DISSERTATION

WILDLAND CLASSIFICATION WITH MULTIVARIATE ANALYSIS AND REMOTE SENSING TECHNIQUES

Submitted by

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY DAVID L. RADLOFF ENTITLED WILDLAND CLASSIFICATION WITH MULTIVARIATE ANALYSIS AND REMOTE SENSING TECHNIQUES BE ACCEPTED AS FULFILLING, IN PART, REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT OF DISSERTATION

WILDLAND CLASSIFICATION WITH MULTIVARIATE ANALYSIS AND REMOTE SENSING TECHNIQUES

Wildland classification is a prerequisite to many tasks in the land management planning process. Although a variety of general wildland classification frameworks have been proposed for the United States, much work remains to develop detailed-level classification. This study was conducted in three parts to examine three related aspects of wildland classification at the detailed level.

The first part of the study was designed to examine the utility of multivariate analysis techniques in developing an ecologic land classification for a specific area. The second part of the study was designed to assess the similarity between two independently developed classifications for the same area. The third part of the study was designed to evaluate the use of remote sensing data for identifying detailed land classification units on the ground.

Vegetation dominance data were collected in 102 sample stands in the Manitou Experimental Forest, Colorado. The data were analyzed by an iterative sequence of cluster analysis, canonical ordination, descriminant analysis, and subjective interpretation to identify important groupings of the sample stands. Ultimately, nine groups were defined that represent the major upland plant communities of the study area. These plant communities form the basis for defining a habitat type land classification of the study area.

A second classification was independently developed for the same sample stands. Cluster analysis was applied to physical environment data (elevation, aspect, slope, position on slope, and soil characteristics) to develop this second classification. The two classifications were then compared to assess their similarities based on class membership of the individual stands. Although the two classifications showed some degree of correlation, they differed from each other in many details.

Digitized aerial photographic data (1:50,000 scale color, infrared) from the sample stands were analyzed to evaluate the ability to identify stands representing the habitat type classes from part one of the study. Discriminant analysis of the remote sensing data indicated the sample stands could be correctly identified 79 percent of the time. Adding three physical site variables--elevation, slope, and aspect--to the analysis increased identification accuracy to 97 percent.

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INTRODUCTION

The study described in this dissertation was designed to examine three hypotheses concerning related aspects of wildland classification. The first hypothesis states, "Multivariate analysis techniques can help develop land classifications efficiently and objectively." Examination of this hypothesis was restricted to considering only detailed levels of ecologic land classification. Study of the first hypothesis was further restricted by selecting the habitat type as the specific classification framework.

This hypothesis has important implications to wildland management planning and operations. Although a variety of general land classifications have been proposed, it is still necessary to develop detailed-level classifications that can be applied to specific parcels of land. Such detailed classifications provide the framework for summarizing and interpreting information used in planning for specific wildland management activities.

The second hypothesis states, "Independently developed ecologic land classifications will show a high degree of similarity." This hypothesis was examined empirically by comparing two classifications for the same area. If this hypothesis is true, it implies that a single classification framework may adequately serve the needs of a variety of management applications.

The third hypothesis states, "Computer-assisted analysis of remote sensing data can be used to identify parcels of land representing different habitat types." Remote sensing offers potential savings of time and money during the process of locating and identifying classes of land units in the landscape. This hypothesis is important because it implies these savings can be realized by applying remote sensing techniques during the implementation of a habitat type land classification.

The study was conducted in three parts to test each of the hypotheses. One set of sample stands representing a variety of environmentally distinct land units was used in all three parts of the study. In the first part of the study, a combination of cluster analysis, canonical ordination, and discriminant analysis was applied to the sample data to develop a classification of plant associations. This formed the basis for defining a habitat type classification.

In the second part of the study, cluster analysis was used to develop a second, independent classification for the same sample stands. This classification was based on physical environment variables. The two classifications, developed in part one and part two of the study, were then compared on a stand by stand basis. In the third part of the study, discriminant analysis was applied to digitized remote sensing data to evaluate the ability to differentiate among the habitat types.

The next chapter of this dissertation ("Land Classification") discusses some concepts and practices of land classification related to the three hypotheses. The "Procedures" and "Results" chapters describe the details of the three sequential parts of the study.

LAND CLASSIFICATION

Overview

Requirements for the intensified, planned management of wildland resources are creating an increasing need for information about the resources. It is the purpose of land classification to provide a framework for systematically organizing this resource information. Therefore, classification is a prerequisite to many other analytical steps in the land management planning process.

Land classification is a synthesizing process. It provides a framework for summarizing information about groups of similar units of the landscape (Hartigan 1975), reducing many variable individual units to fewer homogeneous classes. Classification permits thinking about the landscape in conceptual terms rather than in details (Gilmour 1951) and simplifies data storage and manipulation requirements. By defining a small number of homogeneous groups, classification facilitates communication and evaluation of land areas in terms of resource production potential.

Increasing recognition has been given to the fundamental role of land classification in wildland management in recent years. The October 1978 issue of the Journal of Forestry is devoted to this topic. Classification was the subject of one session of the 1978 Integrated Inventories of Renewable Natural Resources Workshop (Lund and others 1978) and of the 1981 In-Place Resource Inventories Workshop (Brann et al. 1982). In a series of papers concerning management of forest and range resources in the western United States, Alexander (1974), Clary (1975), Jones (1974), Schubert (1974), and Turner and Paulsen (1976) all indicated the importance of land classification in helping to apply resource management techniques.

As the demands for wildland resources grow, the need for managing wildlands from an ecological systems perspective will grow. The need for land classification systems that can help summarize information about the variety of interrelated resources can only intensify. Without such systems, wildland management cannot proceed efficiently.

Approaches to Land Classification

A number of land classifications that have broad applicability have been in existence for many years (Table 1). Some are discussed in a brief review by Bailey et al. (1978). Life zones (Merriam 1898), biotic provinces (Dice 1943), and biomes (Clements and Shelford 1939) represent some of the better known systems. Thornthwaite (1931) developed a classification based on climatic considerations. Fenneman (1928) developed a classification based on physiographic characteristics. More recently, Bailey (1980) has provided an ecosystem region classification of the United States. Bailey described each class in terms of its characteristic land-surface form, climate, vegetation, soils, and fauna. All of these classifications were developed on a very broad scale. They may be appropriate for national or regional level planning, but are less useful for more local planning and activity-level wildland management decisionmaking.

Table 1.--Characteristics of some major land classifications

Classification name	Hierarchy	Comments	Reference
Life zones	Region Division Zone	Based on distribution of mammalian genera. North America.	Merriam (1899)
Climax formation's (biomes)	Climax formation Association	Based on vegetation life-form and climate. North America.	Weaver and Clements (1929) Clements and Shelford (1939)
Climatic regions	Climatic region Climate	Based on quantitative measures of precipitation and temperature. North America (including Mexico).	Thornthwaite (1931)
Physiographic provinces	Major division Province Section	Based on recognizable landforms. United States.	Fenneman (1931, 1938)
Biotic provinces	Biotic province Biotic district Ecologic association	Based primarily on vegetation in large, contiguous areas. Also considers fauna, climate, physiography, and soil. North America.	Dice (1943)
Life zones	Life Zone Association Subdivision	Based on latitude, precipitation, and temperature. Subdivisions are based on vegetation and land use. Central America, South America, Asia.	Holdridge (1947)
Geomorphic regions	Province Section District/Region	Based on topography and geomorphic history. United States.	Thornbury (1965)
Natural regions	Major division Province	Based primarily on geologic structure. United States.	Hunt (1974)
Forest cover types	Forest region Cover type	Based on existing dominant tree cover. North America.	Eyre (1980)

Several classification frameworks have been proposed in recent years to meet the needs for wildland management at a variety of organizational levels. All are hierarchic systems that facilitate aggregating or subdividing information depending on the required management intensity.

The U.S. Geological Survey uses a land-use and land-cover classification system designed to be used with data collected by remote sensing devices (Anderson et al. 1976). This classification is based on man-made and natural features. The U.S. Fish and Wildlife Service has developed a hierarchic classification for wetland areas of the United States (Cowardin et al. 1979). This classification applies to surface wetlands as well as deepwater habitats of rivers, lakes, and coasts.

In Canada, a four-level hierarchic, "biophysical" land classification system is being implemented (Gimbargevsky 1978, Jurdant et al. 1975). Classes are delineated on the basis of geologic, geomorphic, pedologic, climatic, hydrologic, and vegetation characteristics. The four levels in this classification system are land region, land district, land system, and land type. Land type, the fundamental classification unit, is recognized as being homogeneous with respect to landform, soils, topography, and drainage, and having a characteristic vegetation succession pattern.

Buttery (1978) and Merkel et al. (1982) have described classification systems comprised of multiple hierarchies that may meet the classification needs of multi-resource management agencies. Their classifications differ from each other in some details but are similar in overall structure. The classifications of Buttery (1978) and

Merkel et al. (1982) are called component classifications because they use distinct, hierarchic classifications for several ecosystem components. Both classifications identify multiple hierarchies for vegetation, soil, landform, and water components. Individual land units are defined by combinations of class characteristics from the different hierarchies.

Each of the hierarchic classifications mentioned above is rather well defined at the broad class levels. However, the classifications are not well defined at the more detailed class levels. Within any of the classification frameworks, much work remains to develop the classifications of individual, detailed land units.

Much of the past detailed land classification has been functionally oriented to specific, single uses. Timber site index as a means of site evaluation or classification in timber management is an example. Other functional indexes exist for other wildland resources. These indexes provide detailed information about the productivity of specific land units for specific uses. As Jones (1969) indicated in a review of timber site evaluation methods, the functional indexes are probably the best indicators of site productivity. However, Jones (1969) also recognized the need for a broader, ecologic approach to classifying sites.

A significant problem in detailed land unit classification is the measurement of values of the various primary environmental factors. This problem can be reduced or avoided if certain readily evaluated secondary characteristics provide a good indication of the state of these factors. Because of its visibility and ability to reflect environmental conditions, the use of natural vegetation as an indicator of the physical environment is one important approach to ecologic land classification.

Two distinct uses of vegetation in land classification have been made. In the first, specific environmental factors are evaluated based on the known autecologic relations of certain plant species. Each species receives a numerical rating that reflects its requirements for the specified environmental factors. Thus by merely observing the species present, the various factors may be evaluated for a given site. Land units classified according to this "synecological coordinate" method have been found to be correlated with forest geographical subdivisions in Minnesota (Bakuzis, Duncan, and Hansen 1960), timber site index for some tree species in Minnesota (Bakuzis, Hansen, and Kurmis 1962), and Douglas-fir site index in Oregon (Minore 1972).

A second vegetation approach that has begun to receive considerable use in the past decade is the habitat type approach. This method is based on the observation that within a given region, the same plant community will develop on areas where environmental conditions combine to create equivalent environments (Daubenmire 1952, 1968, 1978). Individual environmental factors are not necessarily identified; rather, total unique environments are identified as delineated by the occurrence of discrete plant communities and important physiographic features.

One habitat type comprises all land areas characterized by the same climax plant association (Daubenmire 1952, 1968, 1978). Related habitat types can be grouped into broader categories of land units by various strategies (Daubenmire 1978, Pfister et al. 1977) to fit into hierarchic classifications. Classification of wildlands according to habitat types requires that the regional synecology of the area of concern be studied and described. This is a costly and time-consuming process (Daubenmire 1973). However, many areas in the Northwest and Rocky Mountain West have now been studied with the intent of developing habitat type classifications (Daubenmire and Daubenmire 1968; Dyrness et al. 1974; Pfister, et al. 1977; Hoffman and Alexander 1976, 1980; Layser and Schubert 1979; Moir and Ludwig 1979; Carmichael, et al. 1978; Wirsing and Alexander 1975), and large scale habitat type mapping projects have been undertaken (Deitschman 1973). Classifications according to habitat type have been found to have predictive capabilities for timber site index and productivity of other wildland resources (Roe 1967) and to forest regeneration success (Pfister 1972, Sullivan 1978).

The Inductive Process of Classification

Land classification at the detailed level is largely an inductive process in which specific features of land units are measured, and the units are grouped together on the basis of inherent similarities. Each grouping of land units is defined by a unique fusion of physical and biotic factors. These factors may be grouped into the four fundamental units of an ecosystem; the biota, lithosphere, hydrosphere, and atmosphere (Clapham 1973). It is change in properties of these components from one place to another that serves to distinguish unique classes of land units across the surface of the earth. Therefore, these properties must in some way be accounted in order to develop a meaningful ecologic classification scheme. All the components interact to produce the varied conditions observed in the landscape. The manifest features that are important are climate, soil, landform, and plant/animal communities.

There are innumerable measurements that conceivably could be made to characterize these features. From the land manager's point of view, certain types of information may be more important than others. For example, considering all aspects of water yield from wildlands, Satterlund (1972) lists as important characteristics: precipitation form and seasonal distribution, temperature, hours of sunlight, latitude, vapor pressure, wind, slope and aspect, elevation, location relative to other land features, length of slope, drainage pattern, stream order, mass movement and erosion potential, and soil texture, structure, and depth. For evaluating timber growth potential, Husch (1963) lists precipitation, air temperature, wind, insolation, soil physical and chemical characteristics, soil moisture, soil biota, slope and aspect, elevation, and biotic competition.

It should be realized that to fully describe any ecosystem in all its complexity is most likely an impossible task. However, for wildland management purposes, it should be possible to sufficiently describe land units to permit the recognition of their relative similarity and dissimilarity in resource production potential. The preceding lists include many of the site characteristics that are desirable to know for management decisionmaking. Once the purpose of a classification has been determined, therefore, the first step in the actual classification process should be to select the descriptive variables that are considered important. Of course, the final selection may be modified by the availability of data or the possibility of obtaining new data throughout the area to be classified.

It is the task of classification to examine the selected variables to develop an orderly grouping of the individual land units. Because each unit may be defined by several variables, the classification problem can be considered a problem of multivariate analysis.

Generally, any classification aims at partitioning a set of land units into groups (or classes) so that the members within a group are basically similar while different groups are, on the whole, unlike one another. Degree of similarity can be judged subjectively or objectively according to specific characteristics of the units. Objective, numerical measures enable the use of a variety of analytical techniques in the classification process. Such techniques can enhance the repeatability of the process and can help reduce personal biases in developing a classification. Three analytical techniques that may enhance the land classification process are cluster analysis, discriminant analysis, and ordination.

MULTIVARIATE ANALYSIS IN LAND CLASSIFICATION

Cluster Analysis

Cluster analysis identifies logical groupings of individuals based on their similarities or differences in terms of measured characteristics. Cluster analysis involves three main steps: (1) obtaining multivariate data for the set of individuals, (2) determining the similarities between individuals, and (3) assigning the individuals to groups. These steps are discussed briefly below. Detailed discussions are provided by Sneath and Sokal (1973) and Anderberg (1973).

The measured variables convey the information required to describe individual land units and to quantify the similarity or difference among the land units. Differences in the states of these variables make possible the distinction between individuals. Several other names have been used instead of the general term "variable," including "attribute" and "character" (Michener and Sokal 1957, Cain and Harrison 1958). The terms "variable" and "character" are used interchangeably in this paper. The different forms a character may assume are called the character states.

Descriptive characters may be subdivided into three categories according to the number of states and the possible ways of recording the states (Sneath and Sokal 1973, Anderberg 1973). Binary characters have only two possible states; they are sometimes referred to as two-state, all-or-none, or presence-absence characters. Qualitative characters have more than two possible states that cannot be ranked or represented by some ordinal numbering scale. Quantitative characters have many states that can be numerically ranked.

Some measure of similarity (or conversely, difference) is required as a basis for grouping individuals into a common class. Geometric distance between individuals plotted in a coordinate space is one way of distinguishing among groups. Sneath and Sokal (1973) discuss numerous distance measures, as well as another major group of similarity measures--the association coefficients.

Association coefficients measure degree of similarity. The association coefficient used depends in part on the types of variables involved. Some of the simplest association coefficients have been developed for use with binary characters. For a set of individuals described according to the presence or absence of a series of characters, it is possible to summarize the data pair-wise in the form of a 2 x 2 frequency (contingency) table:

		Individual j	
		present	absent
Individual k	present	a	b
	absent	c	d

where

a = number of characters jointly present for both individuals;

b = number of characters present for individual k but absent for individual j;

c = number of characters present for individual j but absent for individual k;

d = number of characters absent for both individuals.

The cell "d" in a frequency table reflects similarity between two individuals due to the mutual absence of characters. These are called negative matches. Such information may or may not be meaningful. For example, if the individuals are stands of vegetation and the characters are plant species, a negative match may merely indicate the chance joint-absence of some species.

One similarity coefficient that excludes negative matches is Jaccard's coefficient (Sneath and Sokal 1973):

$$\text{Jaccard similarity} = \frac{a}{a+b+c} .$$

The simple matching coefficient, on the other hand, was designed to take account of the effect of negative matches (Sokal and Michener 1958):

$$\text{Simple matching similarity} = \frac{a+d}{a+b+c+d} .$$

Many other association coefficients have been devised for use with 2 x 2 frequency tables; these are discussed by Sneath and Sokal (1973).

Where all three types of characters--binary, qualitative, and quantitative--may be used to describe individuals, a special coefficient must be employed that permits combining the different types. Gower's general similarity coefficient (Gower 1971) is such a measure. In slightly modified form,

$$\text{Gower similarity} = \frac{\sum_{i=1}^{n} W_i V_{ijk}}{\sum_{i=1}^{n} W_i} ,$$

where the summation is over the number of characters, n, and

V_{ijk} = the value expressing the similarity between individuals j and k for character i;

W_i = the weight applied to character i.

For binary and qualitative characters, $V_{ijk} = 1$ if the two individuals match and $V_{ijk} = 0$ if they do not match. For quantitative characters,

$$V_{ijk} = 1 - \frac{|v_{ij} - v_{ik}|}{R_i}$$

where v_{ij} = numerical value of character i for individual j;

v_{ik} = numerical value of character i for individual k;

R_i = the range of values assumed by character i.

Thus, V_{ijk} can take on any value from 0 to 1. It follows that complete identity between two individuals results in a Gower similarity of 1, while a maximum difference between two individuals will give a Gower similarity of 0.

Some users of cluster analysis for classifying wildlands might consider certain characters of more importance than others. Such preferences can be reflected in the similarity coefficient by assigning differential weights (W_i) to the characters. Different weights can also be used to equalize the importance assigned to groups of variables.

Similarity index values between pairs of individuals are recorded in a similarity matrix. The similarity matrix provides the basis for forming groupings of the individuals, because the intracluster similarities are to be as high as possible. While this goal forms the basis for all clustering procedures, there are numerous specific strategies that may be used in an attempt to achieve this goal. Many of the different approaches are discussed by Anderberg (1973), Duda and Hart (1973), Sneath and Sokal (1973), and Lambert and Williams (1967).

Hierarchic clustering methods form a series of groups of individuals at different levels of similarity. Furthermore, most hierarchic methods create nested groups such that each class is a subset of one, and only one, larger class. The results are often expressed in the form of a dendrogram (or tree diagram).

The fundamental steps in a hierarchic clustering procedure are (Anderberg 1973, Duda and Hart 1973):

1. Begin with a set of n individuals (each comprising a cluster of one).
2. Select the most similar pair of clusters (or individuals).
3. Combine this pair into one cluster, thereby decreasing the total number of clusters by one, and recompute the similarity matrix.
4. Repeat steps two and three until one cluster is formed.

Differences in specific hierarchic clustering methods result from various treatments of step number three. One of the simplest variations is known as the nearest-neighbor clustering algorithm. In this method, the similarity between a pair of clusters is determined by the similarity between the closest pair of individuals in the two clusters. Farthest-neighbor clustering is a closely related method in which the most distant pair of individuals determines inter-cluster similarity. A compromise between these two extremes is to use some measure of average similarity between clusters. Anderberg (1973) and Sneath and Sokal (1973) provide complete discussions and illustrate the use of these and other clustering strategies.

Since the 1960s, many workers have used cluster analysis in ecological studies. However, few have been involved with classification of major plant communities or ecologically defined land units. West (1966) used cluster analysis to classify 40 stands into natural vegetation units in the Oregon Cascades. Brady (1971) used clustering techniques in a study of plant communities in Oregon and in New Mexico. In that study, stand similarity was measured by the change in species diversity caused by joining two stands together. The two stands that caused the least change in diversity when merged were considered the most similar pair. Bonham (1974) also used such a diversity index in a hierarchic cluster analysis of 25 range vegetation stands.

Thilenius (1972) distinguished 13 major "habitat units" in an ecologic classification of Black Hills environments using cluster analysis. In another study, Severson and Thilenius (1976) used cluster analysis to describe nine classes of aspen stands in the Black Hills area. Characters used to describe individuals in these studies included plant species frequency; soil chemical and physical properties; and physical site factors such as slope, aspect, elevation, microrelief, macrorelief, rock and litter cover, and bare ground.

Cluster analysis is the direct multivariate analysis approach to classifying individual wildland sites. However, it must be realized that clustering techniques will always define classes for a set of individuals regardless of the structure of the original data. Even for continuously varying data, clusters will be found. This fact should be kept in mind when cluster analysis results are analyzed (Rohlf 1970). To help evaluate the appropriateness of groupings resulting from cluster analysis, two additional multivariate techniques are useful. These are discriminant analysis and canonical ordination.

Discriminant Analysis

Discriminant analysis is a technique that measures the amount of difference between groups of individuals. It estimates how distinguishable the different groups really are. While cluster analysis searches for the structure of a data set whose structure is unknown, discriminant analysis is applied only to data that have been divided into groups or clusters. Therefore, a specific structure is known (or at least hypothesized) in advance of a discriminant analysis.

For a number of groups of individuals--each described by multivariate data--discriminant analysis determines a set of linear functions of the variables that optimally differentiates among the groups (Marriott 1974). An original purpose of discriminant analysis was to use this function to facilitate the assignment of new individuals to one of the recognized groups. This is a problem of identification, rather than classification, as described by Sneath and Sokal (1973). However, discriminant analysis also provides the means for determining whether the groups of individuals are significantly distinct, and step-wise discriminant analysis indicates which variables are most effective in distinguishing the groups (Volland 1974).

Canonical Ordination

Ordination, in general, plots individuals relative to a set of coordinate axes in such a way that the relationships among the individuals are displayed clearly. The plotting of the individuals in the original space formed by all the measured variables might be considered an extreme form of ordination. This does little to summarize the data or facilitate its interpretation, however. Therefore, all ordination techniques have the following two general steps in common:

1. Determine a new set of axes (variables) that will describe the variation in the data in fewer dimensions than the original variables.
2. Plot the individuals in the coordinate space formed by the new set of axes.

Ordination techniques differ in the manner of determining the orientation of the new axes. One method is by the use of reference individuals (Dick-Peddie and Moir 1970). In this approach, the first ordination axis is determined as the line between the two least similar individuals. All other individuals are then located along this axis, their positions set by their similarities with the two reference individuals. A second axis is set up at an approximately right angle to the first. The reference individuals for this axis are chosen in a way similar to those of the first axis such that the individuals are spread out as much as possible in the coordinate plane. More axes may be described if necessary.

Reference-individual ordination is the original ordination approach described for vegetation analysis by Bray and Curtis (1957). In that study, the relationships among a group of forest stands in Wisconsin were studied by displaying the stands in a two-dimensional ordination. Since the work of Bray and Curtis (1957), many synecologic studies have included the use of ordination methods. Dyrness et al. (1974) used reference-individual ordination to assist in the classification of forest plant communities in the Oregon Cascades.

It is implicit in reference-individual ordination that each new axis is some combination of the original variable axes. In other ordination methods the relationship among the old and new axes is explicitly determined for the purpose of specifying the new axes. Perhaps the most widely used of these is principal components ordination (Orloci 1966, Sneath and Sokal 1973, Volland 1974). The principal components are those orthogonal axes that account for the greatest amount of the variation in a data set (Hope 1968, Seal 1964). Each principal component is a linear combination of the original variables. Because of correlations between variables, it is usually possible to represent most of the variation with many fewer axes than are included in the original number of variables. Ordination is accomplished by displaying the individuals in a coordinate space defined by the first few (most significant) principal components. Principal components ordination was used by Volland (1974) to form groups of similar stands in a study of lodgepole pine forest plant communities.

Canonical ordination is an ordination technique that is closely related to discriminant analysis (Hope 1968, Seal 1964). If the distributions of the variables exhibit different variances, then each group of individuals may be thought of as forming an ellipsoidal cluster in a multidimensional space. In canonical analysis, the space is transformed so that these clusters become spherical (the case when variances are equal). A new set of axes is created such that the within-group variation is minimized and the among-group variation is maximized in the new coordinate space. Therefore, when the individuals are plotted in the new coordinate space, the groups will be as compact and as distinct as possible. Canonical analysis may be considered as essentially an ordination of groups rather than an ordination of individuals. It combines aspects of principal components ordination and discriminant analysis. Therefore, canonical ordination may be useful to help refine the results of a cluster analysis.

Volland (1974) used discriminant analysis and canonical ordination in his classification of lodgepole pine communities. Grigal and Ohmann (1975) combined successive cluster analyses and canonical ordinations to classify forest stands in northern Minnesota. Ordination of hypothesized groups permits examination of the relationships among the classes.

REMOTE SENSING IDENTIFICATION OF LAND CLASSES

A classification provides the conceptual framework for organizing information about the landscape. Two kinds of geographic information that must be related to the classification are area and location. Areal information is important at all land management planning levels because management plans are based, in part, on the total area available with certain resource production capabilities.

Location information becomes increasingly important at the more detailed planning levels. Ultimately, management plans must be related to individual parcels of land. Broad-level planning may be related to the conceptual classification units and the areas they represent; detailed-level planning must be related to specific locations. Therefore, in application it is necessary to identify parcels of land within the classification framework. Whether done by sampling individual sites or by regional identification, this provides the needed area and location data.

These data may be recorded on conventional maps or in computerized geographic data systems (Amidon 1978). Regardless of the data recording system, some procedure is required for identifying and locating parcels of land. The ease with which the identification process can be accomplished strongly affects the usefulness of a classification.

Maps of early attempts at land classifications had to be based on extensive personal travels and accounts in scientific journals. Obviously, such maps could not be very accurate and were time-consuming to prepare. Today the ability exists to examine large areas at varying levels of detail by use of remote sensing technology. The utility of a classification can be enhanced if remote sensing data can be used to identify land areas within the classification framework.

The apparent value of remote sensing in applying classifications has led to some classification frameworks being developed explicitly to be compatible with remote sensing technology. The value of remote sensing to applying classifications is unquestionable. However, it does not seem wholly appropriate to require recognizability of classes on remotely sensed imagery as a criterion for a good classification. Not all important features of a useful classification will necessarily be identifiable by remote sensing techniques.

Remote sensing (specifically aerial photography and photogrammetry) have been used in wildland management since the 1930s (Aldrich 1979, Fischer 1975), but the most rapid developments have occurred during the past two decades. This has been the result of improvements in traditional sensors, development of new sensors, and the impetus provided by the National Aeronautics and Space Administration to study the utility of various sensors on satellites for earth resource monitoring. Aldrich (1979) and Reeves (1975, volume 2) provide good reviews of the many applications and tests of remote sensing applied to wildland management. Some recent literature that is particularly germane to wildland classification is reviewed here.

A potentially promising approach to using remote sensing data is computer-assisted analysis of satellite imagery because it offers the capability to rapidly analyze large areas to identify land classes. Aldrich and others (Aldrich 1976) found that Skylab color and color infrared photography could be used successfully to identify very broad land classes. On test sites in Georgia and Colorado, using both manual interpretation and computer analysis of digitized data, they differentiated evergreen coniferous, deciduous, cutover, and nonforest classes. The only identifiable plant community classified at the tree species level was the Douglas-fir community. DeSteiguer (1977) manually interpreted a Skylab color infrared photo of Louisiana to distinguish mixed hardwoods, cyprus-tupelo, cottonwood-willow, nonforest, and water with some success.

Many more studies of Landsat multispectral scanner imagery have shown rather similar results for wildland class recognition. Heller and others (Heller 1975) identified wildland classes in parts of Georgia, Colorado, and South Dakota using Landsat imagery. At the various sites, they were able to successfully make the following delineations: Forest and nonforest; conifer and grassland; conifer, hardwood, wet pasture, dry pasture, bare soil, and water. Both machine-assisted and manual interpretation procedures were used. These results are typical of the early classification studies of satellite imagery.

Recent satellite imagery quality, preprocessing, and analysis techniques have greatly improved. Still only broad land classes are identifiable at useful levels of accuracy. Bryant et al. (1980) identified softwood, mixed wood, hardwood, water, open land, and bog classes in Maine. The three forest types were not clearly distinguishable. Beaubien (1979) was able to distinguish several forest type (black spruce, white spruce, balsam fir, hardwood) and age classes as well as some forest insect damage classes in Quebec. The classification schemes were developed after the imagery analysis to maximize class separability. Studying reforested areas in Brazil, Shimabukuro et al. (1980) distinguished slash pine, other pines, eucalyptus younger than two years, and older eucalyptus. These studies all employed computer-assisted classification procedures to analyze the digital satellite imagery.

Todd et al. (1980) completed a very detailed study explicitly to evaluate the accuracy of computer-assisted Landsat mapping near Lake Mead in Utah and Arizona. Classes of pinyon-juniper on basalt, pinyon-juniper on limestone, shrubs, basalt flows, and cliffs and slopes were delineated with accuracies ranging from 62 to 97 percent. Subdivisions of the pinyon-juniper on basalt and shrub classes were delineated with much lower accuracies (9 to 53 percent).

Heimes et al. (1978) indicate computer-assisted analysis of Landsat data can distinguish among broad level land uses such as urban, agricultural, range, forest, and water. Identification of more specific classes was less satisfactory, although several classes of agricultural, range, sage/grass, brush/shrub, sparse, and forest (deciduous, evergreen coniferous) land were recognized.

These studies all indicate that satellite imagery can be useful for identifying general wildland classes. The primary advantage is that large areas can be analyzed at low costs. The utility of satellite imagery for detailed land unit identification will increase as remote sensing satellites with greater scene resolving capabilities are deployed.

Greater resolution for identifying detailed land units is provided by remote sensing imagery obtained from aircraft. Large scale aerial photos (e.g., 1:3,000 or larger) have been used with great success to identify individual tree species (Heller et al. 1964, Aldrich 1966, Aldred and Lowe 1978, Nielsen et al. 1979), shrubs and grasses (Driscoll and Coleman 1974, Watson and Murtha 1977), and to detect forest damage (Murtha 1972). This makes large scale photos potentially useful for identifying detailed land classes that are based on vegetation. A problem is that only a small area is covered by each photo. Consequently, large scale photos are best used as part of a sampling procedure for estimating quantitative features such as timber volume (Aldred and Lowe 1978, Nielsen et al. 1979).

In general, as aerial photo scale decreases, the recognition of detailed land classes becomes more difficult. Nevertheless, wildland classes at levels useful for management planning have been identified with some success on photos with scales as small as 1:120,000 (Aldrich 1979). At a scale of 1:50,000, a typical 23 cm x 23 cm photograph represents a ground area of about 13,000 hectares. This large area coverage makes small scale aerial photography a feasible tool for identifying individual land units over large areas.

Batson and Elliot (1977) mapped a large area in eastern Montana using 1:80,000 color infrared aerial photos and ground reconnaissance. They recognized 14 grass, shrub, and tree classes. Gammon and Carter (1979) used color infrared photos in scales of 1:20,000 to 1:130,000 along with ground checking to identify 13 evergreen, deciduous, and altered forest classes in the Great Dismal Swamp of Virginia and North Carolina. They were also able to distinguish deciduous shrub, evergreen shrub, and grass understories beneath deciduous canopies on winter photography. Understory species could not be identified.

Watson and Murtha (1977) identified range and forest species groups using a combination of Landsat imagery and aerial photos with scales from 1:4,000 to 1:63,000. Identification of species required the 1:4,000 scale photos or ground verification.

Balice (1979) used color photos at scales of 1:15,840 and 1:32,000 and color infrared photos at 1:16,000 to map subalpine and alpine classes in the Uinta Mountains of Utah. The identifiable classes were open water, wet meadows, dry meadows, sedge-grass, bare rock, krummholz, subalpine conifer, Abies lasiocarpa/Vaccinium scoparium communities, and Abies lasiocarpa/ Vaccinium caespitosa communities. The larger scales were best for distinguishing the more detailed classes.

The preceding studies all involved manual interpretation of photographic imagery. The analysts considered spectral and spatial characteristics of the classes as recorded on film (i.e., color, shape, and texture). They were also able to consider ecological factors that are revealed in the way certain features occur in relation to one another. For example, the five deciduous trees recognized by Gammon and Carter (1979) were correlated with surface water characteristics. Cypress and tupelo were found over standing water, yellow poplar and beach were associated with dry ground, and maple occurred on transitional sites. Similarly, Balice (1979) found the three tall conifer classes could not be distinguished unless topography and position relative to other plant communities were considered.

Decision rules for identifying classes differentiated by such diverse characteristics become quite complex. A real advantage of manual interpretation is the ability of human interpreters to incorporate with little difficulty such complex rules. A disadvantage is the considerable time and expense required to analyze large areas. Therefore, a number of researchers have studied the possibilities of automating the photo-interpretation process, recognizing the possible savings in time and money.

Color or color infrared photographic imagery is a form of encoded multispectral scene data. Color films have three layers that are sensitive to light in different spectral regions (Slater 1975). The data encoded in the three layers are manifest to the human interpreter as different hue, value, and chroma of color. Automated analysis of color film involves measuring the densities (conversely the light intensities) of various regions of the photographic scene.

The overall density of all three layers can be measured, although this fails to take advantage of the multispectral feature of color film. To fully utilize the information in color imagery, the film layer densities are measured individually. This provides 3-variate scene spectral data for analysis. The density measures can be recorded as digital values to permit computerized analysis of the multivariate data.

This enables the use of sophisticated, automated image analysis procedures that have been applied to much Landsat data. Differences exist, however, between multispectral scanner data (Landsat) and color photographic data. On photographic imagery, the image quality is not uniform throughout a single frame or among different frames of the same photo mission. This can complicate automated analysis--especially signature extension--of aerial photos.

Scarpace and coworkers (Scarpace 1978, Scarpace et al. 1975) have described analytical procedures for densitometry of aerial photos. The procedures make it possible to uniformly analyze more than one photo in a mission. This can be particularly important for large mapping projects where many photos must be analyzed for an area. However, less elaborate procedures are adequate for multispectral analysis of a single frame to study identifiability of various land classes. Density measures are made directly on the film through a different colored filter for each film layer (Murtha 1977).

Driscoll et al. (1974) used a microdensitometer to scan several scales of color infrared aerial photographs to test the separability of plant communities, physical land classes, and individual grassland, shrubland, and forest species. They analyzed only the magenta film layer (i.e., using a green filter). Aspen/rock/soil, big sagebrush, spruce-fir, and water were distinguished on 1:139,000 scale photos. At another site, native grassland, bluegrass, and ponderosa pine were distinguished on 1:135,000 scale photos. Uncut versus selectively cut ponderosa pine forest were not separable on the basis of density of the imagery. On large scale photos (1:1,100), Driscoll et al. (1974) could identify some individual species on the basis of film density. Soil, low sagebrush/big sagebrush, bitterbrush, juniper, and pinyon pine/mountain-mahogany were separable.

Jordan et al. (1978) analyzed a multivariate data set of film densities from a variety of film (1:24,000 color infrared and multispectral from two dates) and filter combinations. Discriminant analysis indicated good separability of coniferous/deciduous, deciduous/hemlock, deciduous, grass, and black locust/grass classes.

Martin and McBride (1979) digitized film densities in the three layers of 1:129,000 color infrared imagery to test the feasibility of automatically mapping vegetation of Muir Woods in California. Five broad vegetation classes were separable: redwood, Douglas-fir, hardwoods, brush, and grass. The accuracy and level of detail achieved by the computer-assisted mapping process were lower than achieved by a manual process applied to 1:2,000 and 1:15,000 scale aerial photos of the same area. Manual analysis of the larger scale photos distinguished the more detailed classes old-growth redwood, young-growth redwood, redwood/Douglas-fir, redwood/hardwoods, old-growth Douglas-fir, young-growth Douglas-fir, Douglas-fir/hardwoods, Douglas-fir/brush, hardwoods, brush, grassland/brush, hardwood/brush, and grassland.

Everitt et al. (1980) digitized samples from 11 range sites in south Texas. The grass, brush, and barren range sites were defined according to vegetation and edaphic/geomorphic features. The three film layers in 1:19,000 and 1:42,000 color infrared film were analyzed. Although the film/filter combinations were analyzed individually (treated as univariate), a combination of different film layer densities and photography dates were used to identify the range sites.

These studies show that aerial photography can be used to identify rather detailed land classes based on vegetation features. However, in most of the studies the classes were defined to conform (at least in part) to the information content of the imagery. Therefore, past studies have not necessarily demonstrated if remote sensing analysis is useful in identifying detailed classes in a previously defined classification scheme.

STUDY PROCEDURES

Overview

The study was conducted in three parts related to the three hypotheses expressed earlier. Vegetation was sampled on 102 plots. The sample data were analyzed by multivariate analysis techniques to develop a detailed plant community classification. A second classification for the same sample stands was developed using physical environmental characteristics. These two classifications were compared to determine if they provided similar frameworks for ecological land classification. Discriminant analyses were performed on remote sensing data from the sample stands to determine if the plant communities could be identified on remote sensing imagery.

Study Area

The study area was located at the Manitou Experimental Forest in the Pike National Forest of central Colorado. The Experimental Forest combined a number of features that made it suitable for this study. It comprises a variety of vegetation, soil, and topography in a small, accessible area. Soil class descriptions and a soils map were available for the area, and a variety of scales of remote sensing imagery were available for the Experimental Forest and vicinity.

The geology of the Manitou Experimental Forest is described by Marcus (1973). General descriptions of the vegetation are given by Love (1958), Smith (1967), Currie and Smith (1970), and Morris et al. (1977).

Elevations in the Experimental Forest range from about 2300 m to 2800 m. The east boundary is formed by the Rampart Range crest. The eastern half of the Experimental Forest is characterized by rugged topography developed in Pike's Peak granite. This area is delineated on the west by a narrow band of exposed sedimentary formations. The sedimentary surfaces slope gently to the west, but they are dissected in places by steep-sided valleys. The western half of the Forest is an area of rather gentle topography in alluvial deposits of varying ages. This section is traversed by Trout Creek, a small perennial stream.

Soils throughout the Manitou Experimental Forest have been described by Retzer.[1] He described eight categories of soils according to the parent material: Pike's Peak granite, Sawatch quartzite, Madison limestone, Fountain arkose, old alluvium, intermediate alluvium, recent alluvium, and wet meadow.

At the lower elevations with low relief, grasslands form the predominant vegetation. These grade into pure stands of Pinus ponderosa. At higher elevations with more rugged topography, stands of Pinus ponderosa and Pseudotsuga menziesii are found along with scattered brushlands. The northeast area of the Experimental Forest along the Rampart Range crest is dominated by Pinus contorta.

Field Study Methods

Plot location and data collection followed procedures described by Daubenmire and Daubenmire (1968) and Pfister et al. (1977) for

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[1]Retzer, John L. 1949. Soils and physical conditions of Manitou Experimental Forest. 34 p. Unpublished report on file at Rocky Mountain Forest and Range Experiment Station. Fort Collins, Colo.

defining plant associations and habitat types. Ground reconnaissance and study of aerial photographs revealed apparently homogeneous stands of vegetation that were candidates for detailed study. The plots were concentrated in the Manitou Experimental Forest, although plots in surrounding areas were included to obtain sufficient data to account for variability in vegetation and physical site characteristics. A total of 102 stands were sampled (Figures 1, 2).

A stand was selected for detailed analysis if it met the following criteria (Daubenmire and Daubenmire 1968):

1. The vegetation showed no clear evidence of progressing toward a later seral stage;
2. The stand was apparently homogeneous with respect to physical environment and vegetation.

A 15 x 25 m sample plot was located in each stand selected for detailed study. The plot was oriented with the long axis along the contour and was located to avoid areas of disturbed vegetation or topographic variation such as small drainages. All trees in the large plot were tallied by 1 dm diameter classes.

Fifty sub-plots were located at 1 m intervals on two randomly located lines along the long axis of the large plot. The canopy coverage (Daubenmire 1959) of each herbaceous and shrub species was estimated at each of the sub-plot locations using a 20 x 50 cm plot frame for herbaceous species and low-growing shrubs and a 40 x 100 cm plot frame for tall shrubs. Percent surface area coverage of lichens, mosses, litter, rock, and bare soil, and number of tree seedlings were also recorded at each 20 x 50 cm plot. Slope, aspect, and elevation were recorded for each sample stand. Voucher specimens of

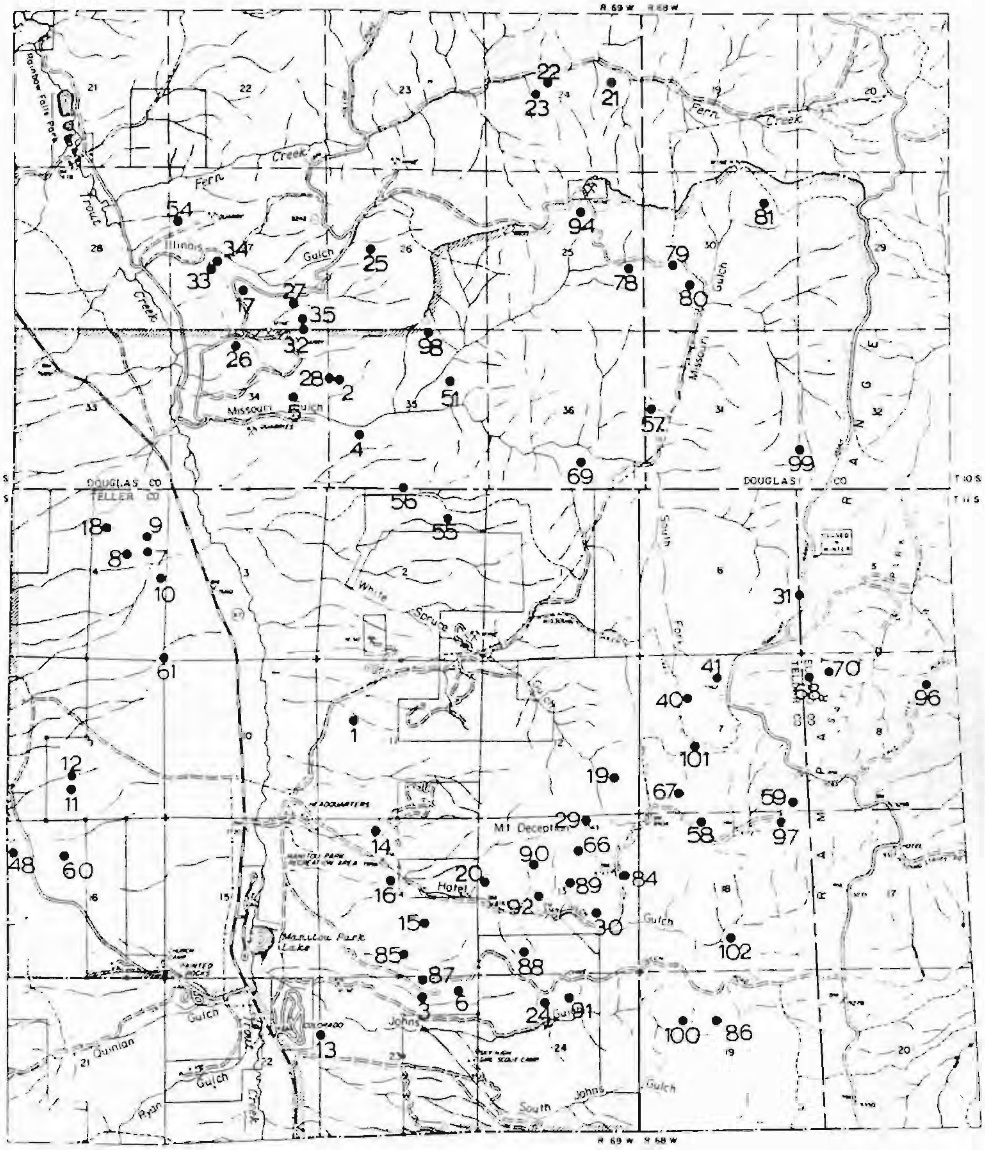

Figure 1.--Sample plot locations in the Manitou Experimental Fore and immediate vicinity.

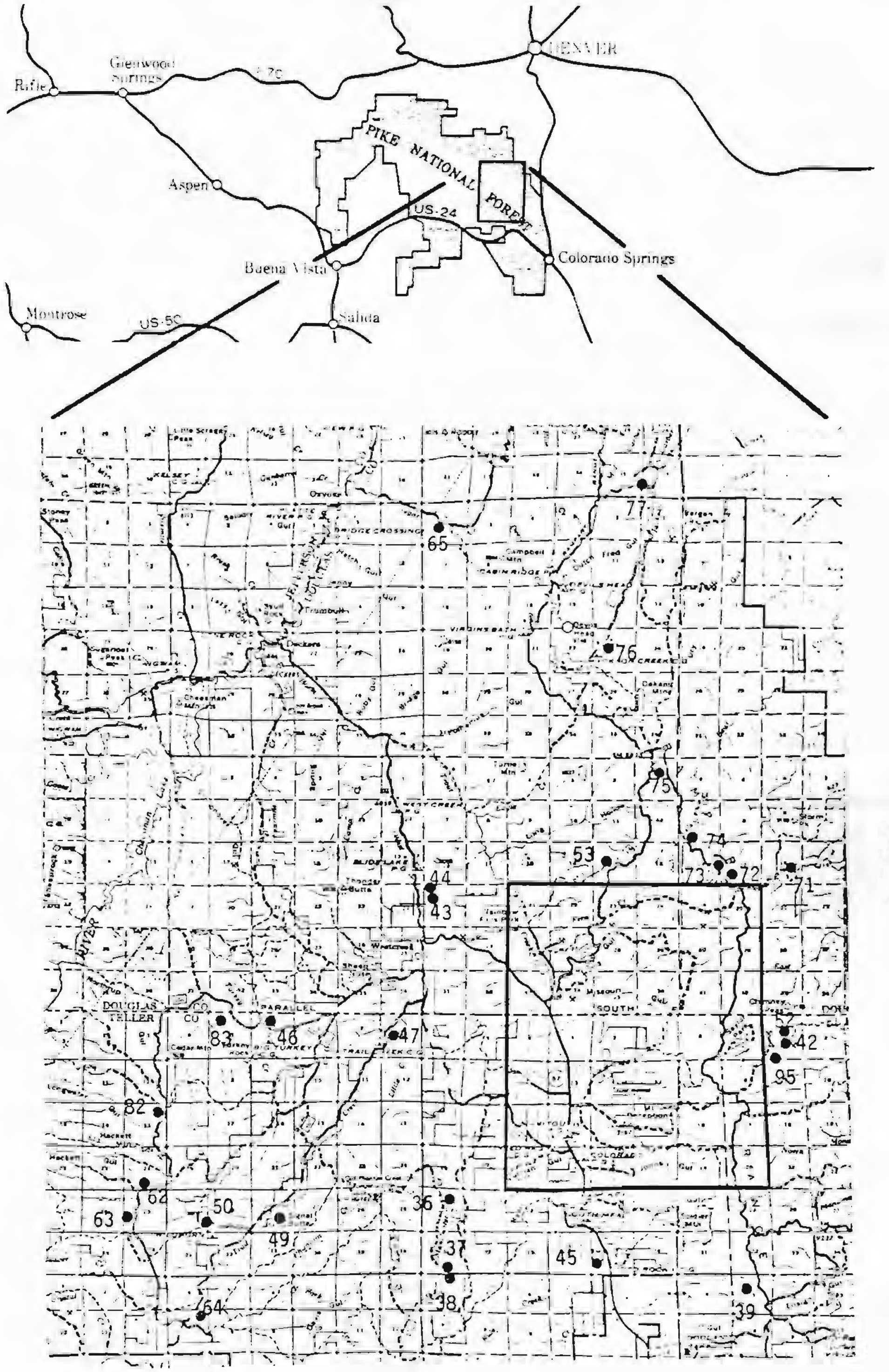

Figure 2.--Sample plots in the Pike National Forest surrounding the main study area.

the recorded species were collected and later verified for correct identification by Charles C. Feddema, USDA Forest Service Herbarium, Fort Collins, Colorado.

Development of the Vegetation Classification

The field sampling procedure provided detailed information about the climax vegetation in the study area. These data were analyzed by a variety of multivariate analysis techniques to develop a classification of the plant communities in the study area. Cluster analysis was used to form initial groups of the 102 sample plots. Discriminant analysis and canonical ordination were used to revise and refine the groups. Ultimately a sequence of iterations involving all three techniques and subjective interpretation of the data was used to develop the plant community classification. The iterative process is described in detail in the "Results" section. The plant community classification formed the basis for a habitat type classification of the study area.

Comparison of Independent Classifications

A second classification of the sample stands was developed using physical environment variables. Only environmental variables that could be measured on U.S. Geological Survey topographic maps, or determined from the available soil map and descriptions, were used for developing this classification. The variables are elevation, aspect, slope, position on slope, minimum average solum depth, maximum average solum depth, degree of soil structure development, subsoil permeability, and soil moisture storage capacity.

Aspect was coded numerically as shown below (after Volland 1974):

Number code	Aspect azimuth (degrees)
2	202.5
4	180 or 225
5	157.5 or 247.5
6	135 or 270
8	112.5 or 292.5
10	90 or 315
11	67.5 or 337.5
12	45 or 360
14	22.5

These codes give high values to cool, moist aspects, and low values to warm, dry aspects.

Position on slope was coded as follows:

Number code	Position
1	Ridge top
2	Valley side
3	Terrace slope
4	Valley bottom.

Soil characteristic codes were subjectively interpreted from narrative soil descriptions. It was not possible to identify the soil category on some of the stands outside the core study area. Therefore, only 93 stands were used in the classification based on physical environment characters.

Remote Sensing Data Analysis

The identifiability of plant communities on remote sensing imagery was tested using discriminant analysis of digitized photographic data. Imagery used was produced by National Aeronautics and Space Administration during aerial photographic mission 205, June 14, 1972, using color infrared positive (i.e., transparency) film. Frame 3-61-068 was selected for this analysis because it includes the entire core study area. Photoscale of the image is approximately 1:51,000.

The central 80 percent of frame 3-61-068 was digitized using an image analysis system comprising a Spatial Data "EyeCom" image scanner and a Data General "Eclipse" mini computer. The system was adjusted so each individual digitized element represented approximately 21 m on the ground. Three color filters were used in sequence during the digitizing process to separate the photographic information into three spectral regions. The filters correspond to film emulsions and original scene characteristics as shown below (Murtha 1977):

Filter	Transmission wavelength	Film layer	Scene reflectance
Red	600 nm	Cyan	Infared
Green	546 nm	Magenta	Red
Blue	435 nm	Yellow	Green

The central 50 percent of the frame contained 62 of the original study plots. These plots were examined visually on the digitized image as projected on a television monitor. Thirty-eight plots were large and distinct enough to permit positive identification of their boundaries on the projected image. These plots represented nine plant communities. However, three communities (*Pinus contorta*, *Populus tremuloides*, and *Festuca arizonica*/*Muhlenbergia montana*) included only one or two plots. Therefore, only six plant communities comprising 33 plots were used in the subsequent analysis.

Analysis software installed on the Data General mini computer was used to measure spectral characteristics of the images of the 33 plots. Mean and standard deviation of light transmission through the film were computed for each plot. This resulted in six spectral variables (one mean and one standard deviation for each filter) to test for their ability to identify the various plant communities.

The six groups (plant communities) were subjected to discriminant analysis to determine how well they could be distinguished on the basis of the six spectral variables. A variety of analyses were performed using various combinations of variables.

RESULTS

Plant Community Classification

The 102 stands sampled in the study area were analyzed by a hierarchic clustering technique to help determine the major groups. The purpose was to assist in defining plant communities that were represented in the sample. A total of 124 shrub, grass, and forb taxa were used to measure inter-stand similarities. In addition, basal area of six tree species, and cover of lichens, moss, litter, bare substrate, and bedrock were used in the similarity coefficient calculations. Thirty-six herbaceous species that occurred on only one or two plots with canopy coverage of only 1 percent were eliminated from the analysis.

In calculating Gower's similarity coefficient, two important parameters must be specified. These are the ranging factor and the weight for each variable. Selection of the values for these parameters can significantly affect the outcome of the cluster analysis.

No prior assumptions were made about relative importance of species for determining groups of stands. In order to give equal consideration to different vegetation layers, weighting factors were used to compensate for different numbers of species (variables) in major growth-form groups. Without such weighting, the most numerous type of variable would exert the greatest influence on the cluster analysis. Forbs were the most numerous in terms of species measured; shrubs and graminoids were next most numerous, and trees were by far the least numerous. Weights of 9 for trees, 3 for graminoids and shrubs, and 1 for forbs were used to equalize these differences. These weights were selected after testing a variety of combinations of weights. The selected weights approximately equalize the sample sizes for shrubs and herbs; tree data were slightly under-weighted to prevent the tree group from completely controlling the results of the cluster analysis.

A procedure for calculating ranging factors must also be selected carefully. Each character has a maximum impact upon the similarity measure when the characters are normalized (ranged) to their respective maximum-minimum values. Strictly, this is the definition of the range of a variable. This approach strongly emphasizes even slight differences among stands.

A dendrogram of the sample stands resulting from such a ranging strategy is shown in Figure 3. The significant feature of this dendrogram is the general lack of well defined clusters of stands. Many highly individual stands are highlighted. This result is typical of an analysis where each variable is scaled over its maximum range. Such an analysis has limited use for delineating plant communities because no major groups are evident.

The problem represented by the dendrogram in Figure 3 is that slight differences in coverage of a given species are accentuated during the cluster analysis. This condition can be alleviated if canopy coverage (basal area for trees) is normalized over the maximum range for all plant species of similar growth form. Therefore, Gower similarities were calculated with ranging factors based on the maximum group ranges for trees, shrubs, graminoids, and forbs. Cluster

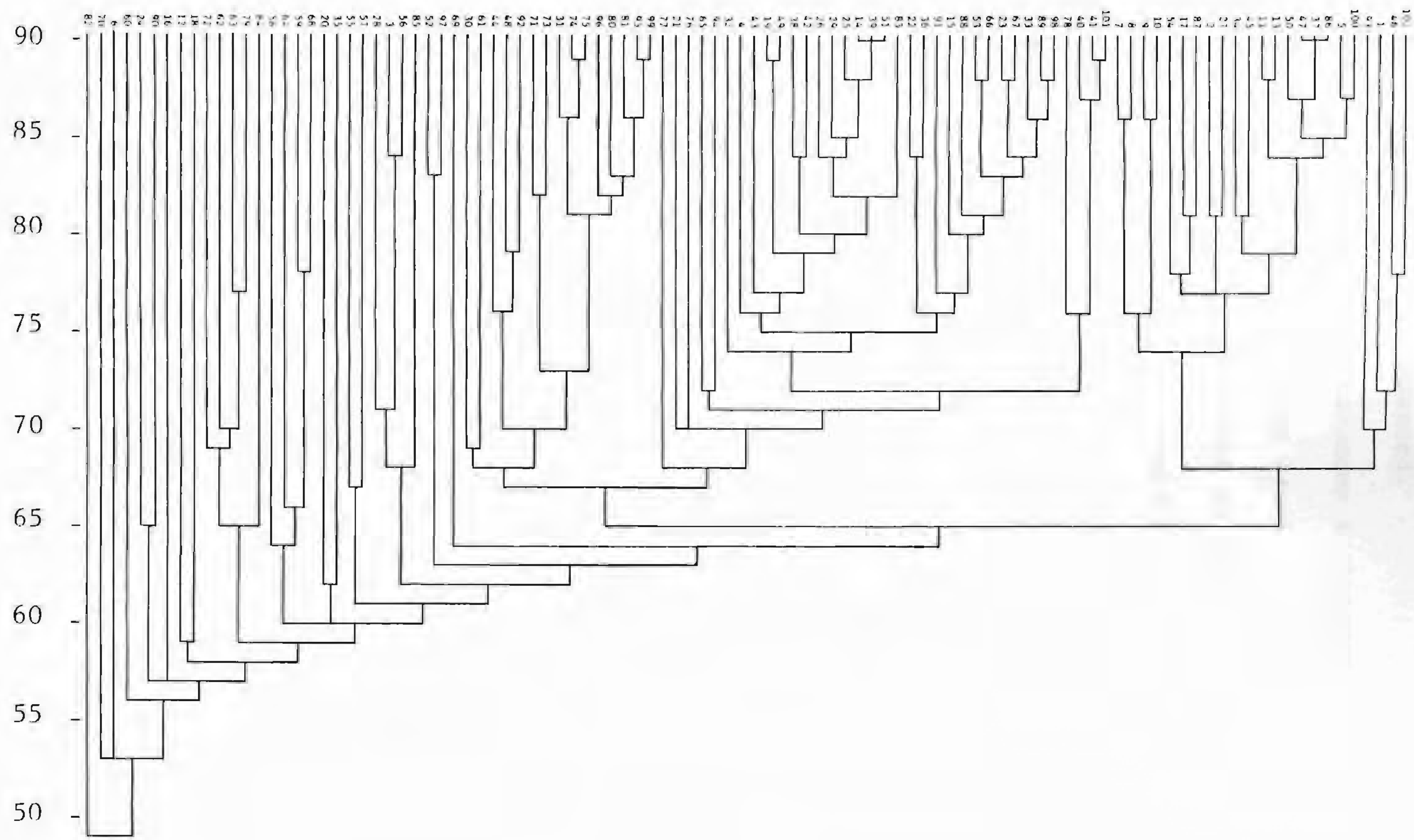

Figure 3.--Dendrogram for 102-stand cluster analysis using equal weights for all variables. Plot numbers are listed at the top. Similarity level (expressed as percent) is shown at the left. Note that the highest similarity level plotted in this diagram is 90 percent.

analysis results using this ranging strategy are shown in Figure 4. This dendrogram tends to emphasize similarities rather than individual stand differences. Major clusters are evident, and a plant community group structure is quite pronounced.

Most users of numerical taxonomy techniques indicate that clusters should all be defined at the same level of similarity in a dendrogram. This approach may result in several to many single-stand groups merely resulting from different sampling intensities of major groups. Furthermore, some groups may be naturally more heterogeneous than other groups. For example, groups B and E (Figure 4) each represent a plant community defined by a common dominant vegetation layer. Communities defined at this level are called series by Pfister et al. (1977). Group B represents the *Populus tremuloides* series, and group E represents the *Pinus contorta* series as sampled in this study. Similarity values in the dendrogram, however, show that group B is considerably more diverse than group E.

Where the dendrogram from a cluster analysis is to be the end product of a classification study, it is probably most appropriate to follow the rule of designating all classes at the same similarity level. However, where the cluster analysis is used to identify tentative clusters that will be subject to further analysis, it seems appropriate to recognize clusters at different levels of the dendrogram hierarchy. This approach was used in enhancing Figure 4 to highlight a fairly evident major group structure. In general, these groups correspond with major plant communities that are readily identified in the field. Thirteen groups are recognized (group I contains only one stand).

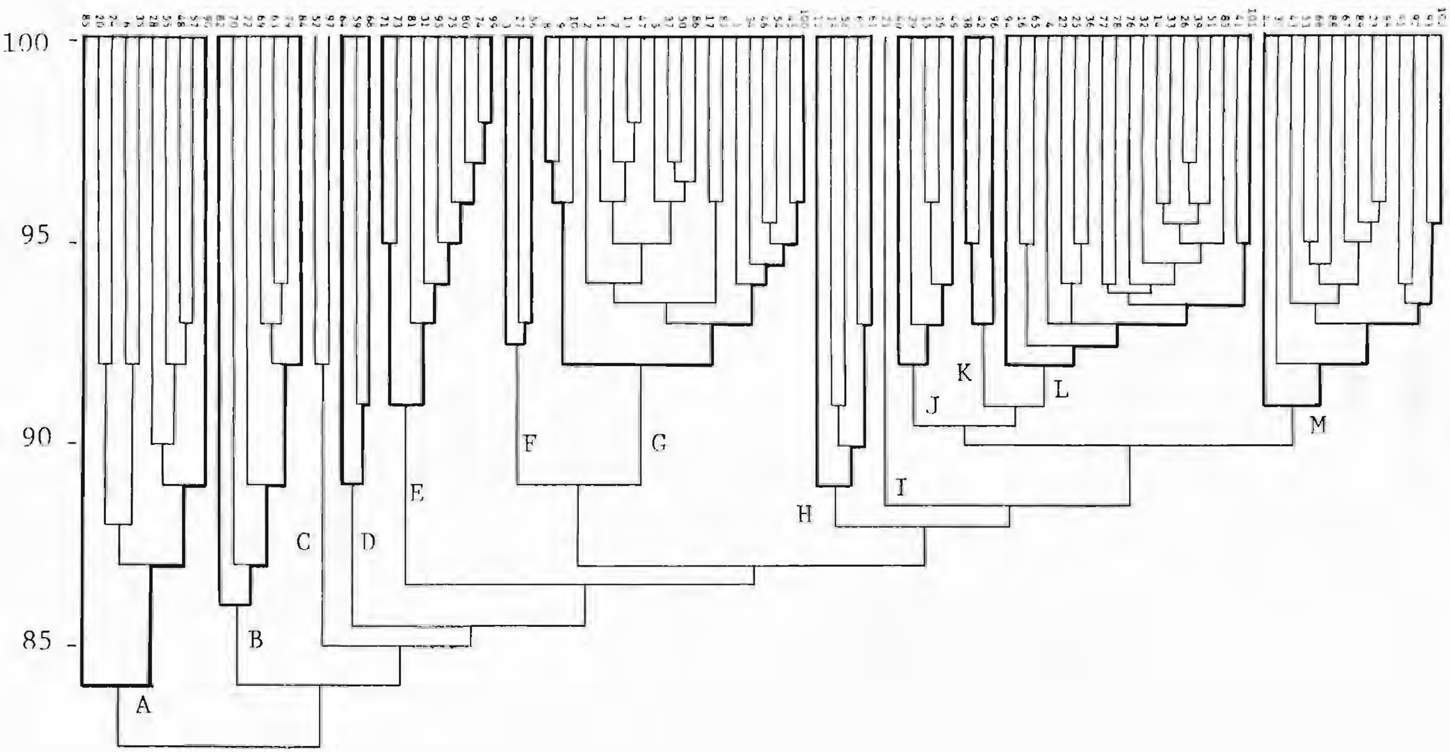

Figure 4.--Dendrogram using adjusted weights and enhanced to show group structure. Plot numbers are listed at the top. Similarity level (expressed as percent) is shown at the left.

The 13 groups from Figure 4 were used as a preliminary grouping to form an association table (Table 2) of the 102 stands. Examination of the association table shows the variables that are important for defining the internal homogeneity of a group and for distinguishing among groups. Table 2 shows the 102 stands and those variables that had high constancy for at least one of the 13 groups. This reduction in the number of variables was necessary because of limitations in the computer program used for subsequent discriminant analysis of the data. In addition, the reduced size facilitates visual interpretation of the association table.

Although the association table reasonably portrays the major differences among the groups, discriminant analysis (Marriott 1974) was used to quantitatively test the separability of the groups. A step-wise discriminant analysis (Dixon 1974) of the 13 groups was executed using 73 variables. The tree data were not used in this particular analysis in order to examine some of the more subtle differences among the groups. After 25 steps, 23 variables were included in the discriminant functions. Table 3 is a summary of the steps of this analysis. Variables are entered (or removed) singly in order of their ability to discriminate among the groups. The discriminating power of each variable is reflected by the value of the F-statistic. The discriminant functions using these 23 variables identified the group membership of the 102 stands with 89 percent accuracy as shown in Table 4.

Additional insight into the separability of the groups is provided by the F-statistic table showing the separability between each pair of groups (Table 5). One feature of Table 5 is the very strong

Table 2.--Association table of the 102 sample stands. Values are percent canopy coverage for shrubs and herbs, basal area (dm^2) for trees, and percent ground cover for moss, exposed soil, and bedrock (continued on next page)

Group	B	B	B	B	B	B	B	B	D	D	B	H	H	H	H	H	A	A	A	A	A	A	A	A	A	A	F	F	F	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
Plot number	82	70	72	62	69	63	79	84	64	59	68	12	18	58	60	61	85	20	24	6	35	28	55	48	57	90	3	27	56	8	9	10	2	11	7	13	47	5	37	50	86	17	87	1	34	46	54	45	100
Arctostaphylos uva-ursi	1	9			23	8	10	1																	2											1			1	6						7			
Epilobium angustifolium	13		4	4	1	1	1																																							1			
Pseudocymopteris montanus	1	1	1	1		1		5	2	2	1																																	1					
Smilacina stellata	5	1	3	1	1	1	1				1																													1	1								
Taraxacum officinale			1	1	1	1	1	1	1		2	1	1																															1					
Potentilla fruticosa		1	1	3		1	3	4	11	20	24																											1							1		1		
Bromus anomalus									1	3	1																																						
Festuca thurberi									40	9	15																																						
Potentilla gracilis		1						1	5	6	14																																						
Andropogon scoparius									1	1		1	1			1						3	3	2			7		1									1				1	1	3	1			1	
Blepharoneuron tricholepis										1	1	13	5	1																														1					
Danthonia parryi		1			1			2	1	14	8	4		29		1																1		1		1						1	6						
Festuca arizonica								1	1			16	1	11	24	34								1			1			1	1	4		4	1	2	1		1		3		1	4		1	2	1	1
Muhlenbergia montana												11	25	1	5	4	6	3	1	1	2	2	1	12	4	9	1	1	1		1	1	1	1			1	1		1	3	1	2	3	4	1	1	1	1
Arenaria fendleri										1			4	2																1					1				1					1					
Cercocarpus montanus																	57	22	28	37	35	31	21	15	20	30	29	12	15								1	1				5	4		2		1		4
Rhus trilobata																	5			1	9			3			1	12					14					1				1	3		4		1		
Bouteloua gracilis									1					1	1	1	1	10	5	4	4			2		3		1																					
Stipa scribneri																	3		1		2	12	22	1	23		2											2					3		6				
Scutellaria brittonii																	1		1	1	1			1	1	1			1																1		1		
Yucca glauca																		4	7		1		1	1	1	2			1													1			1				
Cryptantha thyrsiflora																	1						1				1	1	1														1						
Hymenoxys acaulis																						4	2				2	1	2				1					1				3	3		1		2		
Geranium parryi	2	6		1	1		4	4	1				1	2																1	1	1		1		1	1		1	1	1			2		1	1	1	1
Lithospermum multiflorum																							1		1		1		1				1					1				1	1	1			1		
Exposed soil		1							6	1	1	10		3		8	39	45	58	38	23	25	7	30	36	29	8	2	23								1		4	1	15		3	1	8	1	4	6	15
Juniperus communis		4		18	4	10	18	6																															1							2	9		
Clematis pseudoalpina		1			1																																												
Fragaria americana																																																	
Fragaria ovalis	4	9	1	2	1	4	2	6			4		1									1															1							1		1			
Galium boreale	10		2	1	1	2	1	2	1	3	6			1								1																					1						
Saxifraga bronchialis																																																	
Senecio werneriaefolius																																																	
Solidago decumbens					1			1																																									
Valeriana edulis																																																	
Jamesia americana																																																	
Bedrock																	8				8		1	1	1	19	1	3													1				15			2	1
Moss													1																									1											
Picea engelmannii																																																	
Pinus contorta			1																																														
Pinus ponderosa					4																						65	90	71	193	194	193	144	130	156	150	146	109	120	118	121	116	121	75	94	94	91	78	85
Populus tremuloides	172	69	181	123	117	182	161	236																																1									
Pseudotsuga menziesii	1				8		2																																12		12								5

Table 2 (continued).--Association table of the 102 sample stands

Group	M	M	M	M	M	M	M	M	M	M	M	M	M	M	I	L	L	L	L	L	L	L	L	L	L	L	L	L
Plot number	44	30	43	53	66	88	67	89	23	98	91	92	93	102	21	94	16	65	4	22	25	36	77	78	76	32	14	33
Arctostaphylos uva-ursi			4				3			1			1			2				1	2							1
Epilobium angustifolium																												
Pseudocymopterus montanus																		1				1			1			
Smilacina stellata				1					1		1		1	1									1					
Taraxacum officinale																												
Potentilla fruticosa																												
Bromus anomalus																												
Festuca thurberi																												
Potentilla gracilis																												
Andropogon scoparius																												
Blepharoneuron tricholepis																		1				1						
Danthonia parryi																												1
Festuca arizonica					1		1	2			2			2													1	
Muhlenbergia montana	1	7		2	2	6		8		4	7	13	2	3		2											1	1
Arenaria fendleri																												
Cercocarpus montanus		8				1		1		2	4	10															1	
Rhus trilobata																												
Bouteloua gracilis																												
Stipa scribneri		2																										
Scutellaria brittonii											1	1	1			1												
Yucca glauca	1	1				2				1		1	1			1												
Cryptantha thyrsiflora																												
Hymenoxys acaulis																												
Geranium parryi	1							1	1	1	1	1	1	2												1	1	1
Lithospermum multiflorum																												
Exposed soil	54	14	9	26	11	34	9	20	31	22	30	27	26	25	1	18	1	2		2	1		1		2	1		
Juniperus communis			6	2			3		2						1		1	1	6	9	12	11	7	1	3	3	6	3
Clematis pseudoalpina	1		1			1			1						1		1	1	2		1	1		1	1	5	3	2
Fragaria americana			1												5		1	1	1	2	1	4		1	2		1	
Fragaria ovalis															1				1	1	1	1	1			1	1	
Galium boreale														1	1			1	1		2	1			1	1		
Saxifraga bronchialis			1												6		1			2	1	2		2	2			
Senecio wernerlaefolius															1		1	1		1	1	1			1		1	
Solidago decumbens			1							1					1		1	1	1	2	1	1	1		1	1	1	1
Valeriana edulis																			4			1		1	1	1		1
Jamesia americana			6		2													4							16			
Bedrock	4	13	4	8	10	1	5	1		2		1		1			1					1			4	1		4
Moss			1	1		1			1		1		1		18		20	16	4	9	8	6	3	5	5	7		3
Picea engelmannii																			1			13				2		
Pinus contorta																												
Pinus ponderosa	26	21	20	32	34	27	13	4	21	26	43	36	89	82		30				36	17	18	5				13	7
Populus tremuloides							4	1													1	2						
Pseudotsuga menziesii	18	24	54	64	41	42	90	80	91	90	77	40	77	35	143	182	136	166	145	106	151	105	167	162	148	131	106	90

Group	L	L	L	L	L	L	J	J	J	J	J	E	E	E	E	F	F	F	F	E	C	C	K	E	K
Plot number	26	39	51	83	41	101	50	29	15	19	49	71	73	81	31	95	75	80	74	99	52	97	38	42	96
Arctostaphylos uva-ursi	2	1			1	2								8	4	3	3	3	4	4			1		
Epilobium angustifolium												1	1								1				
Pseudocymopterus montanus												1											1		
Smilacina stellata																					1				
Taraxacum officinale																									
Potentilla fruticosa																									
Bromus anomalus																									
Festuca thurberi																									
Potentilla gracilis																									
Andropogon scoparius																									
Blepharoneuron tricholepis																									
Danthonia parryi																									
Festuca arizonica			1																				1		
Muhlenbergia montana									1																
Arenaria fendleri																									
Cercocarpus montanus									1																
Rhus trilobata									1																
Bouteloua gracilis																									
Stipa scribneri																									
Scutellaria brittonii																									
Yucca glauca																									
Cryptantha thyrsiflora																									
Hymenoxys acaulis																									
Geranium parryi			1									1						1			2				
Lithospermum multiflorum																									
Exposed soil	1		1	3		1		1	2	1				7		16	2	1	1	1		1			
Juniperus communis	1	1	9	1	4	4	2	2		1	2	2		1		2	1	3			3		13	4	2
Clematis pseudoalpina	1	1	1	1				2	1	1	1						1	1					1		
Fragaria americana			1	1		1	3	2		2	1										1	1		2	1
Fragaria ovalis												1						1			3		1		1
Galium boreale																					1		1		
Saxifraga bronchialis		1	2	3			1	1		1														1	
Senecio wernerlaefolius		1	1	1	1	1		1								1							1	1	
Solidago decumbens	2	1	1	1	1	2		1						1	1	1		1					1	1	
Valeriana edulis	1		1																		3		1		
Jamesia americana				1			11	9	15	14	25														
Bedrock	3		1	4	1	1	37	23	21	27	14		1	1				1							
Moss	1	3	2	1	2	3	3	6	1	1	4		1	3		1	1			1	13	10	20	11	14
Picea engelmannii	27	11	15		6		5													7	166	144	50	49	44
Pinus contorta					18							210	171	104	81	120	141	144	136	128					65
Pinus ponderosa	5	7	10				10	4	10	5	2											18	1		26
Populus tremuloides	1	1	1		1	7						4	2	2	1	1	13	2					10		8
Pseudotsuga menziesii	116	127	119	141	78	131	103	161	98	110	112						2					23	68	84	38

Table 3.--Summary of stepwise discriminant analysis of 102 stands in 13 groups

Step number	Variable entered	Variable removed	F-value
1	Potentilla fruticosa		67.9
2	Cercocarpus montanus		37.2
3	Festuca thurberi		32.9
4	Bromus anomalus		22.1
5	Potentilla gracilis		54.9
6	Fragaria ovalis		28.8
7	Bedrock		17.1
8	Moss		15.1
9	Festuca arizonica		12.6
10	Arenaria fendleri		13.3
11	Saxifraga bronchialis		9.7
12	Bare Soil		7.7
13	Smilacina stellata		6.7
14	Jamesia americana		5.6
15	Juniperus communis		5.0
16	Arctostaphylas uva-ursi		5.7
17	Blepharoneuron tricholepis		4.3
18	Taraxacum officinale		5.2
19	Solidago decumbens		4.0
20	Epilobium angustifolium		4.0
21		Smilacina stellata	0.9
22	Pseudocymopteris montanus		4.5
23	Cryptantha thyrsiflora		3.5
24	Stipa scribneri		4.2
25	Bouteloua gracilis		4.5

Table 4.--Stand identification accuracy. Values in table represent number of stands

		Group membership of stands as determined by discriminant functions												
		A	B	C	D	E	F	G	H	I	J	K	L	M
True group membership	A	9												1
	B		8											
	C			2										
	D				3									
	E					9								
	F						3							
	G					3	1	15						1
	H								5					
	I									1				
	J										5			
	K			1								2		
	L											2	16	1
	M												1	13

Table 5.--Group pair-wise F-values (23 and 67 degrees of freedom) for the 13 groups of 102 stands. Values marked by asterisks (*) are not significant the 0.90 probability level

	A	B	C	D	E	F	G	H	I	J	K	L
B	58.2											
C	10.3	11.6										
D	>100	>100	>100									
E	24.5	30.0	1.6*	>100								
F	7.6	20.4	3.2	>100	3.9							
G	31.9	45.0	1.9*	>100	1.1*	3.8						
H	49.9	74.9	19.2	>100	38.3	22.9	39.5					
I	11.8	13.0	3.9	>100	6.8	7.1	7.4	16.3				
J	27.8	35.8	3.9	>100	13.5	9.9	16.3	39.9	9.8			
K	14.3	19.6	0.7*	>100	3.0	4.5	4.0	26.0	4.6	8.5		
L	35.2	48.2	1.6*	>100	2.9	5.5	6.7	49.7	5.5	14.6	1.8*	
M	25.1	42.5	2.6	>100	2.9	4.0	4.3	44.2	7.7	12.0	4.0	6.1

difference between group D and all other groups, as shown by F-values much larger than all others. This separation is seen graphically in Figure 5 which is a canonical ordination of the group means. Group D is comprised of three stands dominated by Potentilla fruticosa and Festuca thurberi (Table 2). The uniqueness of this group overshadowed all other inter-group differences in this discriminant analysis. The first canonical axis of Figure 5 essentially distinguishes only between group D and the aggregate of all other groups. This axis accounts for 99.5 percent of the variation in the data. Comparison of the species list in Table 3 with Table 2 shows that four of the first five variables included in the discriminant functions serve mainly to distinguish group D from the other 12 groups.

Table 5 also demonstrates that several pairs of clusters are quite similar to each other. In fact, six pairs are not distinguishable at the 0.90 probability level. The undistinguishable groups are: C with E; E with G; C with G; C with K; C with L; and L with K.

Groups C and E are characterized by several common understory species (Table 2). They are, however, readily separated on the basis of different tree dominants. The situation is similar for pairs E/G and C/G. Had tree dominance data been included in this discriminant analysis, these groups would have been better discriminated. This was done in a later step in the analysis.

Groups C, K, and L all have several important species in common. Groups C and L are characterized by different climax dominant tree species; Group K is intermediate between the other two. This relationship is readily observed in Figure 6 which is a canonical ordination of the seven least distinct groups as determined by a series of prior

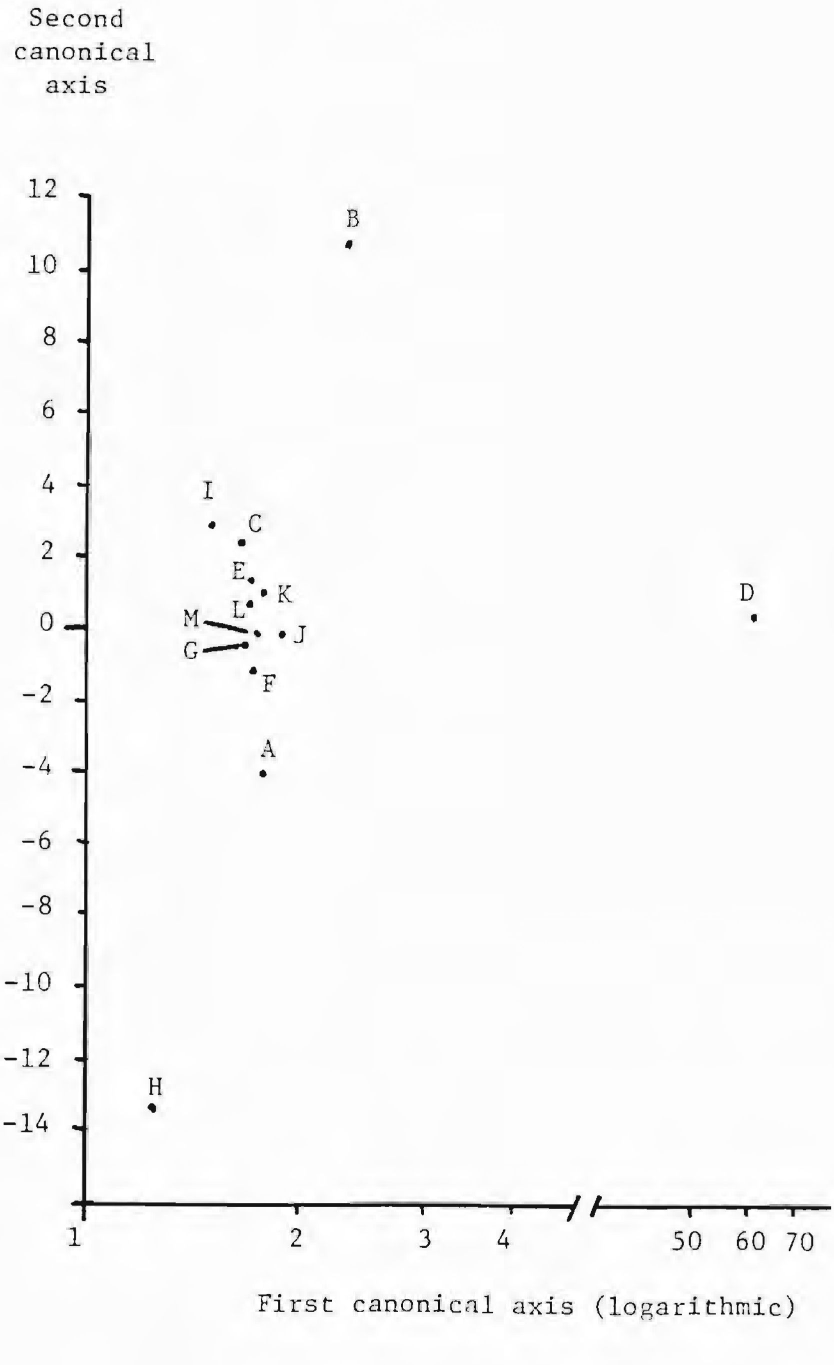

Figure 5.--Canonical ordination of the 13 groups of 102 stands.

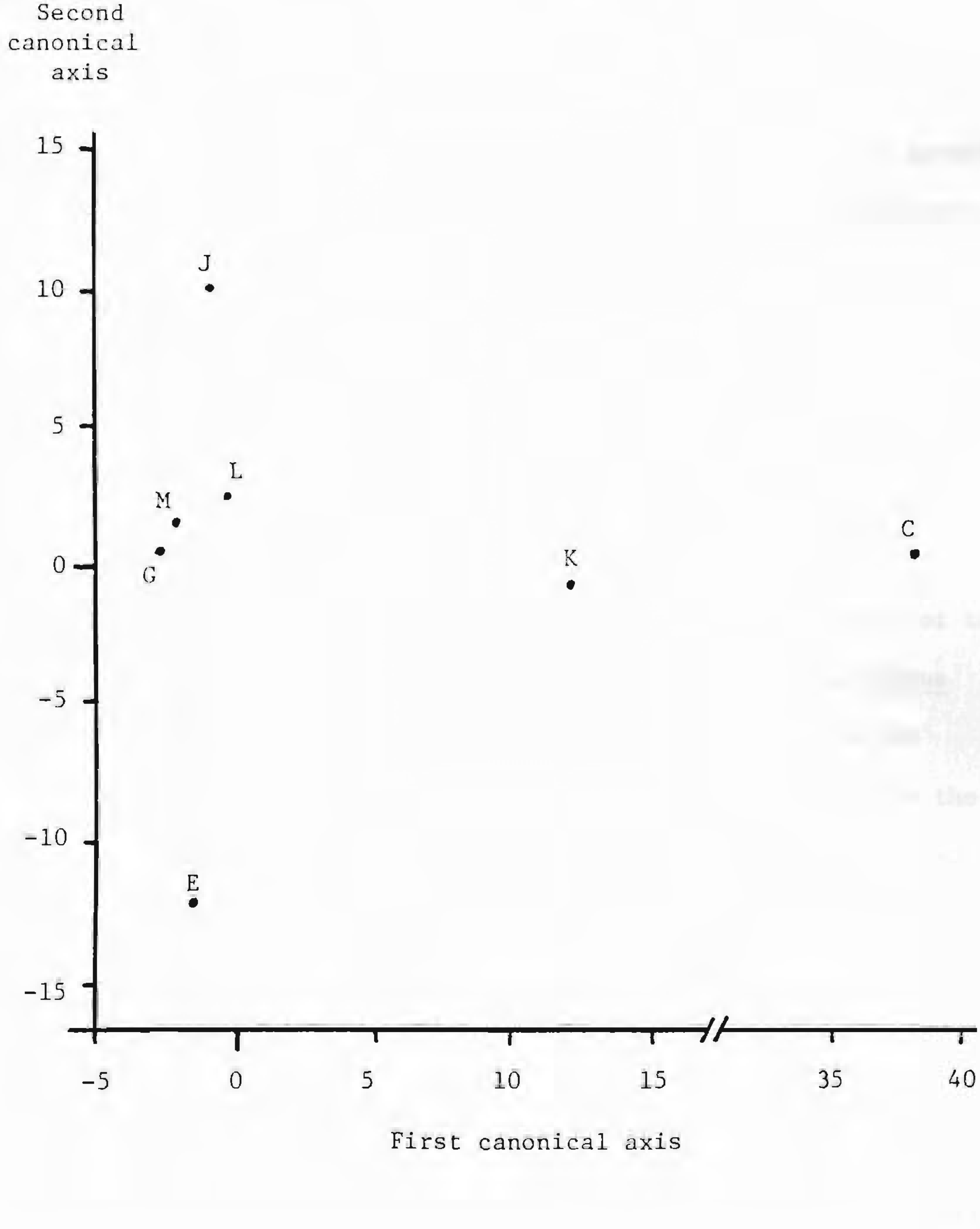

Figure 6.--Canonical ordination of the seven least distinct groups.

discriminant analyses. Tree dominance data were included in this analysis. Table 6 is a summary of the most important variables for discriminating these seven groups. Discriminant functions calculated with the 15 listed variables correctly identified all individual stands in these groups (Table 7). The matrix of F-values (Table 8) shows significant F-values for all pairs of groups.

It is possible to attach tentative, general names to the groups at this time: group B, Populus tremuloides; D, Potentilla fruticosa; H, Festuca arizonica/Muhlenbergia montana; A, Cercocarpus montanus; F, Pinus ponderosa/shrub; G, Pinus ponderosa/grass; M, Pinus ponderosa/Pseudotsuga menziesii; I, Pseudotsuga menziesii/forb; L, Pseudotsuga menziesii/forb; J, Pseudotsuga menziesii/shrub; K, Pseudotsuga menziesii/Picea engelmannii; C, Picea engelmannii; E, Pinus contorta.

The three large groups (G, L, M) comprise over 50 percent of the total sample for this study. They are dominanted by either Pinus ponderosa, Pseudotsuga menziesii, or a combination of these two species. With respect to aerial extent, such stands are by far the most important types in the study area. Therefore, it was decided to further analyze plots that were dominated by either of these two tree species. The 62 stands in groups F, G, I, J, L, and M are included in this category.

These 62 stands were again subjected to a cluster analysis. The reduced variable set (Table 2) was used for this analysis. The variables were normalized over the growth-form group ranges expressed for the 62 stands. Because the data reduction changed the proportions, trees were weighted three times and shrubs twice. Results are shown

Table 6.--Summary of stepwise discriminant analysis of the seven least distinct groups (C, E, G, J, K, L, and M)

Step number	Variable entered	F-value
1	*Picea engelmannii*	421.1
2	*Pinus contorta*	109.7
3	*Pseudotsuga menziesii*	77.4
4	Bedrock	33.8
5	Bare soil	18.9
6	*Pinus ponderosa*	7.0
7	*Jamesia americana*	7.2
8	*Bouteloua curtipendula*	9.0
9	*Vaccinuim myrtillus*	5.2
10	Moss	4.6
11	*Pyrola chlorantha*	3.2
12	*Geranium richardsonii*	3.3
13	*Solidago decumbens*	3.7
14	*Stipa scribneri*	2.4
15	*Erigonum alatum*	2.3

Table 7.--Stand identification accuracy. Values in table represent number of stands

		Group membership of stands as determined by discriminant analysis						
		C	E	G	J	K	L	M
	C	2						
	E		9					
True group membership	G			20				
	J				5			
	K					3		
	L						19	
	M							14

Table 8.--Group pair-wise F-values (15 and 51 degrees of freedom) for the seven least distinct groups of stands. All values are significant at the 0.99 probability level

	C	E	G	J	K	L
E	153.					
G	161.	90.				
J	138.	93.	79.			
K	46.	45.	37.	46.		
L	147.	79.	47.	50.	25.	
M	151.	70.	19.	47.	31.	19.

in the dendrogram in Figure 7. Eight major groups were recognized (A through H). In general, these groups are in agreement with a preliminary subjective classification based solely on observation of stands in the field (Figure 7). However, 11 stands do not agree with the general group structure of the cluster analysis. These stands (labeled in Figure 7) were deleted to be identified later. In addition, stand number 1, a one-member group in the dendrogram, was deleted because the study plot included part of a forest stand and part of an adjacent grass dominated stand. The 50 remaining stands were clustered, resulting in the dendrogram in Figure 8. This dendrogram is very similar to that of Figure 7. The eight groups were again recognized.

Again, a reduced set of variables was determined (Table 9) that includes mainly those that are relatively constant in at least one of the groups. A discriminant analysis using this reduced data set showed the groups to be highly separable (Table 10). The corresponding canonical ordination appears in Figure 9. Three groups, A, B, and D, stand apart from the others. The stands representing these groups are all characterized by _Pinus ponderosa_ overstory with _Cercocarpus montanus_ and _Rhus trilobata_ (one exception) forming a shrub layer in the understory. Furthermore, these plots all occurred on sedimentary substrates. Therefore, groups A, B, and D were combined into a new group, A´.

The two plots in group G are similar to those of group H except for a higher canopy coverage of _Cercocarpus montanus_. Because the physical settings for the two group are much alike, these were joined to form a new group, G´.

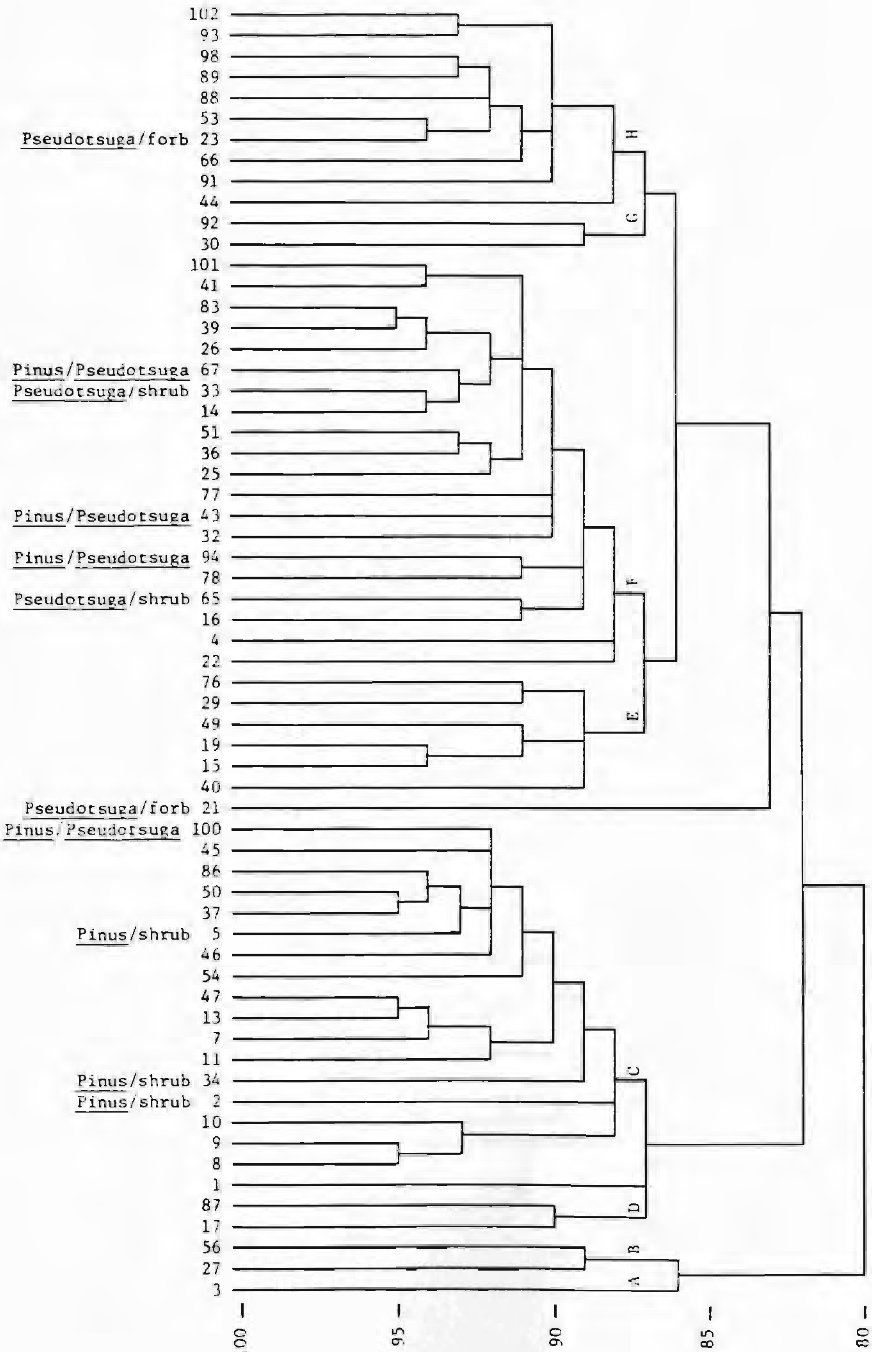

Figure 7.--The 62-stand dendrogram. Groups A, B, and D represent the (preliminary) Pinus/shrub group; C the Pinus/grass group; E the Pseudotsuga/shrub group; F the Pseudotsuga/forb group; and G and H the Pinus/Pseudotsuga group.

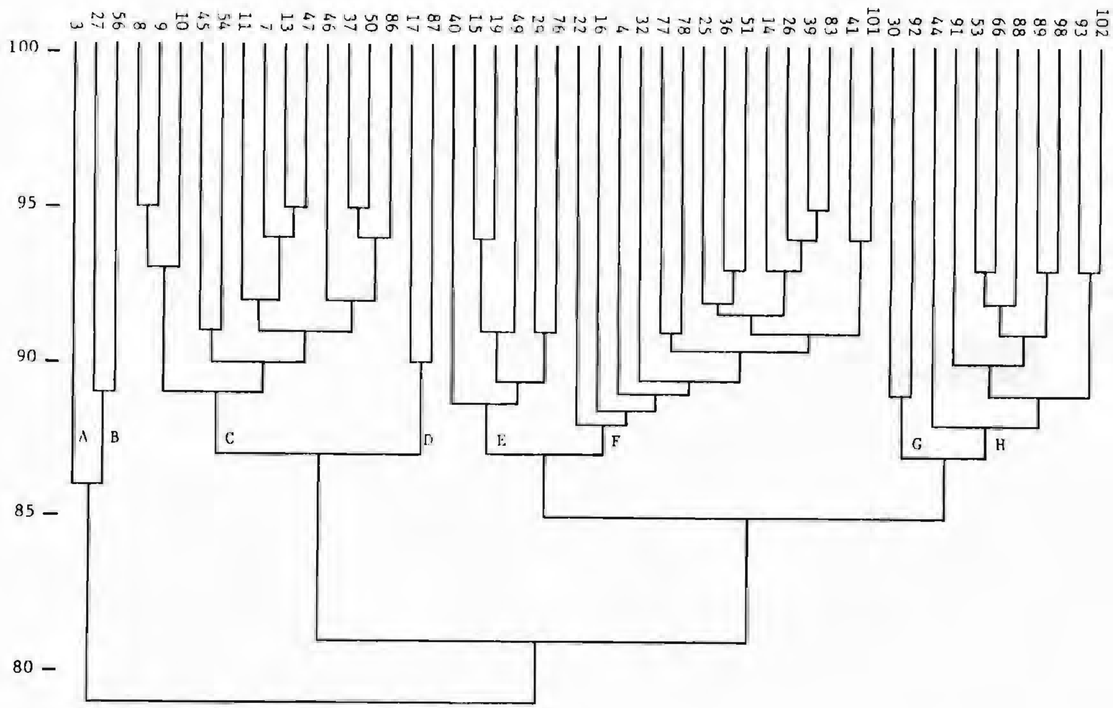

Figure 8.--The 50-stand dendrogram. Plot numbers are listed at the top. Similarity level (expressed as percent) is shown at the left.

Table 9.--Variables used to test separability of eight groups of *Pinus ponderosa*- or *Pseudotsuga menziesii*-dominated stands

Forbs	Shrubs	Graminoids	Other
Achillea lanulosa	*Arctostaphylos uva-ursi*	*Agropyron albicans*	Lichen
Allium cernuum	*Artemisia frigida*	*Andropogon scoparius*	Moss
Anemone patens	*Cercocarpus montanus*	*Bouteloua curtipendula*	Litter
Antennaria parvifolia	*Jamesia americana*	*Calamagrosits purpurascens*	Bare Soil
Artemisia ludoviciana	*Juniperus communis*	*Carex* spp.	Bedrock
Clematis pseudoalpina	*Physocarpus monogynus*	*Danthonia parryi*	
Cryptantha thyrsiflora	*Rhus trilobata*	*Festuca arizonica*	
Eriogonum alatum	*Ribes cereum*	*Koeleria cristata*	
Fragaria americana	*Rosa* sp.	*Muhlenbergia montana*	
Fragaria ovalis	*Symphoricarpos albus*	*Oryzopsis hymenoides*	
Frasera speciosa	*Yucca glauca*		
Galium boreale			
Geranium parryi			
Hymenoxys acaulis			
Lithospermum multiflorum			
Mertensia lanceolata			
Penstemon virens			
Potentilla pensylvanica			
Saxifraga bronchialis			
Sedum stenopetalum			
Senecio fendleri			
Senecio werneriaefolius			
Smilacina stellata			
Solidago decumbens			
Thalictrum fendleri			
Valeriana edulis			

Table 10.--Group pair-wise F-values (17 and 26 degrees of freedom) for the eight *Pinus ponderosa*- or *Pseudotsuga menziesii*-dominated groups. All values are significant at the 0.99 probability level

	A	B	C	D	E	F	G
B	>1000						
C	>1000	366.					
D	>1000	>1000	>1000				
E	>1000	320.	12.5	>1000			
F	>1000	375.	6.4	>1000	9.6		
G	>1000	193.	36.7	>1000	34.6	39.9	
H	>1000	390.	8.8	>1000	13.9	11.1	31.1

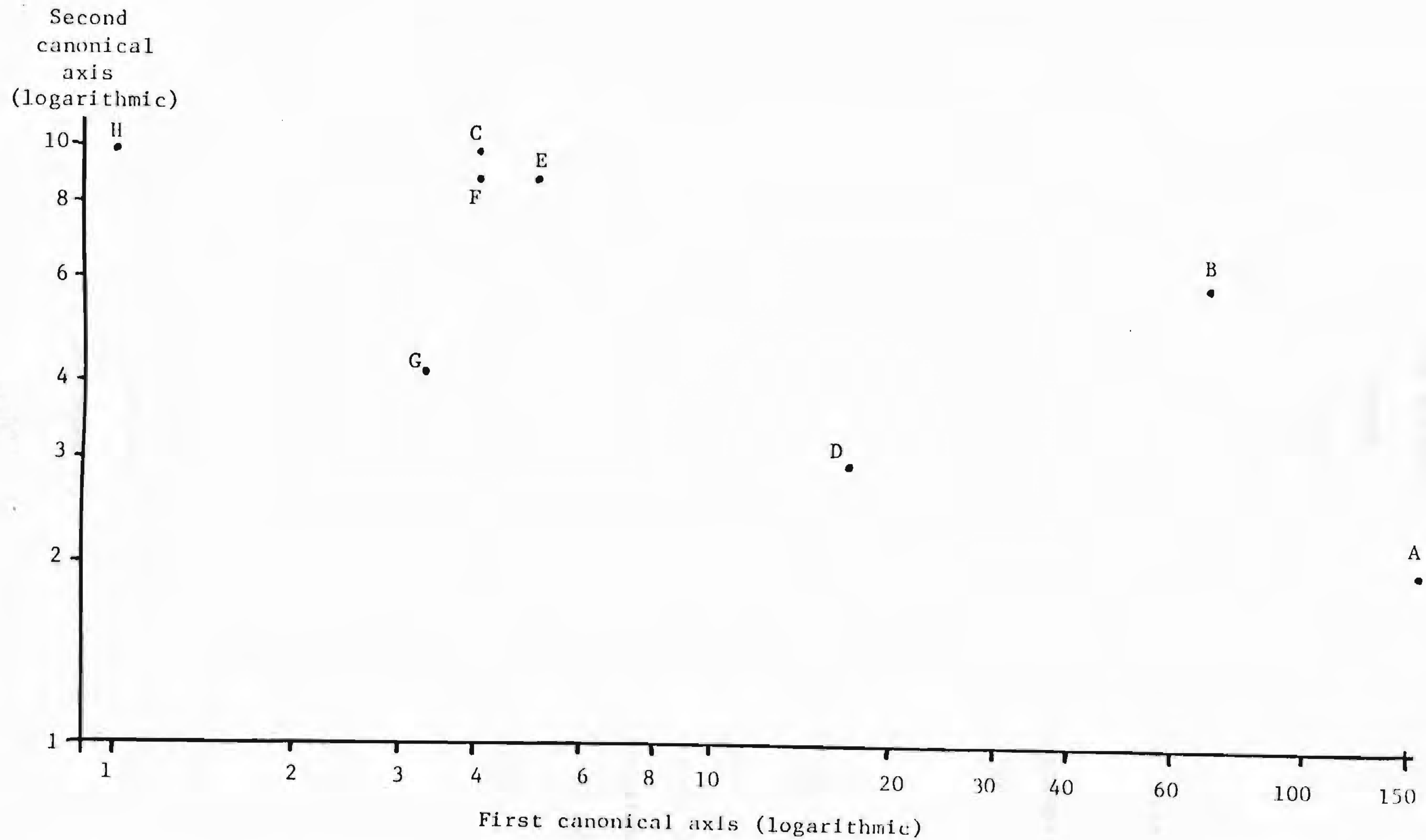

Figure 9.--Canonical ordination of eight groups of 50 Pinus ponderosa- or Pseudotsuga menziesii-dominated stands.

Groups C, E, and F were retained as shown in Figure 8. This new structure of five groups is shown in the association table of Table 11. The five groups are well differentiated by the pattern of variables in the table. This separability was confirmed by discriminant analysis. Discriminant function scores correctly placed all of the stands within their respective groups. F-values to evaluate pair-wise separabilities were all significant (Table 12).

The species associated with these five well defined groups were compared with the species coverage values for the 12 deleted stands to determine the best group membership for each deleted stand. The results are shown in Table 13.

Three of the 12 stands (23, 67, and 100) do not obviously belong with any one group. Indeed, it was this situation that first caused their initial classification to be questioned. This situation is not unusual (Grigg 1965), and it should not be construed to unduly detract from the classification process. More remarkable than the existence of marginal stands is the well defined, homogeneous character of the groups themselves.

Major Plant Communities

The combination of cluster analysis, discriminant analysis, canonical ordination, and subjective interpretation enabled delineation of one grassland, two shrubland, and five forest plant associations. In addition, three forest communities were identified at a broader level (the series level of Pfister et al. 1977). Sampling in these three (series level) communities was not sufficient for the analysis to delineate associations, but some suggestions are made concerning more detailed divisions.

Table 11.--Association table for the five groups. Values are percent canopy coverage for shrubs and herbs, basal area (dm^2) for trees, and percent ground cover for soil and bedrock

Group	A	A	A	A	A	C	C	C	C	C	C	C	C	C	C	C	C	C	G	G	G	G	G	G	G
Plot number	3	27	56	17	87	8	9	10	45	54	11	7	13	47	46	37	50	86	30	92	44	91	53	66	88
Andropogon scoparius	7		1	1	1				1																
Hymenoxys acaulis	1	1	2	3	3					2															
Lithospermum multiflorum	1		1	1	1					1															
Cercocarpus montanus	29	12	15	5	4					1				1					8	10		4			1
Rhus trilobata	1	12		1	3					1															
Festuca arizonica	1				1	1	1	4	1	2	4	1	2	1	1	1		1				2		1	
Geranium parryi						1	1	1	1	1	1		1	1	1	1	1	1		1	1	1			
Muhlenbergia montana	1	1	1	1	2		1	1	1	1	1			1	1		1	3	7	13	1	7	1	2	6
Artemisia frigida		1																1	1	1		1		1	1
Yucca glauca			1	1															1	1	1				2
Exposed soil	8	2	21		3				6	4				1	1	4	1	15	14	27	54	30	26	11	34
Clematis pseudoalpina																					1				1
Fragaria americana																									
Fragaria ovalis															1	1									
Galium boreale					1																				
Saxifraga bronchialis																									
Senecio werneriaefolius																									
Valeriana edulis																									
Juniperus communis										9					2	1							2		
Jamesia americana																								2	
Bedrock	1	3							2									1	13	1	4		8	10	1
Pinus ponderosa	65	90	71	116	121	193	194	193	78	91	130	156	150	146	94	120	118	121	21	36	26	43	32	34	27
Pseudotsuga menziesii																12		12	24	40	18	77	64	41	42

Group	G	G	G	G	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	E	E	E	E	E	E
Plot number	89	98	93	102	22	16	4	12	77	78	25	36	51	14	26	39	83	41	101	40	15	19	49	29	76
Andropogon scoparius																									
Hymenoxys acaulis																									
Lithospermum multiflorum																									
Cercocarpus montanus	1	2												1							1				
Rhus trilobata																									
Festuca arizonica	2			2									1	1											
Geranium parryi	1	1	1	2				1					1	1											
Muhlenbergia montana	8	4	2	3										1							1				
Artemisia frigida	1																								
Yucca glauca		1	1																						
Exposed soil	20	22	26	25	2	1		1	1		1		1		1		3		1		2	1		1	2
Clematis pseudoalpina						1	2	8		1	1	1	1	3	1	1	1				1	1	1	2	1
Fragaria americana					2	1	1			1	1	4	1	1			1		1	3		2	1	2	2
Fragaria ovalis					1		1	1	1		1	1		1											
Galium boreale				1			1	1			1	1													1
Saxifraga bronchialis					2	1				2	1	2	2			1	1			1		1		1	2
Senecio werneriaefolius					1	1					1	1	1	1		1	1	1	1					1	1
Valeriana edulis							4	1		1		1	1		1										1
Juniperus communis					9	1	6	3	7	1	12	11	9	6	1	1	1	4	4	2		1	2	2	1
Jamesia americana																	1			11	15	14	25	9	16
Bedrock	1	2		1		1		1				1	1		3		4	1	1	37	21	27	14	23	4
Pinus ponderosa	4	26	89	82	36				5		17	18	10	13	5	7				10	10	5	2	4	
Pseudotsuga menziesii	80	90	77	35	106	136	145	131	167	182	151	105	119	106	116	127	141	78	131	103	98	110	112	163	148

Table 12.--Group pair-wise F-values (22 and 24 degrees of freedom) for the final five groups of *Pinus ponderosa*- or *Pseudotsuga menziesii*-dominated stands

	A′	C	E	F
C	>100			
E	>100	46.		
F	>100	11.	37.	
G′	>100	13.	49.	21.

Table 13.--Identification of the 12 deleted stands

Stand number	Assigned to group	Based on dominance values for
1	C	*Pinus ponderosa* *Festuca arizonica*
2	A	*Pinus ponderosa* *Rhus trilobata* *Hymonoxys acaulis*
34	A	*Pinus ponderosa* *Cercocarpus montanus* *Rhus trilobata*
5	A	*Pinus ponderosa* *Cercocarpus montanus* *Rhus trilobata*
100	G	*Pinus ponderosa* *Pseudotsuga menziesii* *Cercocarpus montanus* *Muhlenbergia montana* Bare soil
21	F	*Pseudotsuga menziesii* *Clematis pseudoalpina* *Saxifraga bronchialis* *Senecio werneriaefolius*
65	E	*Pseudotsuga menziesii* *Jamesia americana*
94	G	*Pseudotsuga menziesii* *Pinus ponderosa* *Muhlenbergia montana* Bare soil
43	E	*Pseudotsuga menziesii* *Jamesia americana*
33	E	*Pseudotsuga menziesii* *Jamesia americana*
67	G	*Pseudotsuga menziesii* *Pinus ponderosa* *Juniperus communis* *Festuca arizonica* *Penstemon virens* *Potentilla pensylvanica*
23	G	*Pseudotsuga menziesii* *Pinus ponderosa* *Juniperus communis* *Potentilla pensylvanica* Bare soil

Festuca arizonica/Muhlenbergia montana association

Four stands representing this grass-dominated community were sampled. In general, grasslands in the study area tend to be highly disturbed areas due to past agricultural practices, recent range improvement attempts, and grazing by cattle. Two stands sampled are openings within the area of the Pinus ponderosa/Festuca arizonica community; the other two stands are in undisturbed exclosures within relatively large nonforested areas. All four stands tend to have generally similar vegetation, however.

Festuca arizonica, Muhlenbergia montana, Carex sp., and Antennaria parvifolia were present on all plots. Coverage of Carex sp., Festuca arizonica, and Muhlenbergia montana was greater on these areas than in the Pinus ponderosa/Festuca arizonica community. Artemesia frigida was the only shrub found, occurring on three of the plots.

Andropogon scoparius and Blepharoneuron tricholepis were found in both forest opening stands. Muhlenbergia montana coverage was also higher in these stands compared to the undisturbed, grazing exclosures.

One grassland stand was sampled that it is similar to the preceding community except for its very high canopy coverage of Danthonia parryi. The presence of this species gives a very different appearance to this community. The sample stand is located on a gently sloping southerly exposure. Although this appears to be a distinct community, it was not named as an association because it was only found in one location.

Pinus ponderosa/Festuca arizonica association

The major climax forest community that develops on alluvial flats and lower slopes is dominated by a canopy of Pinus ponderosa. Festuca arizonica, Muhlenbergia montana, and Carex spp. are the most constant graminoids associated with this community. Koeleria cristata was present on 50 percent of the stands sampled. The only forb occurring with high constancy is Geranium parryi, although Mertensia lanceolata, Penstemon virens, Potentilla pensylvanica, Anemone patens, and Senecio fendleri may be present. Shrubs play a minor role in this community. Arctostaphylos uva-ursi, Juniperus communis, and Rosa sp. are the three shrubs most likely to be found.

In general, this association is characterized by very low total plant canopy coverage in the understory. Everywhere, the litter cover (pine needles) is nearly complete.

Reproduction of Pinus ponderosa in stands with a closed overstory is essentially non-existent. The characteristic episodic regeneration in open spaces within stands is found here. These open spaces are grass-dominated stands within a matrix of pine forest. Herbaceous production is dramatically increased in these open areas, and establishment of pine regeneration is slow. Pinus ponderosa individuals approximately 4 decimeters in height found in these areas may be 15 or more years old.

Pinus ponderosa/Cercocarpus montanus--Rhus trilobata association

A second well defined community dominated by Pinus ponderosa is found on the gently sloping sedimentary formations and valley sides at elevations higher than the Pinus ponderosa/Festuca arizonica association. This community is characterized by a shrub union consisting of Cercocarpus montanus and Rhus trilobata in varying proportions. These two species appear to occupy equivalent positions in the community; either species may be present without the other. In the eight stands sampled that represent this community, combined canopy coverage of the two shrubs ranged from 2 percent to 30 percent.

Important graminoids included in this community are Agropyron albicans, Andropogon scoparius, Carex sp., and Muhlenbergia montana. Bouteloua curtipendula was found on three plots. Festuca arizonica, an important component of the preceding communities, was found on only two of the Pinus ponderosa/Cercocarpus montanus--Rhus trilobata plots. The forb Hymenoxys acaulis was present in all eight stands: Lithospermum multiflorum in six; and Cryptantha thyrsiflora and Mertensia lanceolata each in four.

In some parts of the study area, the Pinus ponderosa density has been considerably reduced in these stands. This change may be brought about by logging, fire, insect infestation, or other, natural causes. Currently, the change is being affected in many stands by action of the mountain pine beetle (Dendroctonus ponderosae). Where the tree canopy is thinned, the shrub density increases, as, for example, in stand number 3. Ultimately, the forest canopy may be eliminated entirely; the result is a long-lived, relatively dense, shrub-dominated stand.

Cercocarpus montanus/Muhlenbergia montana association

Stands representing this community lack a tree overstory. The community occurs on generally south facing valley sides. The sites that were sampled, however, are not apparently different from adjacent sites that do support Pinus ponderosa. The continued absence of trees on the Cercocarpus montanus/Muhlenbergia montana sites appears to be the result of competition and periodic removal of the tree species.

The dominant feature of these stands is a tall shrub union of Cercocarpus montanus and, in some cases, Rhus trilobata. The small shrubs, Artemesia frigida and Yucca glauca are significant components in some of these stands. Ribes cereum is also occasionally present.

Muhlenbergia montana, Bouteloua gracilis, Stipa scribneri, and Carex sp. are the most constant graminoids representative of this community. Scutellaria brittonii is the only characteristic forb.

Lack of a forest canopy results in a low total canopy coverage. Therefore, stands of this association are characterized by generally less litter cover than the previously described communities. Exposed soil is correspondingly higher, ranging from 7 percent to 58 percent of the total surface area.

Pinus ponderosa--Pseudotsuga menziesii/Muhlenbergia montana association

Large areas of the study area support an open forest community in which neither Pinus ponderosa nor Pseudotsuga menziesii clearly expresses dominance. Either species appears able to reproduce in the open community, although both do so rather poorly. This community might be considered ecotonal between the Pseudotsuga menziesii communities of more mesic sites and higher elevations and the Pinus ponderosa communities of lower elevation areas. However, the Pinus ponderosa--Pseudotsuga menziesii/Muhlenbergia montana community is so well expressed over a large area that it seems to warrant recognition as a distinct plant association. This community is found on moderate to very steep southerly slopes at elevations higher than the previous Pinus ponderosa communities.

Several shrubs are rather characteristic of this community; these include Artemesia frigida, Cercocarpus montanus, and Ribes cereum. Yucca glauca was found on half of the plots. Carex spp. and Muhlenbergia montana are the most constant graminoids. Festuca arizonica occurred on 67 percent of the stands sampled. The most representative forbs are Allium cernuum, Geranium parryi, Penstemon virens, Potentilla pensylvanica, Sedum stenopetalum, Senecio fendleri, and Smilacina stellata. A complete ground cover of litter was not found in any of the stands. Exposed "soil" (a surface layer of gruss) ranged from 9 percent to 54 percent of the ground surface area.

Pseudotsuga menziesii/Clematis pseudoalpina association

In stands representing this community, Pseudotsuga menziesii is clearly the climax dominant. Two seral species, Pinus ponderosa and Populus tremuloides, are often present in these stands. In addition, Pinus contorta, Pinus flexilis, and Picea engelmannii occasionally occur within this community. Ground cover--a combination of litter, lichens, and mosses--is nearly complete in the stands representing this community. This community occurs on north facing slopes at low elevations and on all exposures except south slopes at higher elevations.

The characteristic understory vegetation of the Pseudotsuga menziesii/Clematis pseudoalpina community comprises a group of forbs that may be present in varying combinations. Important species in this Clematis union are Clematis pseudoalpina, Fragaria americana, Fragaria ovalis, Saxifraga bronchialis, Senecio werneriaefolius, *Thalictrum fendleri* and *Valeriana edulis*. *Carex* spp. and *Calamagrostis purpurascens* are the only graminoids that are regularly associated with this association.

Rosa sp. and *Juniperus communis* are the two shrubs that occurred with high constancy. Other shrubs that were found in some sample stands are *Arctostaphylos uva-ursi*, *Physocarpus monogynus*, *Ribes cereum*, and *Symphoricarpos albus*.

Pseudotsuga menziesii/Jamesia americana association

This is the only other plant community in the study area in which *Pseudotsuga menziesii* is the climax overstory. It is similar in general appearance to the *Pseudotsuga menziesii/Clematis pseudoalpina* association; the understory consists of species of the *Clematis* union discussed above. The differentiating feature is the characteristic presence of the shrub *Jamesia americana*. This species may occur sparingly, or it may have a canopy coverage of up to 25 percent. In some areas, the two *Pseudotsuga menziesii* associations are difficult to discriminate. However, the *Pseudotsuga menziesii/Jamesia americana* association generally occurs on steeper slopes with numerous rock outcrops.

Picea engelmannii communities

Picea engelmannii and *Picea pungens* are found in the study area mainly in narrow stands along streams and some lower valley slopes. Only two stands were sampled in which the present forest canopy is dominated solely by *Picea engelmannii*. These two stands differ considerably from each other in their understory vegetation.

One stand has a very depauperate understory, with the exception of lichens and mosses. This appears to be somewhat similar to the Abies lasiocarpa/Carex geyeri community in southern Wyoming (Wirsing and Alexander 1975) and corresponds with the Picea engelmannii/Moss community in Arizona and New Mexico (Moir and Ludwig 1979).

The other stand has a rather rich understory dominated by the small shrub, Vaccinium myrtillus. A variety of other shrubs are present including Juniperus communis, Rosa sp., and Lonicera involucrata. Forbs include Dodecatheon pulchellum, Epilobium angustifolium, Fragaria spp., Galium boreale, Geranium richardsonii, Pyrola chlorantha, and Valeriana edulis. This stand is very similar in general appearance to the Abies lasiocarpa/Vaccinium scoparium (Wirsing and Alexander 1975, Pfister et al. 1977, Moir and Ludwig 1979, Daubenmire and Daubenmire 1968) and Picea engelmannii/Vaccinium scoparium (Hoffman and Alexander 1976) communities throughout the Rocky Mountains. It is likely that Vaccinium myrtillus and Vaccinium scoparium are ecologically equivalent species, so this stand actually represents the Picea engelmannii/Vaccinium scoparium association.

A feature characterized by the stands discussed above is the complete absence of Abies lasiocarpa from the study area flora. This may be attributed either to lack of a seed source or to the fact that conditions amenable to the growth of Abies lasiocarpa simply do not occur in the area studied. Indeed, it is only in the very cool, moist valley bottoms or some north sloping hillsides that favorable conditions are found for the growth of Picea engelmannii. In a few isolated sites within the study area, conditions seem to just barely become favorable for the development of typical "subalpine" plant communities.

Two other sample plots warrant discussion in this section. These two stands were located on ecotones between the respective upland *Pseudotsuga menziesii* communities and valley bottom *Picea* communities. Overstories in these stands were mixtures of *Pseudotsuga menziesii*, *Picea engelmannii*, and *Picea pungens*. These stands were most similar to the other *Picea engelmannii* stands.

Pinus contorta communities

Nine stands were examined in detail that had *Pinus contorta* overstories and that exhibited no trend to develop into stands dominated by any other species. The only other tree consistently found was *Populus tremuloides*. *Pinus contorta* was the only successfully reproducing tree species in the areas where these sample stands were located.

Throughout much of its range, *Pinus contorta* is a seral species. However, in the Front Range of the Rocky Mountains in Colorado (Moir 1969) and north into Wyoming and Montana (Hoffman and Alexander 1976, 1980; Pfister et al. 1977), this tree is recognized as a climax dominant in a zone between the montane and subalpine forest zones. It has already been indicated that subalpine conditions are just barely achieved in local areas in the study area. Therefore, it is reasonable to expect much of the upper Rampart Range to be representative of this intermediate forest zone. The stands representing this community were all located in the upper elevations of the study area along the Rampart Range crest.

The Pinus contorta dominated stands can be separated into two groups. The first group is characterized by a very sparse understory of lichens, mosses, and a few herbaceous species. The most conspicious component is often Arctostaphylos uva-ursi, which achieved canopy coverage of up to four percent in the sampled stands. Juniperus communis and Rosa sp. were also present in some stands. This group corresponds with the Pinus contorta/Arctostaphylos uva-ursi association described by Hoffman and Alexander (1976).

The second Pinus contorta group is distinguished by a layer of Vaccinium myrtillus that gives the community its characteristic appearance. Other shrubs found in some of these stands are Arctostaphylos uva-ursi, Juniperus communis, and Rosa sp. This community is probably ecologically equivalent to the Pinus contorta/Vaccinium scoparium association of Wirsing and Alexander (1975), Hoffman and Alexander (1976), and Pfister et al. (1977).

Populus tremuloides communities

In the study area, Populus tremuloides stands generally are found in rather specialized mesic habitats that are quite small in area. Although they are small, these stands occur quite frequently, scattered along the Rampart Range and in the areas to the west of the core study area. Eight stands were examined that were dominated by Populus tremuloides and did not show strong evidence of succession to some other vegetation.

The initial cluster analysis showed the Populus tremuloides group to be the most heterogeneous of all the forest communities studied. The small sample size thus does not permit the recognition of well defined plant communities at the association level.

Collectively, the Populus tremuloides stands are characterized by dense understories of a rich mixture of species. The most common shrubs are Arctostaphylos uva-ursi, Juniperus communis, Potentilla fruticosa, and Rosa spp. Among the graminoids, Agropyron albicans, Bromus ciliatus, and Carex spp. are the most consistently represented. Considerable diversity exists in the forbs that were found.

One Populus tremuloides stand showed a unique appearance due to a layer of Calamagrostis canadensis that dominated the understory. This species, found in only four other sample stands, was estimated to have a 40 percent canopy coverage. No other examples of this distinct community were found in the study area, so it was not named as an association.

Another stand may be distinguished from the others on the basis of a significant component of Lonicera involucrata. This stand and the Populus/Calamagrostis stand share several common vegetation features not found in the other Populus stands. These include the presence of Lonicera involucrata, Salix sp., Dodecatheon pulchellum, and Ligusticum porteri, and a relatively high Geranium richardsonii cover. The proportions of Lonicera and Calamagrostis, however, differentiate the stands. These two stands do not appear to correspond to any Populus tremuloides communities described by other authors.

Potentilla fruticosa/Festuca thurberi association

Three isolated examples of a very distinct shrub community were sampled. No other representative stands of this community were found in the study area. The stands were located in level, but narrow, valley bottoms without surface drainage channels.

This community is distinguished by its high canopy coverage of Potentilla fruticosa and Festuca thurberi. This tall grass, found nowhere else in the study area, is the major herbaceous component of the community. A high total graminoid cover also includes Agropyron albicans, Bromus anomalus, Carex sp., Danthonia parryi, and Koeleria cristata. Several forbs were found with 100 percent constancy. Of these, Potentilla gracilis is most significant in discriminating the Potentilla fruticosa/Festuca thurberi association from all other communities.

Comparison of the Classifications

The major plant communities defined at the association level identify the habitat types (Daubenmire 1968) of the study area. The resulting habitat type classification represents one kind of ecologic classification of land units that is based mainly on vegetation characteristics. To examine the second hypothesis concerning similarity of independent classifications, the habitat type classification was compared with a classification derived strictly from physical environment variables including elevation, aspect, slope, position on slope (cf. p. 37), and soil characteristics (Table 14). The plant communities that could not be defined at the association level were used to represent the series level of habitat type classification, and were included in the comparison.

The results of the physical environment classification are shown in the dendrogram in Figure 10. At the 0.85 similarity level, 11 classes are defined. Descriptions of the classes appear in Figure 11 which also summarizes the aggregation of the land units into more

Table 14.--Soil characteristic codes used in the physical site classification (based on narrative descriptions of soil types by Retzer[1])

Soil Category	Solum depth (cm)		Soil structure	Subsoil permeability	Moisture capacity
	Minimum	Maximum			
Wet meadow	13	61	2	3	3
Recent alluvium	13	46	2	3	2
Intermediate alluvium	41	64	3	2	2
Old alluvium	33	69	4	1	2
Fountain arkose	13	43	1	1	2
Madison limestone	15	30	4	3	3
Sawatch quartzite	10	25	1	1	1
Pikes Peak granite	13	36	2	2	2

[1]Retzer, John L. 1949. Soils and physical conditions of Manitou Experimental Forest. 34 p. Unpublished report on file at Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

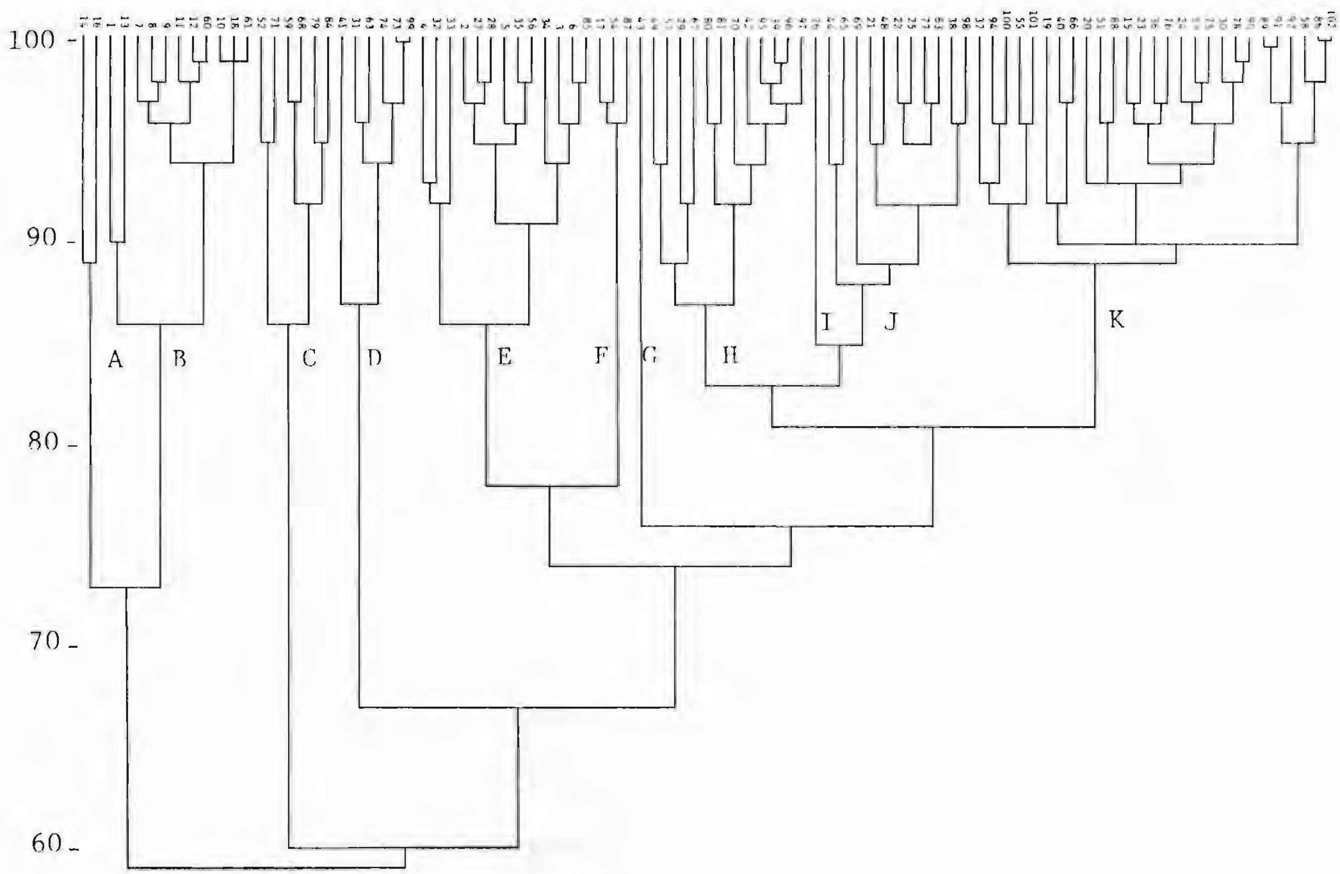

Figure 10.--Dendrogram of the cluster analysis based on physical environment characters. Plot numbers are listed at the top. Similarity level (expressed as percent) is shown at the left.

0.60	0.70	0.80	0.85	Soil	Position	Elevation (m)	Aspect Code	Slope (%)
				- - - - - - - - - - - - - - - - - - Description	- - - - - - - - - - - - - - - - - -			
A´	A´	A	A	Middle alluvium	Valley side	≤ 2440	12-14	25-55
		B	B	Old alluvium	Terrace slope	≤ 2450	5-14	4-14
C	C	C	C	Pikes Peak granite	Valley	2630-2800	4-12	5-17
	D	D	D	Pikes Peak granite	Ridge	2710-2840	6-12	5-21
D´		E	E	Madison limestone	Valley side	≤ 2510	2-12	28-48
		F	F	Madison limestone	Terrace slope	2380-2490	4-5	8-11
	E´	G	G	Pikes Peak granite	Valley side	2340	8	86
			H	Pikes Peak granite	Valley side	2610-2820	8-12	23-60
		H´	I	Fountain arkose	Valley side	2330	10	30
			J	Pikes Peak granite	Valley side	2160-2660	10-12	23-68
			K	Pikes Peak granite	Valley side	2460-2820	2-6	16-70

Figure 11.--A hierarchy of physical environment land classes developed by cluster analysis.

general physical environment classes at lower similarity levels. At the 0.60 similarity level only three broad classes are recognized:

A′ . . . All the middle and old alluvium stands. These are the low elevation, generally low slope areas nearest Trout Creek.

D′ . . . All the Madison limestone stands, the Fountain arkose stand, and all the Pikes Peak granite stands that are not in valley bottoms. This includes most of the broken topography country in the experimental forest and vicinity.

C . . . All the Pikes Peak granite stands in valley bottoms.

The physical environment classification has some similarities with the habitat type classification. However, the two classifications differ in many details. They are compared in Figure 12.

Some of the habitat type/physical environment class pairs show a rather high degree of fidelity. For example, the four grass habitat type stands and seven of the nine *Pinus ponderosa-Festuca arizonica* habitat type stands are associated with physical environment class B--the old alluvium land units.

In general, however, each habitat type is associated with several physical environment classes, and conversely. Among the physical environment classes, H, J, and K are the most diverse. Each is associated with at least six habitat types. This diversity in the sites in the broken topography parts of the study area is further emphasized by the right half of Figure 12, where physical environment class D′ is shown to be associated with nine of the eleven habitat type (or series) classes. Of the habitat types, the *Pseudotsuga*

------ Habitat types ------	------ Physical site classes ------													
	A	B	C	D	E	F	G	H	I	J	K	A'	C	D'
Festuca arizonica/Muhlenbergia montana		4										4		
Pinus ponderosa/F. arizonica		7				1					2	7		3
Cercocarpus montanus/M. montana					4			1		1	4			10
P. ponderosa/C. montanus					6	2								8
Pseudotsuga ponderosa--Pseudotsuga menziesii/M. montana								1		2	11			14
P. menziesii/Clematis pseudoalpina	2			1	2			1	1	5	4	2		14
P. menziesii/Jamesia americana					1		1	2		1	4			9
Pinus contorta series			1	4				3			1		1	8
Pontentilla fruticosa/Festuca thurberi			2										2	
Populus tremuloides series			2	1				1		1			2	3
Picea engelmannii series			1					3		1			1	4

Figure 12.--Cross-tabulation of study plots with respect to the habitat type (vegetation based) classification and the physical environment classification.

menziesii/Clematis pseudoalpina habitat type shows the greatest diversity in terms of associated physical environment land units.

The similarities in the two classifications suggest that the classifications share some common basis. This observation should not be surprising. The habitat type classification relies on vegetation because of the ability of vegetation to reflect the influences of numerous, and often subtle and compensating environmental factors. Thus the vegetation incorporates in the classification such factors as precipitation, drainage, evapotranspiration, temperature, soil moisture, and soil stability. The factors are interpreted indirectly as expressed in plant community structure, and there is no way to know exactly what combination of characteristics will be present in any stand on a given habitat type.

The physical environment classification, on the other hand, is based on direct measurement of specified land features. The specific features used (soils, elevation, aspect, slope, and position on slope) influence the same set of factors that is interpreted indirectly by the vegetation. It is because the same general set of environmental variables is considered in both classifications that the two classifications exhibit some general similarities.

The many specific differences between the classifications result because each classification accounts for the environmental factors in its own unique way. This observation should also not be surprising. Different classification criteria and procedures will always produce a unique classification. As a result of these inherent differences, different classifications will not demonstrate the same capability to summarize specific kinds of management information. This is stated succinctly in the axiom "No land classification will be all things to all people."

The habitat type classification would probably be best suited to summarize information related to vegetation management applications. The physical environment classification might be better for engineering, erosion control, or hydrologic applications. These inherent differences in utility of specific classifications lends some support for a component approach to land classification. Each component represents a unique classification that is suitable for some uses. Across components, classes can be combined (and thus refined) in various ways to meet the needs of specific management problems. This component approach would allow for standardization of classification procedures while allowing considerable flexibility to respond to the needs of unique management situations.

Remote Sensing Identification of Plant Communities

A series of discriminant analyses was performed on digitized, color infrared photographic data for 33 of the original sample stands representing six of the major plant communities (Table 15). The analyses were performed to determine if the plant communities (and thus land areas of different habitat types) could be identified from remote sensing information. The percent accuracy of identifying correct group membership for the individual plots was computed for each analysis. This percent accuracy represents a measure of the ability of selected variables to discriminate among (or identify) the various groups using the digitized photographic data. Results of the analyses are summarized in Table 16.

Table 15.--Plots, plant communities, and variables used in discriminant analysis of plant communities with remote sensing data

		----Spectral means----			---Spectral standard--- deviations			--Physical environment-- variables		
Plot number	Plant community	Infrared	Red	Green	Infrared	Red	Green	Elevation (m)	Aspect code	Slope (%)
1	P. ponderosa/F. arizonica	37.2	29.5	42.6	2.2	3.3	2.4	2390	8	4
9		39.5	38.9	50.5	1.6	2.8	2.0	2350	11	5
10		40.7	37.5	49.6	1.8	3.0	2.0	2350	14	5
11		28.9	25.1	35.5	1.2	1.3	1.1	2440	11	5
13		19.2	13.2	20.5	1.3	1.4	1.4	2400	5	6
2	P. ponderosa/C. montanus	34.7	27.8	42.0	3.3	4.5	2.7	2430	4	30
5		33.3	29.2	42.7	1.8	2.5	1.6	2390	6	35
17		25.7	23.6	33.0	1.4	1.4	1.0	2400	5	8
24	C. montanus/M. montana	42.9	37.4	42.0	3.1	4.2	3.0	2620	5	43
28		43.7	43.0	54.1	6.4	10.6	5.5	2430	5	25
35		33.0	24.4	37.0	1.0	1.8	1.1	2440	5	40
57		52.8	42.7	51.8	5.2	9.5	5.8	2610	8	56
90		31.8	22.7	34.4	4.2	4.7	3.0	2620	5	55
30	P. ponderosa--P. menziesii/	37.0	29.8	37.1	3.7	5.2	3.8	2620	5	60
66	M. montana	39.0	31.4	39.8	3.1	5.2	3.7	2760	5	49
67		38.2	28.4	36.5	3.8	5.1	4.3	2780	11	52
89		22.3	13.2	22.4	2.6	2.0	1.7	2620	2	50
91		26.8	18.2	25.1	3.7	3.8	3.1	2620	2	55
94		20.1	11.4	18.8	1.4	1.6	1.3	2640	4	31
98		39.6	36.0	48.1	2.2	3.1	2.4	2550	10	43
100		19.2	13.3	18.6	2.6	3.0	2.0	2690	4	42
102		15.8	10.1	16.0	1.9	1.7	1.7	2710	2	48
4	P. menziesii/C. pseudoalpina	33.1	22.0	38.1	1.8	2.1	1.4	2400	12	40
14		27.4	17.6	29.8	2.0	2.8	2.0	2420	12	25
25		21.9	14.6	23.6	1.1	1.5	1.2	2510	12	50
26		30.8	24.3	36.3	2.2	2.9	2.2	2330	10	30
32		30.2	20.3	33.9	1.3	1.6	1.8	2430	10	28
41		19.5	11.1	18.3	2.0	2.4	1.7	2840	6	16
51		25.3	16.8	30.1	2.8	4.4	3.1	2460	4	46
78		18.1	11.2	18.0	2.6	2.6	2.1	2630	5	51
15	P. menziesii/J. americana	16.8	10.1	19.2	2.4	1.9	1.9	2540	6	47
19		12.5	7.8	16.0	1.2	.9	1.2	2740	4	70
40		13.3	8.3	15.8	1.6	1.3	1.3	2820	5	53

Table 16.--Summary of discriminant analysis results of identifiability of plant communities using spectral remote sensing data and topographic data

- - - - - - Variables - - - - - -			
Three spectral means	Three spectral standard deviations	Three topographic variables	Identification accuracy (%)
X			55
	X		61
X	X		79
		X	64
X		X	79
X	X	X	97

The results indicate that for the six major groups represented on the image, up to 79 percent of the plots could be correctly identified on the basis of spectral information. In other words, the plant communities were distinguishable by remote sensing spectral information about four-fifths of the time.

Considering additional variables that are correlated with plant communities should help improve the identification accuracy. Terrain slope, elevation, and aspect are site variables that have a definite influence on plant community development and distribution. Furthermore, these variables can be readily measured on stereophotographic imagery or determined from digital elevation data (USDA Forest Service 1976). Slope, elevation, and aspect might, therefore, add useful information for plant community recognition without greatly increasing data collection costs.

Discriminant analysis was again used to test the value of the three terrain variables for distinguishing among the plant communitites. Analyses were made using the slope, elevation, and aspect variables as a set and in combination with the remote sensing spectral variables. Results are summarized in Table 16.

The three terrain variables have discriminating power roughly comparable to the spectral variables. However, the two variables sets in combination show improved ability to distinguish among the plant communities--up to a 97 percent accuracy.

It is instructive to examine some possible reasons for the different identification accuracies. Consider first the identification results using the three mean spectral intensity variables. The classification accuracy was 55 percent. Fifteen plots were classified incorrectly (Table 17). Although no pattern was evident in the confusion among groups, it was evident that the plant communities were not recognizably unique in terms of mean spectral characteristics. In remote sensing jargon, the groups did not have unique signatures.

This result is not surprising, considering the factors that influence the recorded photographic images of the plots. In this case, the important factors are vegetation type, canopy coverage (overstory and understory), substrate type, and orientation to the sun and camera (as determined by slope and aspect). The plant communities showed considerable internal variation with respect to these factors, so highly accurate identification of the plots was not possible using only the mean photographic intensities.

A similar situation was observed for the photographic intensity standard deviation variables, although the identification accuracy was slightly better (61 percent). Variations in tree canopy and shrub densities within plant community groups again precluded accurate identification of the plots.

Thirteen plots were incorrectly identified using the standard deviation variables; six plots were different than those missed when using the mean intensities as discriminating variables (Table 17). This indicates that some of the confusion in identifying plots was caused by different plot features for the two sets of variables. Each set was correlated with different scene characteristics. Therefore, combining the two sets of variables improved identification accuracy (Table 16).

The third variable set (elevation, slope, aspect) showed the best identification accuracy of any single set (Table 16). The

Table 17.--Incorrectly identified plots using various combinations of variables. The numbers are plot identification numbers except in the last line where the numbers represent total numbers of plots

	- - - - - - - - - - - Variables - - - - - - - - -			
Plant community	Three spectral means	Three spectral standard deviations	Three topographic variables	All variables
P. ponderosa/	1			
F. arizonica	13	13		
P. ponderosa/		2		
C. montanus--	17			
R. trilobata				
C. montanus/		24	24	
M. montana	28		28	
	35	35		
			57	
	90		90	
P. ponderosa--	30		30	
P. menziesii/	66			
M. montana	67		67	
	89	89		
		94	94	
	98	98	98	
		100		
	102	102		
P. menziesii/		4		
C. pseudoalpina		25		
	26			
	41	41	41	
	78	78	78	78
P. menziesii/			15	
J. americana				
Number of plots	15	13	12	1

overall accuracy (64 percent) was still rather low, however. Some of the plant communities were relatively homogeneous with respect to topographic characteristics of their plots (Table 15). Others, however, showed much heterogeneity.

As a result 12 plots were incorrectly identified. Only three missed plots were the same as those missed by both of the other variable sets (Table 17), indicating the topographic variables were correlated with different features of the plant communities than were the photographic variables.

Because the three variable sets each accounted for some different aspects of the plant communities (that is, each contributed new information for identification of plots), it was possible to achieve a 97 percent accuracy with the combined variables.

CONCLUSIONS

Hypothesis One

Multivariate analysis techniques proved to be very useful in developing the plant association (habitat type) classification. However, even with the help of multivariate analysis, the classification process was not automatic. The analyst must have a concept of the classification goal, carefully interpret each step of multivariate analysis, and make subjective judgments to help form the structure of the final desired classification.

Cluster analysis helped form hypotheses about group structure inherent in the sample data. Canonical ordination, by displaying relationships among groups and individual sample stands, helped refine and reallign the organization of the groups. Subjective interpretation of tabulations of the grouped data was also useful in refining the groups. Discriminant analysis provided a way to help confirm or refute the hypothesized group structure. Together, the techniques form an iterative process that leads to a well defined classification framework.

There are two significant advantages to a multivariate analytic approach to classification as compared to a strictly subjective approach. First, multivariate analysis may provide insights into the structure of the sample data that otherwise might not be observed. Second, objective analytical techniques help minimize the impacts of personal biases that are not justified by the data.

Hypothesis Two

The habitat type classification (based mainly on vegetation characteristics) and the physical environment classification showed some general similarities. However, the main feature of the comparison is that the two classifications were not highly correlated. The hypothesis of similarity between independent ecologic land classifications was not supported by this study. Rather, it appears that independent classifications may give quite different structures for summarizing land resource information.

This implies that a single land classification probably will not satisfy the classification needs for the variety of management decisions on multiple use wildlands. Therefore, it is important that the intended goal of a classification guide its development. This should ensure the broadest applicability of the classification. Ultimately the utility of any classification will be determined by how well it meets some practical management needs.

Hypothesis Three

Remote sensing imagery was shown to be useful to help efficiently identify habitat type classes. However, identification accuracy using remote sensing data alone was too low to be practically useful. Ancillary data--elevation, slope, and aspect--were required to raise identification accuracy to a useful level. Nearly 100 percent accuracy was achieved using the combined remote sensing spectral data and topographic data. This indicates computer-assisted analysis of remote sensing data can play an important role in increasing the efficiency of implementing a habitat type classification.

Concluding Caveats

Results reported in this study were derived from empirical analysis of a small study area. In a strict sense, the results are applicable only to the local study area. However, the classification methods described should be useful for developing detailed land classifications in a wide variety of locations. The specific classifications are local, but the methodology is not.

The specific results from comparing the classifications and evaluating remote sensing data might have less general applicability. These results depend on the structure of the compared classifications and the specific plant associations used in the study. Therefore, results from the last two parts of this study might best be used to formulate hypotheses that can be empirically tested in other areas.

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APPENDIX

Scientific Names of Plant Species

Abies lasiocarpa (Hook.) Nutt.
Achillea lanulosa Nutt.
Agropyron albicans var. griffithsii (Scribn. & Sm.) Beetle
Allium cernuum Roth
Andropogon scoparius Michx.
Anemone patens L.
Antennaria parvifolia Nutt.
Arctostaphylos uva-ursi (L.) Spreng.
Arenaria fendleri Gray
Artemisia frigida Willd.
Blepharoneuron tricholepis (Torr.) Nash
Bouteloua curtipendula (Michx.) Beauv.
Bouteloua gracilis (H. B. K.) Steud.
Bromus anomalus Rupr.
Bromus ciliatus L.
Calamagrostis canadensis (Michx.) Beauv.
Calamagrostis purpurascens R. Br.
Carex geyeri Boott
Carex sp.
Cercocarpus montanus Raf.
Clematis pseudoalpina (Kuntze) A. Nels.
Cryptantha thyrsiflora (Greene) Pays.
Danthonia parryi Scribn.
Dodecatheon pulchellum (Raf.) Merr.
Epilobium angustifolium L.
Eriogonum alatum Torr.
Festuca arizonica Vasey
Festuca thurberi Vasey
Fragaria americana (Porter) Britt.
Fragaria ovalis (Lehm.) Rydb.
Frasera speciosa Griseb.
Galium boreale L.
Geranium parryi (Engelm.) Heller
Geranium richardsonii Fisch. & Trautv.
Hymenoxys acaulis (Pursh) Parker
Jamesia americana T. & G.
Juniperus communis L.
Koeleria cristata (L.) Pers.
Ligusticum porteri C. & R.
Lithospermum multiflorum Torr.
Lonicera involucrata (Richards) Banks
Mertensia lanceolata (Pursh) A. DC.
Muhlenbergia montana (Nutt.) Hitchc.
Oryzopsis hymenoides (R. & S.) Ricker

Penstemon virens Pennell
Physocarpus monogynus (Torr.) Coult.
Picea engelmannii Parry
Picea pungens Engelm.
Pinus contorta var. latifolia Engelm.
Pinus flexilis James
Pinus ponderosa Laws.
Populus tremuloides Michx.
Potentilla fruticosa L.
Potentilla gracilis Hook.
Potentilla pensylvanica L.
Pseudocymopteris montanus (Gray) C. & R.
Pseudotsuga menziesii var. glauca (Beissn.) Franco
Pyrola chlorantha Swartz
Rhus trilobata Nutt.
Ribes cereum Dougl.
Rosa sp.
Saxifraga bronchialis L.
Scutellaria brittonii Porter
Sedum stenopetalum Pursh
Senecio fendleri Gray
Senecio werneriaefolius Gray
Smilacina stellata (L.) Desf.
Solidago decumbens Greene
Stipa scribneri Vasey
Symphoricarpos albus (L.) Blake
Taraxacum officinale Weber
Thalictrum fendleri Gray
Vaccinium myrtillus L.
Vaccinium scoparium Leiberg
Valeriana edulis Nutt.
Yucca glauca Nutt.