an increase in classification accuracy of approximately 11 percent. This was deemed acceptable for this problem.

Recognition Processing

A decision rule which utilizes a likelihood ratio test is applied to each data point, where each data point has n components corresponding to the n channels of spectral data. The decision rule states that this data point is classified as a particular material, depending on the outcome of the likelihood ratio test. If there are two materials the likelihood ratio test is as follows:

$$\frac{f(M_1)}{f(M_2)} > 1;$$ then the data point is recognized as originating from material, M_1

where

$f(M_i)$ is the multivariate Gaussian probability density function for material, M_i.

When there are n materials, then there would be n(n-1) ratios to compute. The rule for recognizing a particular material is that the following n-1 ratio tests are satisfied simultaneously,

$$\frac{f(M_i)}{f(M_j)} > 1;$$ then the data point is recognized as originating from material, i

for $j = 1 \ldots n$
$i \neq j$

The likelihood ratio test for n materials is then equivalent to recognizing that material which has the greatest value of its probability density function for the data point than the values of the other probability density functions representing each of the other materials.

RESULTS AND DISCUSSION

The digital recognition processing produced a color recognition map (Fig. 6). The area of this map is approximately 7.28 square kilometers (2.81 square miles). The reader should refer to Figure 5 to assist in interpreting this map.

Generalized plant communities were acceptably classified. These included the forested areas, areas with hydrophytic vegetation, and areas of upland herbaceous vegetation. This was expected, however, since others have reported similar results (Smedes et al, 1971; Heller et al, 1971). Ground conditions of these units at the time of the mission were very dissimilar and this produced high contrast in apparent radiance signals among these vegetation systems.

However, problems existed for classifying the upland herbaceous plant communities (categories 5-9). For example, the bluegrass seeding in the northwest portion of the area was synonymously identified with category 8 (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.

Generally, this problem was apparently due to the variable proportions of foliage cover, plant litter, and bare soil as related to apparent scene radiance. Therefore, a part of the bluegrass seeding in the northeast part of the area was selected to investigate this problem. This unit was subdivided into two parts. One, category 6-1, represented an old seeding contaminated with yellow sweetclover. The average amount of foliage cover, plant litter and bare soil of this part was 85%, 15%, and 0% respectively. The other category, 6-2, represented an old seeding contaminated with numerous herbaceous species. Plant foliage cover, litter cover, and bare soil in this part was much less proportionately, 32%, 41%, and 27% respectively. The clustering technique previously described did predict that two units were in fact spectrally dissimilar and resulted in a realistic separation of the two units. This verifies that community species mixtures in addition to proportional amounts of foliage cover, plant litter, and bare soil are important characteristics to consider for analyses and recognition processing of multispectral scanner data for grassland systems.

It was not possible to follow this procedure with the other upland grassland communities where severe mixing occurred in the recognition processing. The ground control plan did not allow location in the imagery of specific areas where the ground control data was obtained. Even with the severe mixing of these categories, it does not mean that multispectral scanner data cannot be used for identifying and classifying specific plant community types within a generalized herbaceous system. Rather, it means that more discrete selection must be done of training sample areas to represent the community types relevant to specific ground control. For example, the native range (category 7) areas identified by the recognition processing were 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 in the northwest corner of the area and the more sparsely vegetated native range areas.

It may be that the relative radiance of herbaceous vegetation is not sufficiently contrasting to provide discrete separation of community types within the general system. If this is the case, more consideration must be given to the combined relative amounts of vegetation cover, litter cover, and bare soil surface which may provide the information needed for acceptable multispectral recognition processing. Controlled experiments need to be initiated whereby the effective ground resolution elements can be isolated in the multispectral data for absolute information about the three ground cover characteristics. Also more information is needed about the ground scene radiance of various combinations of ground cover characteristics to determine the effects of these characteristics on effective scene radiance.

The multispectral data from the six optimum channels was also processed through the Michigan SPectral Analysis and Recognition Computer. The SPARC system accepts analog data and presents the results as a color map in analog form. Since the SPARC system can accept data about only 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 7.

There was some confusion interpreting the SPARC map as compared to the digital map. For example, the SPARC seeded crested wheatgrass (category 5) and other seeded grassland (category 9) was identified as nearly synonymous units. Interpreting the digital map point by point shows some mixing of these two categories in the crested wheatgrass area, but the major portion of the data points, in fact, represent the crested wheatgrass area. The reason for this result in the analog data was that the preprocessing required to remove the scan angle effect was done incorrectly. The correcting function was subtracted from the data rather than being divided into the data. Available evidence indicates that interpretation of the digital map may provide more discrete data about the individual plant community types than the results of SPARC processing. A similar relationship existed in SPARC classification of category 6-2 and category 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 change in vegetation over time and determining cause/effect relationships of the change. 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 scene radiance in subsequent scanner data. This assumes that discrete limits of the information stored, that is the mean relative radiance levels with variance that are discrete for specific plant communities, can be identified. The percentage of data points representing a kind of plant community can then be computed (Table IV) and any change in these relative values can be determined using sequential imagery. This would then represent a change in area comprising a specific community type. Theoretically, this technique would provide more accurate information than photointerpretation only since interpreter error would be minimized. The concept needs substantial additional research to identify the minimum level of integrity the recognition processing can classify plant communities and then tested over time to determine the repeatability of the technique.

SUMMARY AND CONCLUSIONS

1. Serious scan-angle effects were identified in multispectral scanner imagery taken at 1000 hours on July 29, 1970 at the Manitou Experimental Forest, by the University of Michigan's multispectral scanner system. This effect was attributed to the bidirectional reflectance properties of the materials in the scene. Atmospheric effects were not a serious influence on the scanner data since visibility was in excess of 160 kilometers (100 miles) at the time of the data mission and the flight altitude was only 915 meters (3,000 feet) above the terrain.

2. Preprocessing was performed on the data to remove the scan angle effect using an empirical technique developed at The University of Michigan Willow Run Laboratories.

3. Channel optimization for recognizing 11 vegetation and two nonvegetation categories representing mapping units was based on the average probability of misclassification in which the six best channels were chosen on an ordered selection scheme. These were, in order of selection,

Channel No.	Spectral Band (μm)
10	0.604-0.700
12	0.725-0.920
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) hydrophytic herbaceous vegetation. Two nonvegetation categories, asphalt roads and bare soil, were acceptably classified.

5. Not all specific community types were classified as belonging to their appropriate grassland systems. This problem occurred whenever the properties of bare soil and/or plant litter exceeded the proportion of healthy vegetative ground cover. For example:

(a) Certain seeded areas of big bluegrass having low proportion of vegetative ground cover (i.e., 16% to 22% vegetation cover and 70% natural litter) were classified along with areas of native range.

(b) Some areas of native range were classified along with abandoned fields with native vegetation significantly different from native range.

6. The clustering technique which used the probability of misclassification as the criteria was a very useful tool in this study to determine:

(a) Spectral similarity and separability between specific community types and those grassland systems with variable ground cover.

(b) The best training area to represent the similarity grouping.

7. In future studies, the problem of classifying some of the upland herbaceous plant communities could be surmounted by using the convex mixtures concept. The convex mixtures concept relates the influence of the relative amounts of plant foliar cover, bare soil, and dead plant litter on the soil surface to the apparent radiance of the mixtures. A sufficient amount of ground truth information would have to be obtained on the grassland communities with low proportions of vegetation ground cover. In addition, species components of the plant communities, especially the amounts of grass versus other herbaceous vegetation, should also be considered in relation to multispectral recognition processing for plant community classification by the convex mixtures approach.

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TABLE I. SPECTROMETER CHANNELS AND WAVELENGTHS USED FOR TARGET RECOGNITION BY THE UNIVERSITY OF MICHIGAN AIRBORNE SCANNER SYSTEM

Spectrometer Channel No.	Wavelength (micrometers)
1	.398-.431
2	.423-.456
3	.446-.475
4	.458-.487
5	.478-.508
6	.492-.536
7	.514-.558
8	.538-.593
9	.566-.638
10	.604-.700
11	.656-.775
12	.725-.920

TABLE II. GENERALIZED DESCRIPTION OF VEGETATION MAPPING UNITS AND NONVEGETATION INCLUSIONS (RECOGNITION CATEGORIES)[1/]

Mapping Unit (Recog. Cat.)	Description	Ground Surface Characteristics: Plant Foliage	Plant Litter	Bare Soil
		--------Percent--------		
2T	Ponderosa pine forest; vegetation of forest floor mainly mountain muhly (Muhlenbergia montana (Nutt.) Hitch.), Arizona fescue (Festuca arizonica Vasey) and pussytoes (Antennaria sp. Gaertn.)	38.7	54.0	11.3
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 (Fisch.) Schult.) grassland	27.7	51.4	20.9
6	Seeded big bluegrass (Poa ampla Merr.) grassland	19.2	72.4	8.4
7	Native grasslands; no tree or shrub components; Arizona fescue and mountain muhly most conspicuous species; other herbaceous species more prominent locally	36.5	58.4	5.1
8	Abandoned agricultural fields; land once tilled but native vegetation different from Unit 7 reestablished, primarily lacking in variety and abundance of perennial forbs	41.9	49.1	9.0
9	Other seeded grasslands; old seedings of crested wheatgrass, big bluegrass, and Russian wildrye (Elymus junceus Fisch.) which have been infested with native herbaceous species	31.7	46.6	21.7
12	Willow (Salix sp. L.) occurring along the flood plain of a stream; herbaceous species occurring within open areas between shrub groups either Unit 14 or 15	98.0	1.0	1.0
14	Native bluegrass (Poa praetensis L.); species of sedge (Carex sp. L.), rush (Juncus sp. L.) and native clover (Trifolium sp. L.) ubiquitously scattered throughout the area	85.0	12.7	2.5
15	Sedge/rush/bulrush (Scirpus sp. L.) meadows; normally occurring with standing water or in seasonally ponded areas	94.7	5.3	0
16	Asphalt roads	0	0	0
17	Bare soil; alluvial fans, unstable gullies, road cuts and fills	0	0	100

[1/] Not all categories are included since they either did not occur in the area or were not used for this study.

TABLE III. SPECTRAL CHANNELS ORDERED FOR CLASSIFICATION OF SEVEN HERBACEOUS PLANT COMMUNITIES, THREE PONDEROSA PINE FOREST COMMUNITIES, ONE SHRUB COMMUNITY, AND TWO NONVEGETATED CATEGORIES

Spectrometer Channel No.	Spectral Band (micrometers)	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.

TABLE IV. 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	227,772

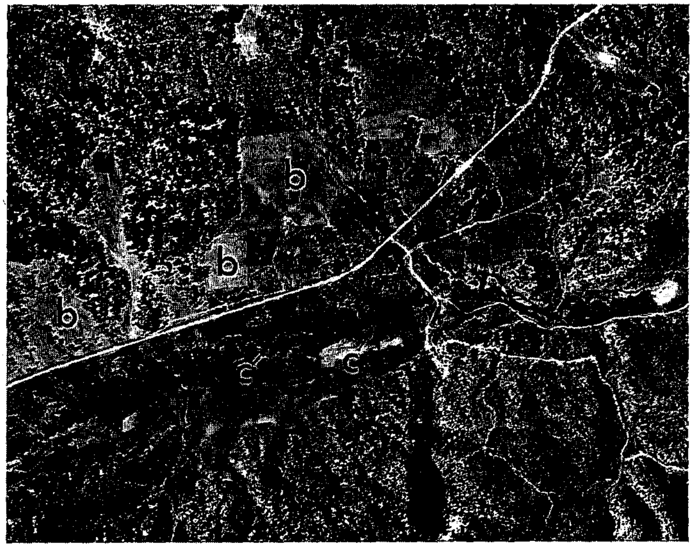


FIGURE 1. AERIAL VIEW (SCALE 1:24,000) OF THE GENERAL RESEARCH AREA AT THE MANITOU EXPERIMENTAL FOREST, COLORADO. Three general kinds of vegetation are easily discerned: (a) ponderosa pine forest, (b) upland grasslands, and (c) hydrophytic communities. Stereo-interpretation with color infrared aerial photographs and ground search provided ecological classifications of three forest vegetation types, five upland grassland types, and three hydrophytic types.

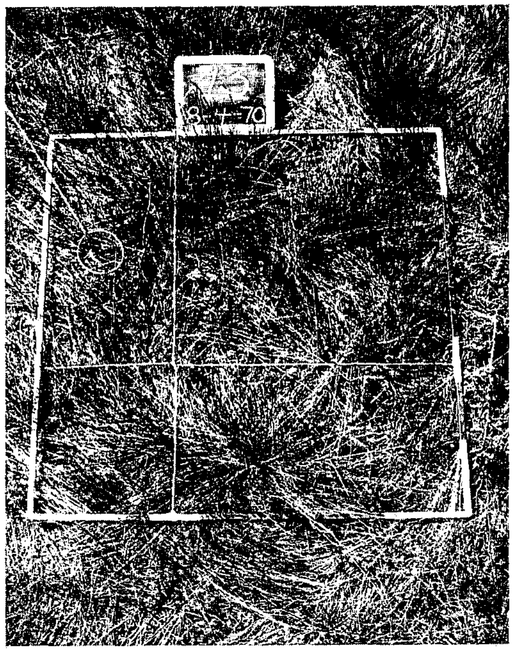


FIGURE 2. Three-foot (0.91 meter) square plots were used to obtain estimates of percent foliar cover, bare soil surface, and plant litter cover from a series of 7.5 square meter (81 square foot) plot areas within each plant community. The 81 square foot areas represented the equivalent resolution element scene for the 915 meter (3,000 foot) flight altitude.

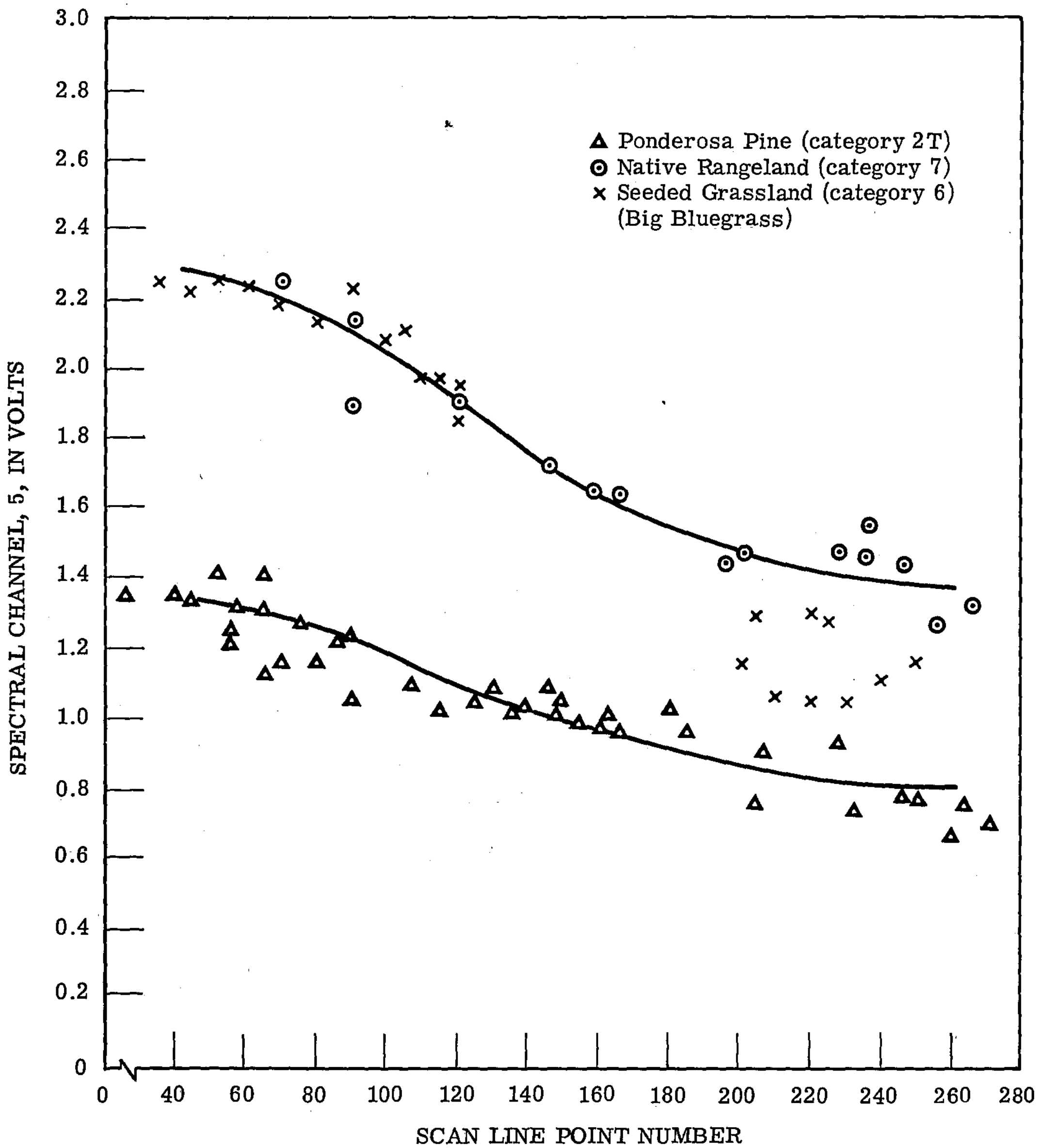


FIGURE 3. THE SMOOTH CURVE REPRESENTATION OF THE POLYNOMIAL SCAN ANGLE FUNCTIONS FOR UNITS 2T (PONDEROSA PINE FOREST), AND 7 (NATIVE RANGE) FROM DATA IN SPECTRAL CHANNEL 5 (0.478 - 0.508 μm). The points for seeded big bluegrass (unit 6) represent a special situation discussed in text.

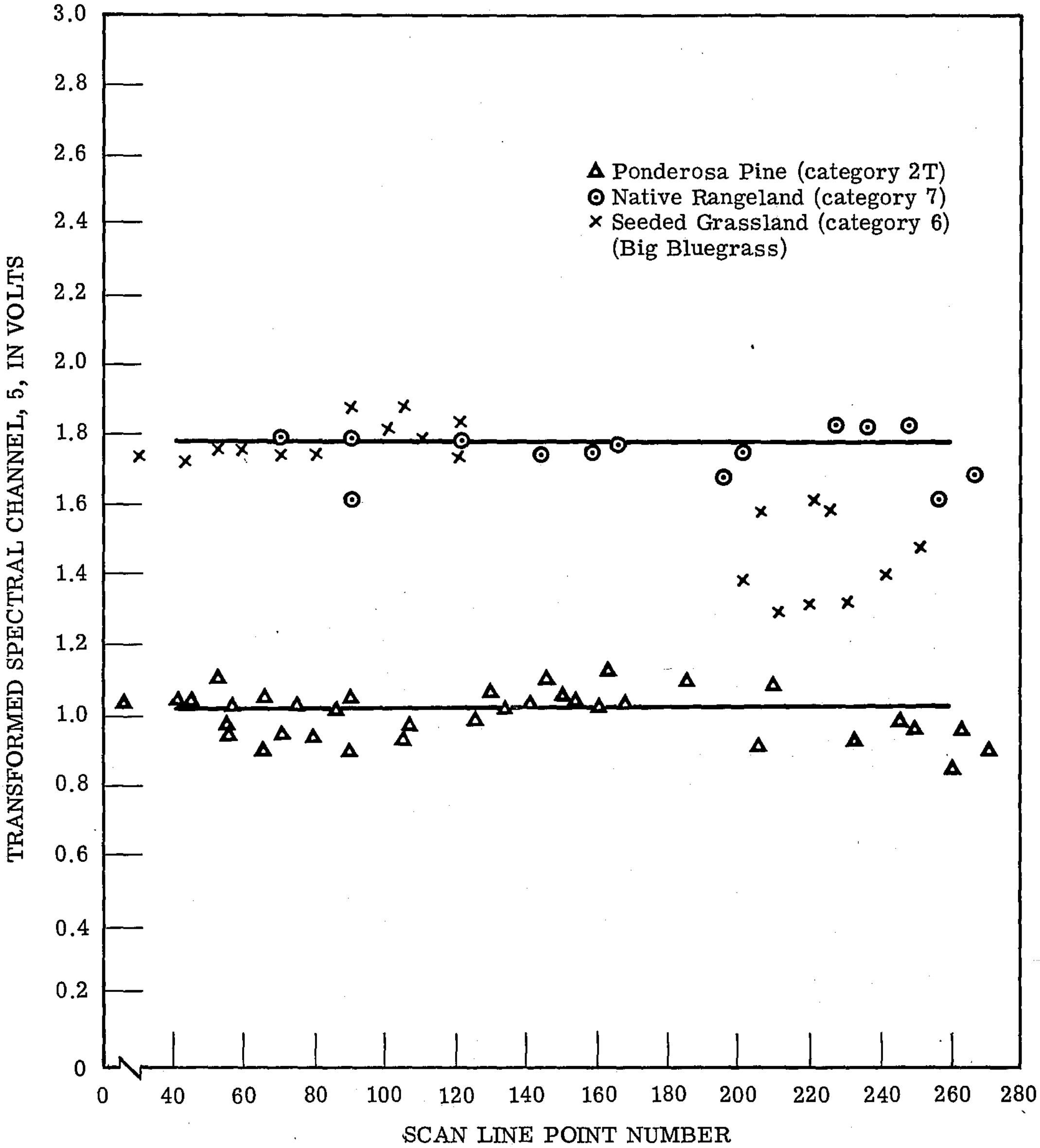
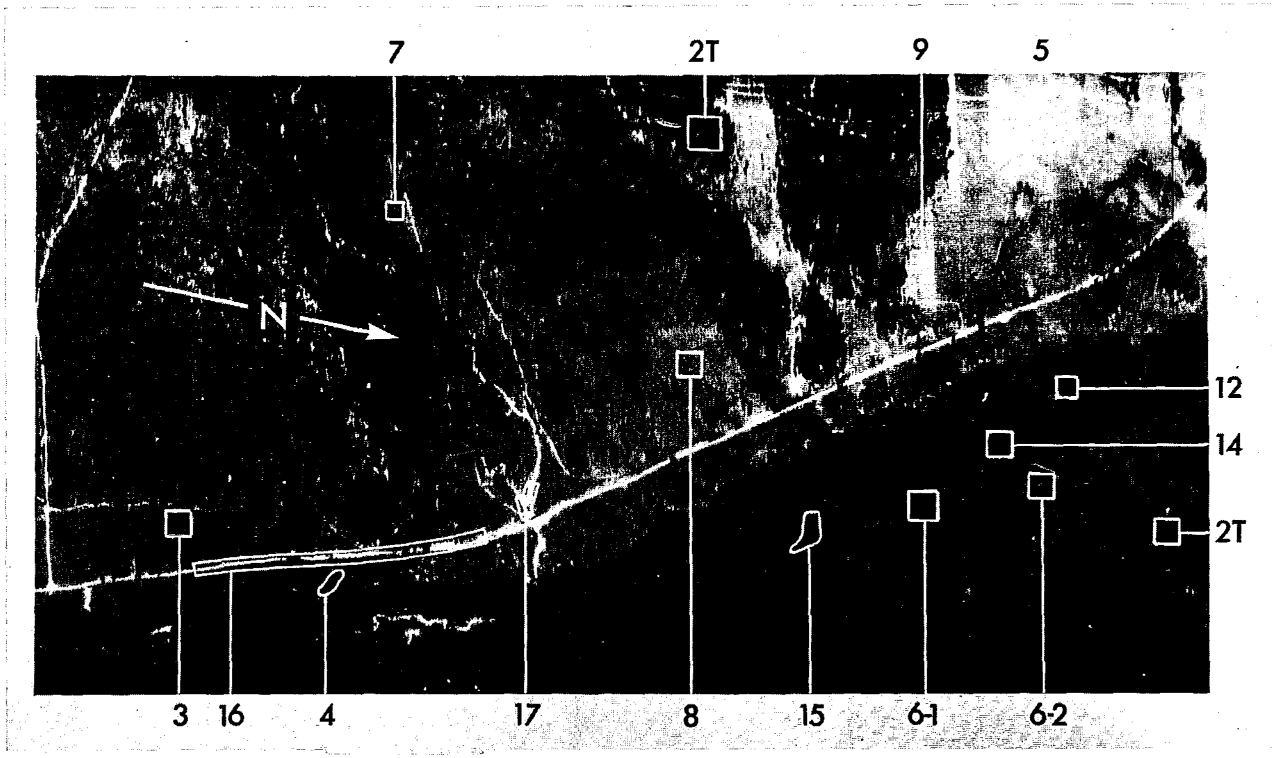


FIGURE 4. DATA FROM CHANNEL 5 (0.0478-0.0508 μm) AFTER PREPROCESSING WITH THE SCAN ANGLE EFFECT ELIMINATED



Legend

2T	Ponderosa pine forest	9	Other seeded rangeland
3	Dense natural ponderosa pine regeneration	12	Willow type vegetation
4	Dense planted ponderosa pine regeneration	14	Native bluegrass meadows
5	Seeded grassland (crested wheatgrass)	15	Sedge/rush/bulrush meadows
6	Seeded grassland (big bluegrass)	16	Asphalt roads
7	Native grasslands	17	Bare soil (alluvial fans, unstable gullies)
8	Abandoned fields with native vegetation different from 7		

FIGURE 5. LOCATION OF TRAINING AREA IDENTIFIED BY CATEGORY (MAP UNIT) NUMBER

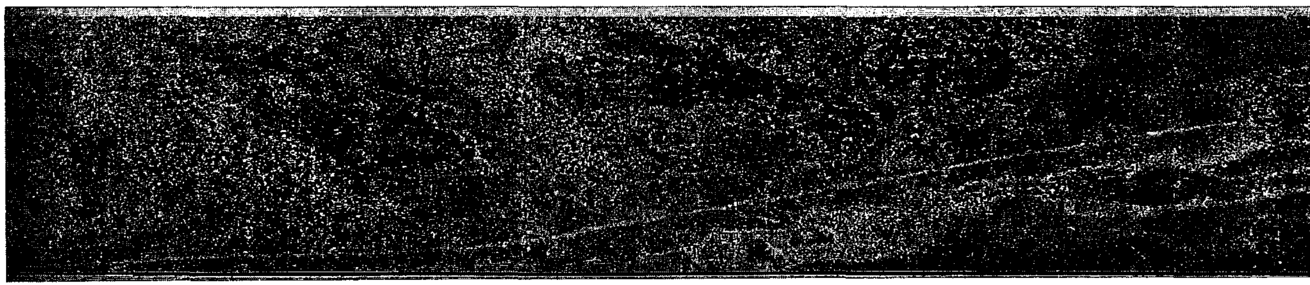


FIGURE 6. BLACK AND WHITE COPY OF DIGITAL COLOR RECOGNITION MAP OF THREE PONDEROSA PINE FOREST COMMUNITIES, FIVE UPLAND GRASSLAND COMMUNITIES, THREE HYDROPHYTIC COMMUNITIES AND TWO NON-VEGETATION CATEGORIES. The training area map (Fig. 5) will assist in interpreting this map.

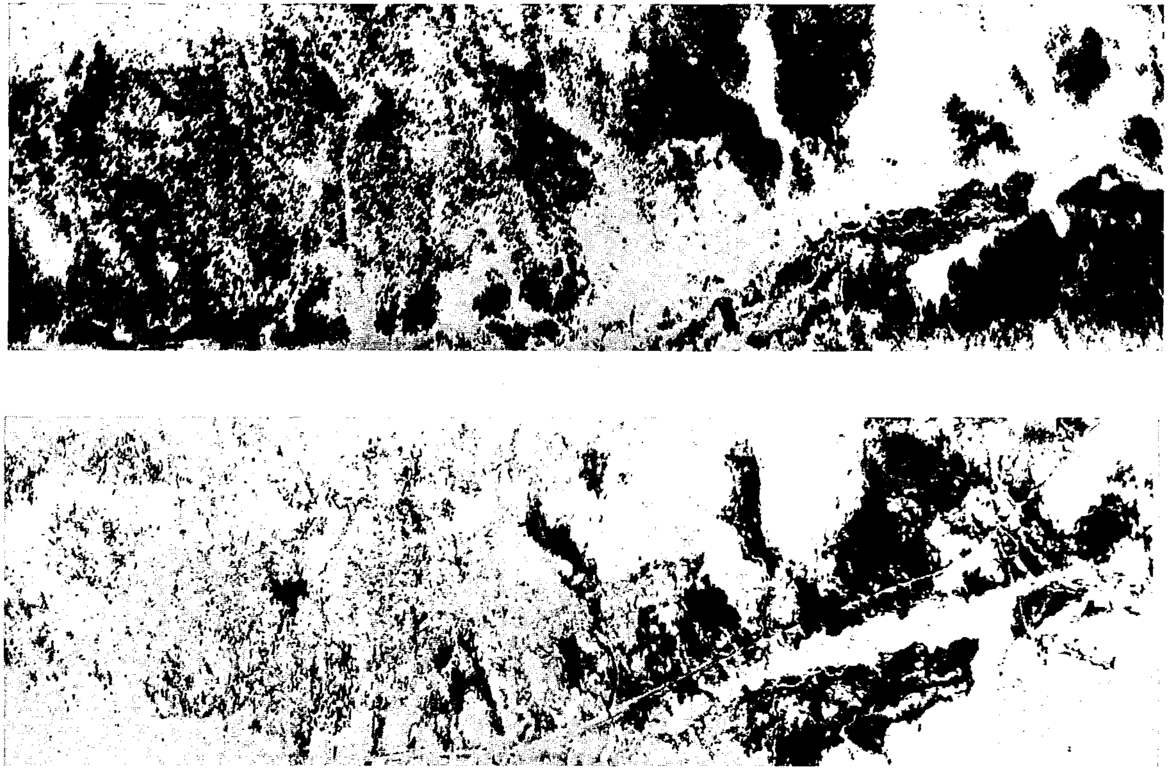


FIGURE 7. ANALOG DISPLAY OF PLANT COMMUNITIES OVER THE TOTAL TEST AREA. In the top strip, black areas are forest communities, darker gray areas are herbaceous hydrophytic communities and lighter gray areas are willow communities. In the bottom strip, black line or areas are bare soil, the next darkest areas are seeded grasslands, darkest gray areas are native range and the lightest gray areas are mostly hydrophytic communities. Correspondence between gray tones of the vegetation classes is not the same for the two strips.