A preliminary classification and characterization of big sagebrush, Artemisia tridentata Nutt., communities in central Montana
by Darrel Wayne Smith

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Range Management
Montana State University

Abstract:
This research was initiated in 1966 to supply basic information about sagebrush rangelands. The purpose of the study was to classify and characterize big sagebrush communities in central Montana.

Fifty-eight study locations were subjectively chosen in Petroleum and Fergus counties. Site, vegetation and soil data were taken at each location. Site data included exposure, slope, and altitude, Vegetational (Frequency) data were collected from 50 nested plots and canopy cover of big sagebrush was estimated in 50 3 by 6 decimeter plots. The soils were described by horizons including name, depth, color, texture, consistence, pH, salinity, and boundary.

Vegetational data were subjected tp three different methods of analyses, These included cluster, ordination and association techniques. Each of these techniques offered important insight into the nature of the vegetation, The cluster method grouped the vegetation into 13 units while the ordination technique displayed the study locations on a two dimensional chart. Tfye association table was used to combine the results of the first two methods into meaningful groups. These groups were related to the site and soil data, The study locations were grouped into six units including one containing two subgroups. These include: Group I (Artemisia/Poa group); Group II (Artemisia/Agropyron smithii/A. dasystachyum group); Group III subgroup a. (Artemisia/Bouteloua/Bromus). subgroup b. (Artemisia/Bouteloua/Carex); Group IV (Artemisia/Koeleria/Bouteloua group); Group V (Artemisia/Stipa/ Koeleria group); and Group VI (Artemisia/Agropyron/Poa group). The vegetation of this area appeared generally to represent a continuum with the exception of Group VI which seemed to be a discrete community.

Geological material and soil texture affected big sagebrush distribution, Big sagebrush was found on heavy soils derived from shales but was generally absent from two sandstone-derived soils.

A PRELIMINARY CLASSIFICATION AND CHARACTERIZATION OF BIG SAGEBRUSH, *ARTEMISIA TRIDENTATA* NUTT., COMMUNITIES IN CENTRAL MONTANA

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Fifty-eight study locations were subjectively chosen in Petroleum and Fergus counties. Site, vegetation and soil data were taken at each location. Site data included exposure, slope, and altitude. Vegetational (Frequency) data were collected from 50 nested plots and canopy cover of big sagebrush was estimated in 50 3 by 6 decimeter plots. The soils were described by horizons including name, depth, color, texture, consistence, pH, salinity, and boundary.

Vegetational data were subjected to three different methods of analyses. These included cluster, ordination and association techniques. Each of these techniques offered important insight into the nature of the vegetation. The cluster method grouped the vegetation into 13 units while the ordination technique displayed the study locations on a two dimensional chart. The association table was used to combine the results of the first two methods into meaningful groups. These groups were related to the site and soil data.

The study locations were grouped into six units including one containing two subgroups. These include: Group I (*Artemisia*/*Poa* group); Group II (*Artemisia*/*Agropyron smithii*/*A. dasystachyum* group); Group III subgroup *a.* (*Artemisia*/*Bouteloua*/*Bromus*), subgroup *b.* (*Artemisia*/*Bouteloua*/*Carex*); Group IV (*Artemisia*/*Koeleria*/*Bouteloua* group); Group V (*Artemisia*/*Stipa*/*Koeleria* group); and Group VI (*Artemisia*/*Agropyron*/*Poa* group). The vegetation of this area appeared generally to represent a continuum with the exception of Group VI which seemed to be a discrete community.

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INTRODUCTION

Big sagebrush (*Artemisia tridentata*) is a shrub of low forage value for livestock. Beetle (1960) described big sagebrush as an erect, gray-green shrub. It is characterized by an aromatic smell and three toothed leaves. Big sagebrush may appear either dwarfed, shrubby or treelike. It occupies a great variety of sites in Montana and other western states. Beetle (1960) estimated 18 million acres of rangeland in Montana support big sagebrush communities.

Several methods for reducing sagebrush cover are used to increase forage productivity from heavily infested range. The economic feasibility of sagebrush control, however, often depends on rates of reinvasion and the responses of associated vegetation. Also, many ecological implications of sagebrush control such as effect on wildlife, soil stabilization, and watershed relationships need to be understood before vast sagebrush acreages are controlled. Study of these factors produced a need for basic research into the nature of sagebrush communities.

This study was initiated to classify and characterize big sagebrush communities in central Montana in an attempt to provide a basic understanding of these communities for further research work and the development of management practices. 1/

1/ This research was supported under Montana Research Station Project M.S. 132 and contributes to regional Project W-89.

REVIEW OF LITERATURE

INTRODUCTION:

The classification of vegetation should logically precede the study of vegetation-soil relationships (Smith, 1966). The necessity for designating of broad vegetation associations has been recognized and used for many years (Stoddart and Smith, 1955). As management and the study of vegetation-environment interaction becomes more specific, the need for more precise classification methods develops (Poulton and Tisdale, 1961). This literature review will be confined to (1) a brief report of two approaches commonly used in classification studies and (2) some environmental factors which may be relevant to the vegetation involved in this study.

APPROACHES TO STUDY:

Community Approach. Clements (1916) introduced the concept of the existence of discrete plant communities and the succession of vegetation toward a "climax" governed by climate. Tansley (1920) modified the "monoclimax" theory of Clements by introducing edaphic, topographic, biotic and other climax concepts, resulting in the "polyclimax" theory. This basic idea of plant communities has been very influential in forest and range ecology and has developed into the use of the "range site" and "habitat-type" concepts (Smith, 1966).

Passey and Hugie (1962a.) described a range site as a "kind of rangeland" with a given potential for producing native plants and having its own combination of environmental conditions, a part of the ultimate expression of which is a distinctive plant community. Poulton and Tisdale (1961) used the concept of the habitat-type and described it as an abstract unit that may be defined as the collective area which is capable of supporting the same relatively homogeneous climax plant association. It denotes a specific ecosystem which is the fundamental unit of the landscape classification and management purposes. They proposed that habitat types would differ not only in their climax vegetation and soils, but also in their seral vegetations which develop as a result of management treatments or disturbances such as grazing, fire, insects, and artificial revegetation. Poulton and Tisdale (1961) and Passey and Hugie (1962a.) advocate the use of a vegetational association table as the first step in the interpretation of community data. These tables enable one to see the degree to which the abstract classification units are distinct or tend to intergrade and represent a continuum. After interpreting the vegetation data the results can be related to other data such as soils data (Poulton and Tisdale, 1961).

Continuum Approach. Gleason (1939) opposed the community concept and advocated an "individualistic concept" of vegetation. This concept often referred to as the "continuum concept" rejects the idea of plant communities as homogeneous units with characteristics that are fixed and repeated wherever the community occurs. This school favors the idea that vegetation changes continuously along environmental gradients according to the requirements and tolerances of the individual members of the population (Whittaker, 1953).

Analysis of vegetation using this concept usually involves the use of gradients in environmental factors, vegetational characteristics, or both (Smith, 1966). Curtis and McIntosh (1951) and Dix (1958) used the continuum concept in vegetation studies. They used the variation of the vegetation itself to order the stands into meaningful groups. Indexes were used to allow an objective, quantitative measure of the similarity between stands. Whittaker (1956) used environmental characteristics for ordination of the stands and used association tables to arrange stands along a gradient. Waring and Major (1964) described two approaches that could be used to analyze environmental characteristics affecting plant growth. One approach was to study factors such as temperature which directly affect plant growth. The other was to measure environmental characteristics such as soil texture which indirectly affect plant growth.

Comparison of the Two Approaches. One difference between these methods of study lies in a basic disagreement about natural vegetation. The extreme community concept postulates that the individuals and species within a community interact to increase each others potential for survival. This concept implies more or less sharply defined boundaries between one community and another. The other extreme holds the view that there are no discontinuities in natural vegetation except where there are discontinuities in the physical environment (Grieg-Smith, 1964). Many authors have taken an intermediate position. Webb (1954) stated that, "The fact is that the pattern of variation shown by the distribution of species among quadrats of the earth's surface chosen at random hovers in a tantalizing manner between the continuous and the discontinuous". Other authors have found vegetation to be in discrete communities in some situations and to form a continuum in others (Hyder, et al., 1966).

In using the community approach relatively undisturbed sites are selected for study. Stratification is required and ecotones and transitions are avoided (Poulton and Tisdale, 1961). This requires that the units of classification be defined to a considerable degree before actual study is begun. The continuum approach would study the relationships among soil and vegetational characteristics along gradients of these characteristics. Study locations would be selected to effectively reflect these gradients whether a given location represents a large uniform area or an ecotone (Smith, 1966).

Smith (1966) concluded that significant differences in philosophy of approach exist, but that the nature and usefulness of the results was less significant than the differences in the underlying philosophies. Grieg-Smith (1964) stated that the reality or otherwise of distinctive units of vegetation in the field remained to some extent an open question, but that this was of little importance in many fields of ecological interest.

SOME FACTORS AFFECTING *ARTEMISIA TRIDENTATA* DISTRIBUTION:

This review is an effort to focus attention on some of the relevant environmental factors affecting big sagebrush distribution. Poulton and Tisdale (1961) stated that, "Methods used must attempt to sample essentially all features of the vegetation and soil since at the outset, it is impossible to predict relevant or limiting factors or to identify correctly all diagnostic characteristics of each habitat-type".

Edaphic Factors. Many authors have reported that big sagebrush prefers deep to moderately deep soils where deep root penetration is possible (Beetle, 1960; Fautin, 1946; and Thatcher, 1959). Soil texture is also an important factor. Patten (1963) described most sagebrush soils in his study area as sandy loams in the surface horizon. Robertson, Nielsen and Bare (1966) found big sagebrush on soils with a sandy loam to loam surface horizon and a sandy clay loam to clay loam subsurface horizon. Houston (1961) observed big sagebrush on the clayey soils and Fautin (1946) found it on all textures but especially on a soils with high water holding capacities. Cook (1961) found that soils supporting sagebrush had significantly lower bulk densities and higher absorption rates than soils associated with desert molly (Kochia vestita). Fautin (1946) found sagebrush communities confined to permeable soils. Thatcher (1959) reported that soil permeability and structure affected big sagebrush size more than distribution, with large plants growing on well structured permeable soils.

Big sagebrush's preference for a low salt content has been reported by Fautin (1946), Gates (1956), and Thatcher (1959). Gates, Stoddart, and Cook (1956) found sagebrush soils varied widely in pH. Smith (1966) stated that most of the studies he reviewed reported a pH from about 6.5 to 7.5 in the surface horizon and 7.5 to 8.5 in the subsurface horizons.

Biotic Factors. Man has had a profound effect on vegetation through the use of grazing livestock. Lommasson (1946) after a 31 year study in Montana concluded that sagebrush was extending its range as a result of heavy grazing. Thatcher (1959) referring to big sagebrush stated that, "Changes in local distribution occur primarily through reduction of competition from herbaceous species through grazing. Local distribution undoubtedly has been affected more than outside limits of total range, but the extent of these modifications could not be determined". After a review of the literature Johnson (1966) stated that there seems to be a general concensus that sagebrush is increasing in both range and density.

Pyric Factors. Man has also altered natural fire patterns. Passey and Hugie (1962b.) cited fire as a factor causing sagebrush fluctuations. Fire is often used as a sagebrush control (Blaisdell, 1953; and Pechanec, Stewart, and Blaisdell, 1954), but Quinnild and Cosby (1958) after ring count studies found that many big sagebrush plants became established following disturbance by fire.

Topographic Factors. Many authors have reported differences in production and composition associated with slope position, slope gradient, and aspect (Thatcher, 1959; Dix, 1958; and Smith, 1966). Dix (1958) further stated that slope will strongly influence vegetational cover and that it is impossible to separate the effects of slope from other factors.

DESCRIPTION OF THE STUDY AREA

LOCATION AND HISTORY:

The area studied is located in central Montana within Petroleum and Fergus counties. This region has been heavily grazed since the early 1880's. During the hot, dry summer of 1886, the range was overstocked and the vegetation was grazed down to its roots by fall (Burlingame, 1942). Since this early history of over-use, the range has been generally exploited up to the present time.

GEOLOGY, TOPOGRAPHY AND SOILS:

The central Montana geology is composed predominantly of Cretaceous sedimentary deposits belonging to the Montana and Colorado groups (Lawlor, 1956). Most of the study locations are on Colorado shale, which is composed primarily of dark gray shale and siltstone with many sandy units included. Soil and vegetation on the Bearpaw shale (a dark gray and brownish clay shale) and the Hell Creek formation (containing sandstone, clay shale and mudstone) were studied. Other locations are on Quaternary alluvium consisting of silt, sand, and gravel valley fills (Ross, Andrews, and Witkind, 1955).

The landscape is of relatively even rolling uplands with creeks and gullies forming a well-developed drainage pattern. The study locations range from 2700 to 3500 feet above sea level with slopes from one to 39 percent.

Wide variations in soil depth, texture, structure, pH and salinity were encountered. Site and soil data for the 58 study locations are presented in Appendix I.

CLIMATE:

Central Montana has a typical Northern Great Plains climate. Four seasons are evident with cold winters, often reaching -30° F, and hot summers, usually approaching 100° F. Extreme climatic variation is characteristic. Forty year records from a station near Flatwillow, Petroleum County, show a record low of -48° F and a high of 108° F (U. S. Department of Commerce, 1965). Most of the average annual 12.6 inches of precipitation comes in the spring and summer. Wind and high temperatures reduce the effectiveness of summer rains. Annual precipitation extremes of 7.0 to 19.5 inches were recorded at the Flatwillow station in 1952 and 1962, respectively. In 1967 the area received almost 3 inches more than the average amount of precipitation (U. S. Department of Commerce, Annually) with a very wet spring and fall and a dry summer. Temperature and precipitation data from the Flatwillow station are presented in Table I.

VEGETATION:

All the study locations were placed in areas where mountain big sagebrush (*Artemisia tridentata* subspecies *vaseyana*) was present. Fringed sagewort (*Artemisia frigida*) is a common half-shrub. The wheatgrasses (*Agropyron* spp.) dominate the herbaceous cover. These include western wheatgrass (*A. smithii*), thickspike wheatgrass (*A. dasystachyum*), and bluebunch wheatgrass (*A. spicatum*). Needleandthread (*Stipa comata*) and green needlegrass (*Stipa viridula*) also are common. Blue grama (*Bouteloua gracilis*), prairie junegrass (*Koeleria cristata*) and Sandberg bluegrass (*Poa secunda*) are ubiquitous understory grasses. Common forbs include American vetch (*Vicia americana*), scarlet globemallow (*Sphaeralcea*

Table I. Precipitation and temperature records from a station 4 miles ENE of Flatwillow, Petroleum County; Elevation 3140 (U.S. Department of Commerce--Weather Bureau, 1965).

Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
					NORMAL TOTAL PRECIPITATION								
1931-1960	.31	.38	.64	.85	1.94	3.17	1.40	1.19	.98	.88	.44	.39	12.57
					MEAN TEMPERATURE								
1931-1960	20.8	23.6	30.9	44.2	54.6	61.9	71.5	69.2	58.9	48.0	34.2	26.7	45.4
					MEAN DAILY MAXIMUM TEMPERATURE								
1915-1960	33.0	36.1	43.8	57.7	68.4	76.1	87.7	85.8	73.6	61.3	46.4	37.4	58.9
					MEAN DAILY MINIMUM TEMPERATURE								
1915-1960	8.2	11.5	19.1	30.2	39.2	47.6	53.8	51.3	42.2	32.5	21.0	12.9	30.8
					HIGHEST TEMPERATURE								
1915-1960	69	76	79	91	98	107	108	108	104	90	81	70	108
					LOWEST TEMPERATURE								
1915-1960	-40	-46	-30	-14	8	30	34	31	8	-18	-29	-48	-48
			MEAN NUMBER OF DAYS WITH TEMPERATURES ≥ 90° or ≤ 32° F										
1951-1960													
≥ 90° F	0	0	0	T	1	2	18	13	4	0	0	0	38
≤ 32° F	30	28	28	19	4	0	0	0	3	16	26	30	184

coccinea), spindle plantain (*Plantago spinulosa*), and prairie pepperweed (*Lepidium densiflorum*). A comprehensive species list is found in Appendix II.

METHODS AND PROCEDURES

FIELD METHODS:

Selection of Study Locations. The central Montana area was selected for study because it represents the eastern edge of big sagebrush distribution. Here big sagebrush is associated with vegetational communities far different from those occurring to the west and south. It was felt that an understanding of these communities would help complete the knowledge of the total environment supporting big sagebrush.

Within this grass area 58 study locations were selected (Figure 1). These locations were subjectively chosen to represent the apparent variation in sagebrush rangeland.

Several criteria were used in choosing these areas. The presence of big sagebrush on public land was a prerequisite. Locations were chosen to represent the greatest possible range in density and cover of big sagebrush, associated vegetation, topography, geologic material, and soils. A visual reconnaissance was conducted to find all the various combinations of these factors. Many apparently similar sites were sampled so that the accuracy of field observations could be checked later by more detailed data analyses.

Recording Study Locations. After selecting a study location its position was indicated on large scale (1:63,360) maps. Each location was recorded using bearings and distances from prominent landmarks. Four to seven landmarks were used for most locations. A steel post was driven in the ground and used as a landmark if natural reference points were not adequate. Posts were placed 60-70 yards from the study locations to minimize the effects of attracted livestock. The center of each location was

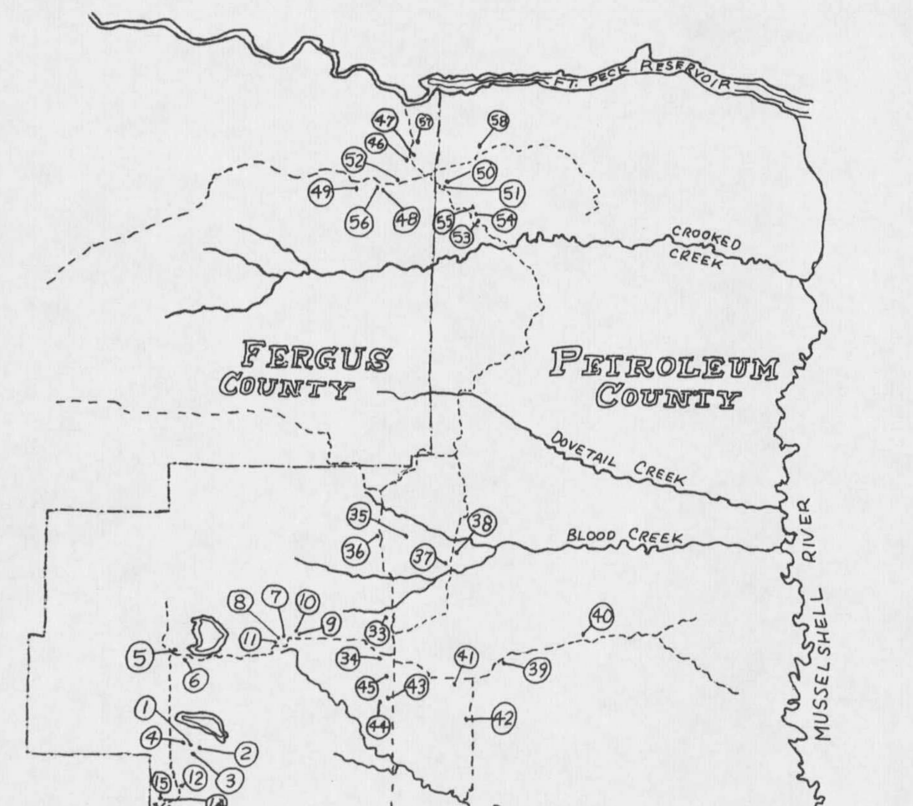

Figure 1. Map of central Montana showing the 58 study locations.

marked with a concrete stake. The stakes are 18 inches long and 4 inches square at the top with a wider bottom. They were buried about 14 inches deep.

Transect Placement. A compass and steel metric tape were used to determine the position of each transect. The compass was placed in the center of the study location and the transects were distributed along predetermined bearings from this position. The beginning and end of each transect were 3.16 and 10 meters, respectively, from the center (Figure 2).

Ten transects were used in the beginning of the study, one every 36°, starting from magnetic north. A study of the results from the first four study locations indicated that the site was being sampled more intensely than necessary. Five of the transects were discontinued by eliminating every other transect starting with the one bearing N 36° E.

Construction and Placement of Plots. A nested plot was used consisting of four different size subplots (Figure 3). The plot was a 3 by 6 decimeter rectangle. This frame had a handle on one 3 decimeter side for ease of handling. The opposite side was open so that it could be slipped under brushy species. Within this frame a 3 by 3 decimeter subplot was formed by a removable crosspiece. Outside this subplot a 1 by 1 decimeter subplot was delineated by a 1 decimeter prong. This further contained a one-half by one-half decimeter subplot formed by a one-half decimeter prong (Figure 3).

The data from the first four study locations indicated that the smallest subplot was too small for the purposes of this study and its use was discontinued.

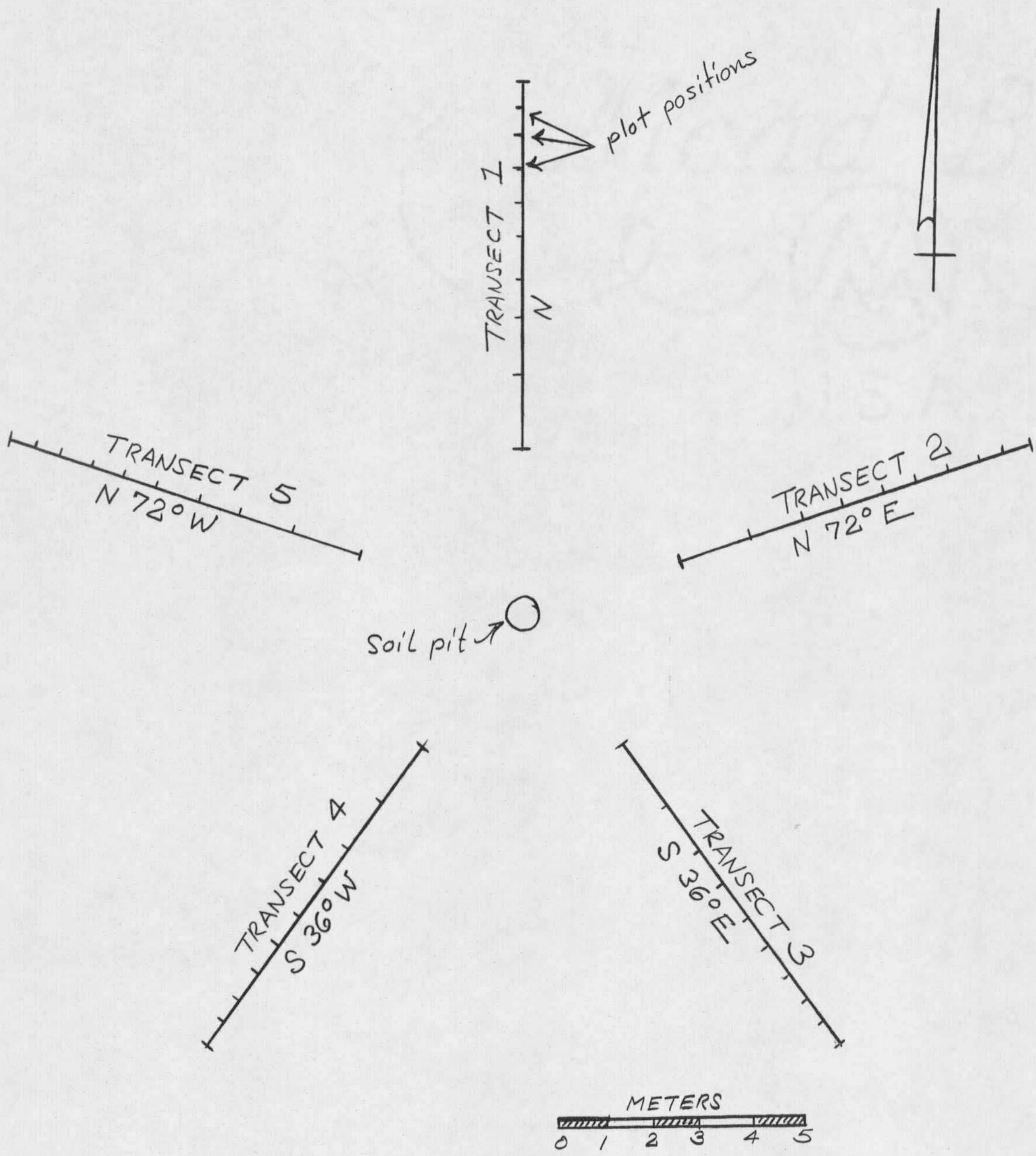

Figure 2. Diagram of study locations indicating positions of transects, plots, and soil pit.

The nested plot was placed at diminishing intervals along the transects using a formula developed by Van Dyne (1960):

$$ri=\sqrt{\frac{r_m2-r_o2}{10}+(r_i-1)2}$$

where r_i = the radius of one of 10 subdivisions

r_m = the maximum sampling area radius

r_o = the minimum sampling area radius

r_i-1 = the radius of the next smaller subdivision

The maximum radius used was 10 meters while the minimum radius was zero meters. Using the formula, plots were placed at 3.16, 4.47, 5.48, 6.32, 7.11, 7.75, 8.37, 8.94, 9.49, and 10.00 meters from the center stake along each transect. The 3 decimeter side of the plot frame lay parallel to the transect. Ten plots along five transects resulted in 50 observations per study location.

Collection of Data. Site vegetation and soil exposure, slope, and altitude were recorded at each location. Each area was visually checked for a history of fire or cultivation. The amounts of erosion and grazing also were visually estimated. The immediate topographic features were briefly described in relation to the study location.

Presence or absence data were taken in each subplot and converted to percent frequency data. Canopy cover of big sagebrush was estimated in the 3 by 6 decimeter plot. A species was regarded present in the plot frame if it were rooted in the frame (except for lichen, for which foliar cover constituted presence). All species that were not identified in the field were collected and submitted to Dr. W. E. Booth, Curator of the Montana State University Herbarium for identification.

After recording the site data and placing the transects, a soil pit approximately 2 feet deep and 2 feet in diameter was dug (Figure 4). The soil was described by horizons including name; depth; color - wet and dry; texture; structure; consistence - dry, moist, and wet; pH; electroconductivity; and boundary (Soil Survey Staff, 1951). Soil samples of each horizon were collected and the pH and electroconductivity were determined in the laboratory. Some samples were checked for texture in the laboratory by mechanical analysis. The results indicated the field estimates were similar to laboratory results although the amount of silt was often underestimated. On some sites a soil probe was used to examine for parent material to a depth of 5 feet.

Black and white and color photographs were made of each location showing vegetation, soil, and general aspect.

METHODS OF ANALYSIS:

Introduction. The data collected were coded and punched on cards for computer analyses. Many of the necessary calculations for the anslyses were made by the computer. Data coding and computer programs used in these analyses are on file at the Montana State University Computing Center.

These data were subjected to three methods of analysis. These were clustering, ordination, and association techniques.

Clustering. The clustering technique was developed and used by Gengerelli (1963). It has been modified and adapted to range research

Figure 3. The nested plot with the cross piece removed. Note the position of the plot along the transect.

Figure 4. A soil pit.

work by Pyott (1967) and used by Zamora (1968). In many respects this is the simplest of the three techniques used. Presence and absence data from each possible pair of study locations is compared. A matrix is formed based on the number of species occurring on only one member of each pair. The numbers in this matrix are graphed and a cutoff number is chosen. Any two study locations having less than or equal this number in the matrix are considered to be "neighbors". Two locations having a number in the matrix larger than this critical number are considered "strangers". Study locations are systematically grouped into clusters of mutual neighborly sites.

This method was used to assign the 58 study locations to 13 groups.

Ordination. The ordination technique is a more sophisticated method explained and used by Bray and Curtis (1957). Beal (1960) used this same technique and simplified some of the necessary calculations. A wide range of quantitative data or several types of data may be combined into one importance value and compared. Data from each study location are compared with data from every other study location using the formula:

$$C = \frac{2w}{a + b}$$

where: $\underline{a}$ is the sum of the quantitative values of all species in one study location

$\underline{b}$ is the sum of the quantitative values in another study location, and

$\underline{w}$ is the sum of the quantitative values that the two study locations have in common for each species.

The index of Similarity "C" is subtracted from unity to give an Index of Dissimilarity. Two study locations that are very dissimilar are chosen as the end points of an axis. The remaining study locations are arranged along this axis on the basis of their dissimilarity to the two locations chosen as end points. Two other end points may be chosen and the study locations arranged along another axis. The resulting two-dimensional figure may be expanded into a third dimension by repeating this process. In this research frequency data were used. The study locations were ordered along two axes (Figure 6).

Association Technique. The association table was briefly described and used by Poulton and Tisdale (1961). It is the most subjective of the three methods employed. Either presence and absence or quantitative data may be used. The study locations are placed along one axis of the table with the plant species encountered in the research listed on the other. The study locations and plant species are rearranged in the table until patterns are evident. Gradual species change across the table may represent a vegetational continuum in the field. If a group of species are present only in certain study locations, however, a discrete community may be indicated. In this research presence and absence data were used in the first analysis with frequency data being used later to refine the results. The study locations and plant species encountered in this research are presented in Table II.

RESULTS AND DISCUSSION

TAXONOMY OF BIG SAGEBRUSH:

In a phytosociological study the correct taxonomy of individual species is essential to an understanding of the community. Thatcher (1959) recognized that an ecological study of sagebrush and its distribution will lead to a problem with the complexity in the taxonomy of the genus *Artemisia*. Beetle (1960) recognized many intermediates and hybrids in this genus. He reported that many characteristics which serve to differentiate the species were either difficult to describe or failed to show satisfactorily on herbarium specimens. These difficulties give rise to continued controversy about the taxonomy within this genus.

The big sagebrush in this region has been referred to mountain big sagebrush (*Artemisia tridentata* subsp. *vaseyana*) by Beetle (1960). Young (1965) using chromatographic techniques described a new subspecies of big sagebrush called Wyoming big sagebrush (*Artemisia tridentata* subsp. *Wyomingensis*). This subspecies is intermediate between the two previously recognized subspecies of this species. This discovery has renewed speculation about the taxonomy of big sagebrush in the study area. Chromatographic samples from the area have been analyzed without conclusive results.

While further study may clarify the subspecies present in the study area, the work by Beetle (1960) referring this material to mountain big sagebrush (*Artemisia tridentata* subsp. *vaseyana*) will be accepted in this thesis.

DISTRIBUTION OF BIG SAGEBRUSH:

Introduction. During the early reconnaissance and data collection phases of this research many observations about the study area were made. These observations suggested the importance of geological substrates and the effects of disturbance on the distribution of big sagebrush in the area.

Effect of Geological Material. Differences in big sagebrush presence and distribution were observed on various geological substrates in the study area (Figure 5). These are discussed below by parent material types.

Bearpaw Shale - The Bearpaw shale was described by Ross et al. (1955) as a "dark-gray and brownish clay shale having thick units of nonfissile bentonitic shale with calcareous and ferruginous concretions throughout". The big sagebrush present appeared more uniform in size and distribution, and denser than on any other geological substrates in the study area. Only occasional openings were free from big sagebrush cover. These openings ranged from several square yards to many acres. A greasewood (*Sarcobatus vermiculatus*) - big sagebrush mixture was prominent near the Missouri River breaks.

Clagget Formation - This formation was described (Ross, et al., 1955) as "Chiefly dark-gray shale with iron stained concretions. Sandstone was locally present with numerous bentonite beds near the base". The Clagget formation was very similar to the Bearpaw shale in the general appearance that the vegetation assumes.

Colorado Shale - The Colorado shale is a "dark-gray shale with many concretions and sandy units". This shale group includes equivalents of at least nine other formation (Ross et al., 1955). The big sagebrush on this geological material formed irregular patterns. These patterns varied from

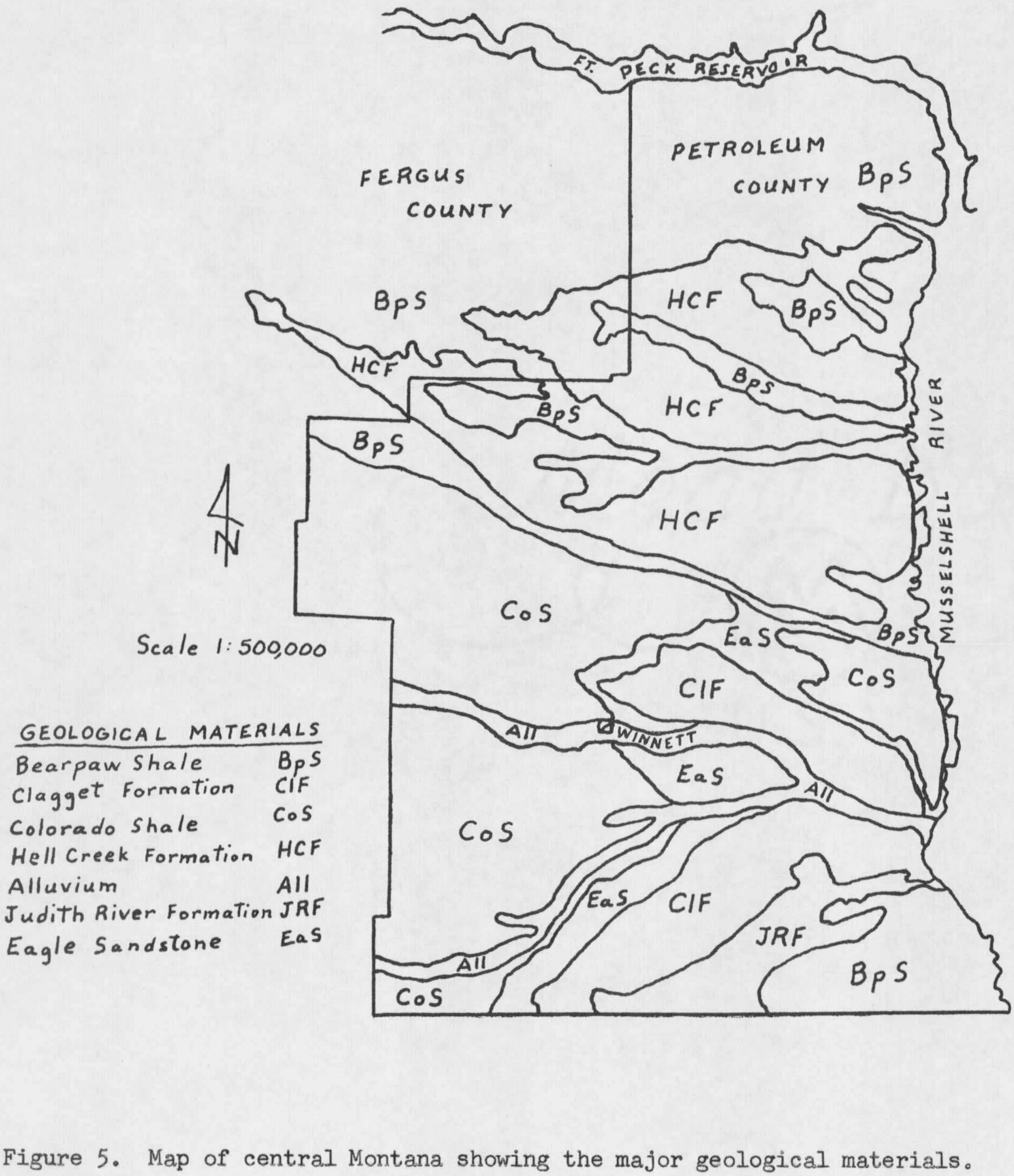

Figure 5. Map of central Montana showing the major geological materials.

large dense stands to openings largely devoid of big sagebrush.

Hell Creek Formation - This formation is a somber-gray sandstone with greenish shaly clay and mudstone also present (Ross _et al_., 1955). It mainly supported a grassland with ponderosa pine (_Pinus ponderosa_) along ridges and coulees. Silver sagebrush (_Artemisia cana_) was more common than big sagebrush on this material.

Alluvium - Many valleys in the study area contained alluvium valley fills consisting of silt, sand and gravel with some terrace deposits and glacial drift (Ross _et al_., 1955). The vegetation on this material varied considerably and had a greasewood-silver sagebrush aspect[1] or a greasewood-big sagebrush aspect. These two types occasionally were mixed. Sometimes a grassland aspect was observed.

Judith River Formation - This formation is a light colored sandstone with somber-gray siltstone and sandy shale members. It contains some greenish gray clay and lignite beds (Ross _et al_., 1955). Big sagebrush was generally absent, but scattered individuals of silver sagebrush were present on this formation.

Eagle Sandstone - The Eagle sandstone is a sandstone and shaly sandstone containing some lignite beds (Ross _et al_., 1955). No big sagebrush was observed on this geological material.

The above observations are broad, subjective generalizations. Some of the differences in sagebrush distribution, as between the Bearpaw shale and the Clagget formation, are small and not very obvious. The vegeta-

1/ In this thesis aspect refers to the general physiognomy of the vegetation.

tional differences between the Bearpaw shale and the Eagle sandstone, however, were pronounced, with big sagebrush almost always present on the Bearpaw shale and almost never present on the Eagle sandstone.

These differences in big sagebrush distribution could be caused by many factors or combinations of factors. The soils derived from the Eagle sandstone may not have a high enough water holding capacity to support big sagebrush growth. Certain elements such as nitrogen or phosphorus could be limiting on the Eagle sandstone soils. Further research into the differences in the soils on these geological materials may isolate the factor or factors involved.

Effect of Disturbance. Sagebrush invasion and increases in density due to disturbance are well documented. This increase and invasion was observed in the research area and was especially noticeable along fence lines. Thatcher (1959) recognized that an ecological study of sagebrush and its distribution would lead to a problem differentiating increase and invasion from normal occurance on various types of sites. He realized that the extent of these modification could not be determined. In the present situation the effects of management and site on big sagebrush distribution could not be separated. This problem complicated and confused data collection and analysis.

CLASSIFICATION OF BIG SAGEBRUSH COMMUNITIES:

Introduction. Three different systems were used to arrange the study locations into meaningful groups. These include cluster, ordination and association techniques. These are synthetic methods based on the relative similarities and differences among study locations.

Results from the Cluster Method. This technique grouped the 58 study locations into the following clusters:

Clusters		Study Locations
A	-	(36, 35, 44, 22)
B	-	(50, 48, 56, 57, 53, 54, 49, 47, 55)
C	-	(1, 27, 31)
D	-	(5, 8)
E	-	(4, 2, 3, 30, 58)
F	-	(38, 24)
G	-	(13, 14, 15, 28, 41)
H	-	(7, 19, 37, 20, 18, 34)
I	-	(11, 16, 52, 46, 9, 51)
J	-	(40, 23)
K	-	(39, 12, 42, 6)
L	-	(17, 32, 10, 45, 26)
M	-	(21, 33, 25, 29, 43)

The clusters are designated by letters only for purposes of presentation. This method does not present any indication of how the study locations are related within an individual cluster. Neither does it indicate the relationships among clusters. The clusters were very useful, however, in interpreting the ordination data and developing the association table.

Results from the Ordination Technique. Figure 6 shows the results of the two-dimensional ordination used in this research. The study locations were arranged on the basis of their dissimilarity to the study locations chosen as end points (locations 18 and 24; 32 and 44).

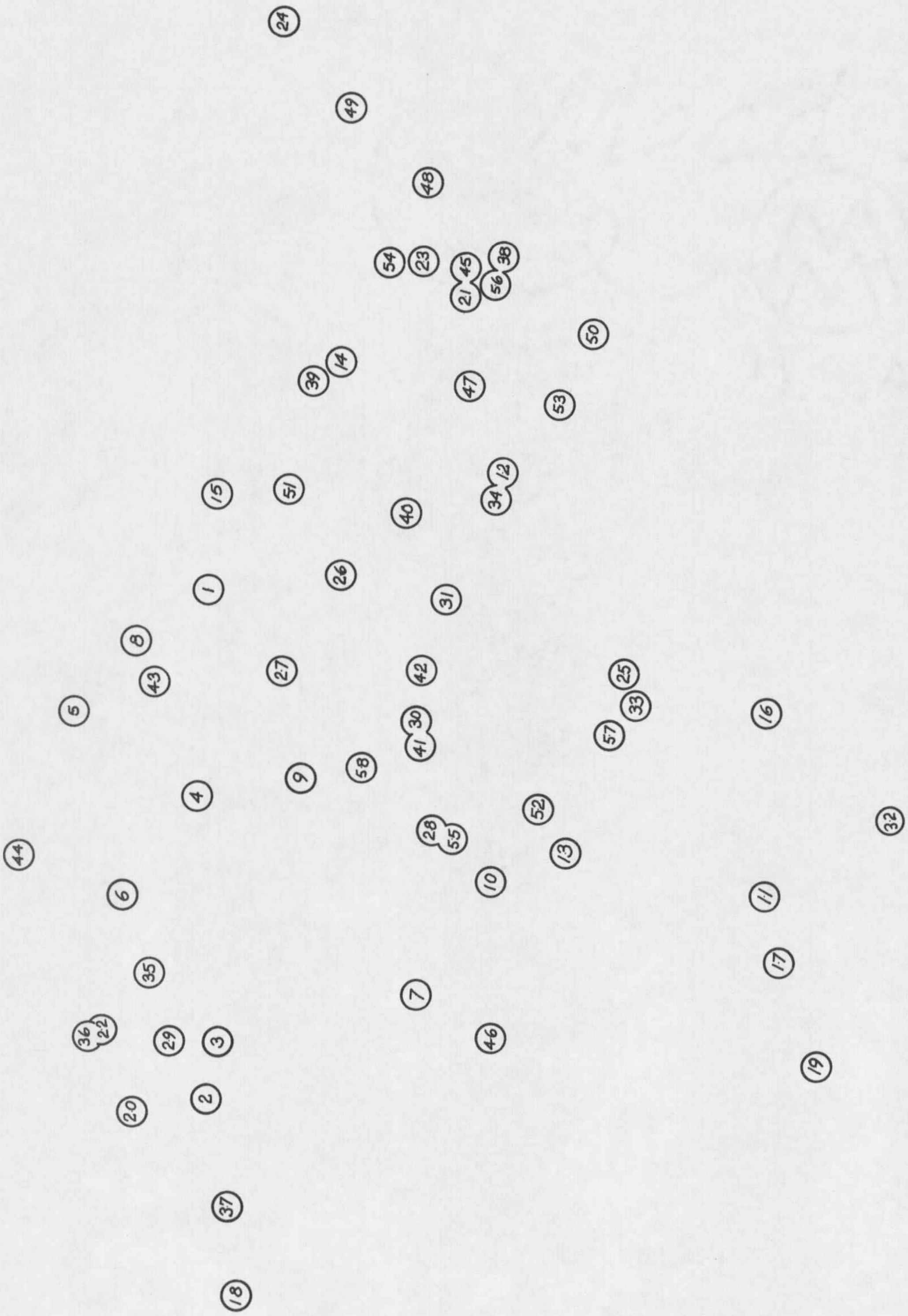

Figure 6. Results of a two-dimensional ordination of the 58 study locations based on frequency data.

Of the three methods used, this technique presented the clearest indication of the similarities among study locations.

Results of the Association Technique. The association table with the 58 study locations[1/] and the plant species encountered at more than one location is presented in Table II. This table is restrictive in the sense that it requires the study locations to be arranged along one axis. It is the only method used, however, that allows quantitative data from each study location to be shown.

Comparison of the Methods. Limitations of data restrict the accuracy of the results of any methods. The cluster method uses presence and absence data. This equalizes the importance of every species in a stand. The ordination technique is designed to use any type of quantitative data. Any combination of data may be used if the data for each species can be combined into one value. The association table can be used with any type of data, but as the numbers of study locations and plant species increases the table becomes unwieldy. The choice of types of data used in these methods is flexible and is an important consideration in this type of study.

Most of the calculations involved in the cluster and ordination methods were completed on the computer. The information gained from these methods was helpful in reducing the time required to construct the association table. This approach allows large masses of data to be compared in a reasonable amount of time.

1/ Locations 59 and 60 are locations 1 and 2, respectively, resampled at the end of the field season.

Table II. Association table showing the 58 study locations and the plant species occurring at more than one study location.

Species	Location 11	52	16	32	51	58	6	42	9	25	33	26	45	41	10	17	15	28	30	13	18	37	20	19	7	3	29	35
Artemisia tridentata vaseyana	24	80	80	10	8	58	44	68	14	70	18	46	38	40	34	10	38	78	26	80	4	32	64	68	40	60	14	42
Agropyron smithii		86	4	46	78	24	4	92	6	52	100	96	86	100	44	80		92	70	38	52	100	92	98	72	90	92	94
Opuntia polycantha	22	48		4	34	44	4	12	8		8	2	14	28	2	4	12	16	12	2	26	24		10	8	18	22	6
Poa secunda	36	38	86	14	88	20	52	38	56	98	76	94	28	82	86	98	76	40	40	50	98	72	38	64		88	72	82
Vicia americana			4		6		8	60	24	78	42	100	84	94	10	2	54	58	52	26			60	22	26	36	48	
Sphaeralcea coccinea								30	2	6	38	6	32	38	26	16		18	8		6	8	12	52	24	14	58	4
Allium textile	4				20		14	8	32	4		4	12	26	44		4	14	12	8					6	28		6
Stipa viridula										72	92	86	32	72		12	22	12		14			14	8	2		4	
Draba nemorosa										6	14	24	14	14			14			10		4			22			
Phlox spp.		6			12	32		34	10		8	22	22	18			18										12	2
Agropyron spicatum					2	54	8					40					86		70	2								
Koeleria cristata		46	8	4	30	12	72	74	60	14		78	80	16	34	2	44	32	22			18	48	8		84	70	86
Lichen	48	68		16	90	82	94	76	88	2	14	70	6	30	22		70	58	86	14	70	52	86	16		92	92	50
Bouteloua gracilis	8	36	4	6	94	82	78		50			2			78		20	12	50		90	56	76	46	36	6	94	48
Lepidium densiflorum		6	2	6	12	18	64	18	36	6		4	4	14	54	42	10	10	2		14		14	2	16	72	4	
Artemisia frigida		32	10	10	32	8	34	26	30		32		16	2	24	16	30	12	38	4		6	16	8	2	62		6
Plantago spinulosa			6	6	76	10	64	38	34	2		4			26		12	26	20	28	82	10	74	52	12	50	70	30
Agropyron dasystachyum	30		14	36			72	10	94	46	24	52	100		88	98	88	64	44	60						10	36	
Stipa comata			2		2	2	22	2					4	2			2	22	42	26		86	44	8	78		60	46
Taraxicum officinale							2	2	2			2	2			56	4	2		50			2	58		20	4	
Camelina microcarpa								2						6	2	42		18	6				8	4				
Bromus japonicus	4		16							4				10	4	50	4	2	2	26	4	8	2	42	14			14
Microseris nutans														2	2	8	2	2		2		2		4	4			
Lappula echinata	6								22					2	6	10	8			18	8	10	4	8		2	2	
Bromus tectorum			2														10	4	2	44	74	4	18	52	70			
Moss				12								8				10		4	18		58	12	82	6	6	80	16	
Carex eleocharis							6	48			58							58		4	24	62	70	12	12	74	78	46
Hedeoma hispida																				20	22	78	28	2	2	14		24
Chenopodium leptophyllum																				38		30	2	2	2			6
Selaginella densa		14			24	22	48														78	74	78	38		74	18	70
Festuca octoflora							48		18									4	4		44	36	30	30	66	36	10	
Erigeron pumilus							2	12			2							20	14			4	4				14	4
Gutierrezia sarothrae			14	10		4	8	14	4	4					16				12				6			2		
Calamagrostis montanensis																									6	4		
Arenaria hookeri							14				8								50									
Antennaria rosea																						6				6		40
Achillea millefolium								10					2			2		2		48				14		18		
Schedonnardus paniculatus		42		4	14	12									38					4								
Petalostemon purpureum																												
Carex filifolia																												4
Chrysothamnus nauseosus																										2		
Erigeron ochroleucus			2																									
Muhlenbergia cuspidata																												
Psoralea argophylla																			2								2	
Tragopogon dubius													2			6							2	4	2	2		
Comandra umbellata													36															
Phacelia linearis																				2								
Melitotus officinalis									14						2	8												
Poa canbyi		10		12		24					54							8	18				46	70				
Collomia linearis											2			2		6				26				2				22
Lomatium foeniculaceus																												
Aster canescens	2								6	16					2													
Atriplex nuttalii		6		4	12				6		4		2		14	2												
Rumex spp.		2						4			18																	2
Sarcobatus vermiculatus	46			4												34					12							
Sitanion hystrix	48		36							6															10			
Sporobolus cryptandrus	20								30						14													
Mamillaria vivipara																						2					4	
Grindelia squarrosa																								2				
Aristida longiseta																												
Potentilla hippiana																				2								
Penstemon nitidus																												
Astragalus gilviflorus																												
Astragalus missouriensis																												
Artemisia cana																58				8								
Plantago elongata				14												42												
Poa pratensis																												
Polygonum ramosissimum																												
Epilobium paniculatum																												
Distichlis stricta				68				42																				
Calochortus nuttallii																									2			
Eriogonum umbellatum																												
Juniperus horizontalis																												
Psoralea tenuiflora																								4				
Spergularia																				2								
Thermopsis rhombifolia																												

Species	Number 60	2	36	4	44	22	8	43	5	27	31	1	59	38	24	14	34	39	21	40	12	23	55	49	50	56	48	54	57	53	47	46
Artemisia tridentata vaseyana	20	22	16	50	48	12	22	56	54	60	34	70	60	72	38	50	82	46	34	24	10	46	22	32	28	58	42	54	76	72	44	42
Agropyron smithii	64	58	54	24	54	98		84	8	66	58	76	72	84		36	90	58	36	94	80	78	100	90	98	96	90	86	56	96	94	100
Opuntia polycantha	4	4	8	8	20	22	42	42	10	8	4	12	8	2	4	10	2	20	18	4	12	18	6	16	2		4	12	30	24	6	32
Poa secunda	22	46	64	62	66	70	68	64	60	70	28	34	22		2	48	14	4	20	4	4	2	66	2		14	12	4	32	2	52	82
Vicia americana					54	36	58	84	70	88	82	64	54	6	18	70	24	54	60		16	20	12	64	30	36	42	38	8	18	36	30
Sphaeralcea coccinea			22		12	20	36	14	6	6	14	18	28	4		6	18	24	64	24	12	34	12	6	4	2	6	26	10	26	12	18
Allium textile	4	16		48	12		4	22	46	8	12	44	10			8	4	2	12				20	2		14		8	18	26	8	8
Stipa viridula						12	68		10	2	22	40	32		42	44	12	46	52	12	68	44	10	28	12	22	52	60	12	44	6	
Draba nemorosa			6		8	6	34	16	6		4					20	2	14	6		16	2	18	14	32	24	4	42	40	6	24	6
Phlox spp.			24		30	28	42	38	38	6	2	44	74	76	52	50			78	14	14	46	2	38	2	56	30					
Agropyron spicatum		2		4	50			40			48	20	46		98	6					14	80	16	86	18		6	68			62	
Koeleria cristata	70	90	70	88	80	60	78	96	92	90	50	86	62	54	80	72	90	86	66	60	4	10	6	64	8	40	36	12			36	
Lichen	98	100	64	86	86	98	40	84	38	90	76	78	70	42	6	64	32	2	12		6	10	36	10		20			6		6	78
Bouteloua gracilis	80	86	88	10	78	86	84	20	56	28	40	10	22	28	22	20	2		24	56	42	56	8	4			30					
Lepidium densiflorum	32	52	10	56	50	22	20	58	78	6	6	54	8				18	12		12	4	4	70			6						20
Artemisia frigida	90	90	30	52	22	24	54		72	2		66	60	2	22	44	12	64		2	4	4		4								
Plantago spinulosa	92	92	64	34	68	72	38	36	32	8	12	66	54			2	6	4	2	4		4		2								
Agropyron dasystachyum	78	44		88	46	10	90	94	88	90	68	8	84		2	84			68		26	10										
Stipa comata		12	90	32	56	38	8		70	6	2	6	4	10			50	98	6	86	52	16										
Taraxicum officinale	2	4		6		2	4		16			2			6	4						2				4						
Camelina microcarpa								6					8						4			2										
Bromus japonicus						2		4									2	2				10										
Microseris nutans			4	8					8	2		2	2				4	4				2					4		2	2		
Lappula echinata					4		8	8													4		2								2	
Bromus tectorum										4												4										
Moss		92	4	28			4		16		4	30							2													
Carex eleocharis	66	68	56	32	36	68	86		50	22					4	4		12	2	2	56	8	2									
Hedeoma hispida	48	44	44		8	18			22								2	2														
Chenopodium leptophyllum	2	6	4	4	2	2		28					4							8												
Selaginella densa	66	84	88	72	66	36			26			2					2															
Festuca octoflora	20	50	38	2	8	26	2	2	20	14		2						22														
Erigeron pumilus	10	4	10		6	20	10	8	14	2	4	4							6					4		6						
Gutierrezia sarothrae	38	44		12			26		4	4	16	26	32	40	6	38	2	2	22					10	4							
Calamagrostis montanensis	10	72	2	72	8				56		24	48	40	28																		
Arenaria hookeri				4						74	48	60	36	2	8				38			2										
Antennaria rosea			14	10	6	2			16			2																				
Achillea millefolium				18	2				2			6	8			6							2	10	4							
Schedonnardus paniculatus	4	6				2				4	6		4	2		4																
Petalostemon purpureum													2	18	38							4										
Carex filifolia			18				10							2	28					76	46	2	2									
Chrysothamnus nauseosus	28	34						8		8		6	6												8	4	2					
Erigeron ochroleucus													2	12		66		2														
Muhlenbergia cuspidata														24	34	62		4		4	8	32					42					
Psoralea argophylla			10											24	28			14			38	40			14		26					
Tragopogon dubius				2			2	4	2				2									8	10	18	12	6	16	4	2	2		
Comandra umbellata													2	24	56									78	84	86	94	38	8	56	42	
Phacelia linearis					44				2														34	66	84	78	84	66	52	76	6	
Melitotus officinalis													2										90	4	28	12	26	26	8	4		
Poa canbyi						10					6						2		2			6	80	34	10	28	14	2	42	14	12	60
Collomia linearis			8						56			22	14			2								12	54	38	14	24	62	48	42	6
Lomatium foeniculaceus							2					28	6										10	12	12	10		14	46	20	40	66
Aster canescens															20	2									4							
Atriplex nuttalii																																
Rumex spp.	6		2																													2
Sarcobatus vermiculatus																																
Sitanion hystrix																																
Sporobolus cryptandrus																																
Mamillaria vivipara					2																											
Grindelia squarrosa	2	6																														
Aristida longiseta			8															6			12											
Potentilla hippiana										6						10																
Penstemon nitidus			10											14				2														
Astragalus gilviflorus														10					2													
Astragalus missouriensis																	2				2											
Artemisia cana																																
Plantago elongata																																
Poa pratensis				2								6																				
Polygonum ramosissimum			10																													
Epilobium paniculatum																																
Distichlis stricta																									28				2			
Calochortus nuttallii																				2												
Eriogonum umbellatum		2													44																	
Juniperus horizontalis				8																						2						
Psoralea tenuiflora																			22													
Spergularia																					4											
Thermopsis rhombifolia																									58		2					

These techniques use different approaches to classification. The cluster method groups study locations on the basis of their mutual dissimilarity. The ordination technique considers both similarities and differences among study locations. The association table is constructed subjectively, also on the basis of similarities and differences among study locations.

The methods have different inherent advantages and weaknesses. Each offers insight into the nature of the vegetation and serves to reinforce or challenge results of the others.

Comparison of Results. The results of the cluster and ordination methods are compared in Figure 7. In Figure 7 the clusters are indicated by the letters (A) through (M). The clusters that are closely grouped by the ordination technique such as (A) and (B) generally fit together in the association table (Table II). When the cluster and ordination techniques give different results, however, the study locations involved usually do not fit well in the association table (Table II). Examples of this are locations 6, 34, 14, 29, 43, and 21).

TENTATIVE GROUPINGS:

Introduction. The study locations were assigned to tentative groupings on the basis of the results from the cluster, ordination and association techniques. The association technique (Table II) was used to make the final adjustments in the groups.

The vegetation of the study area appeared to exhibit characteristics of continua and of discrete plant communities. Based on the data the 58

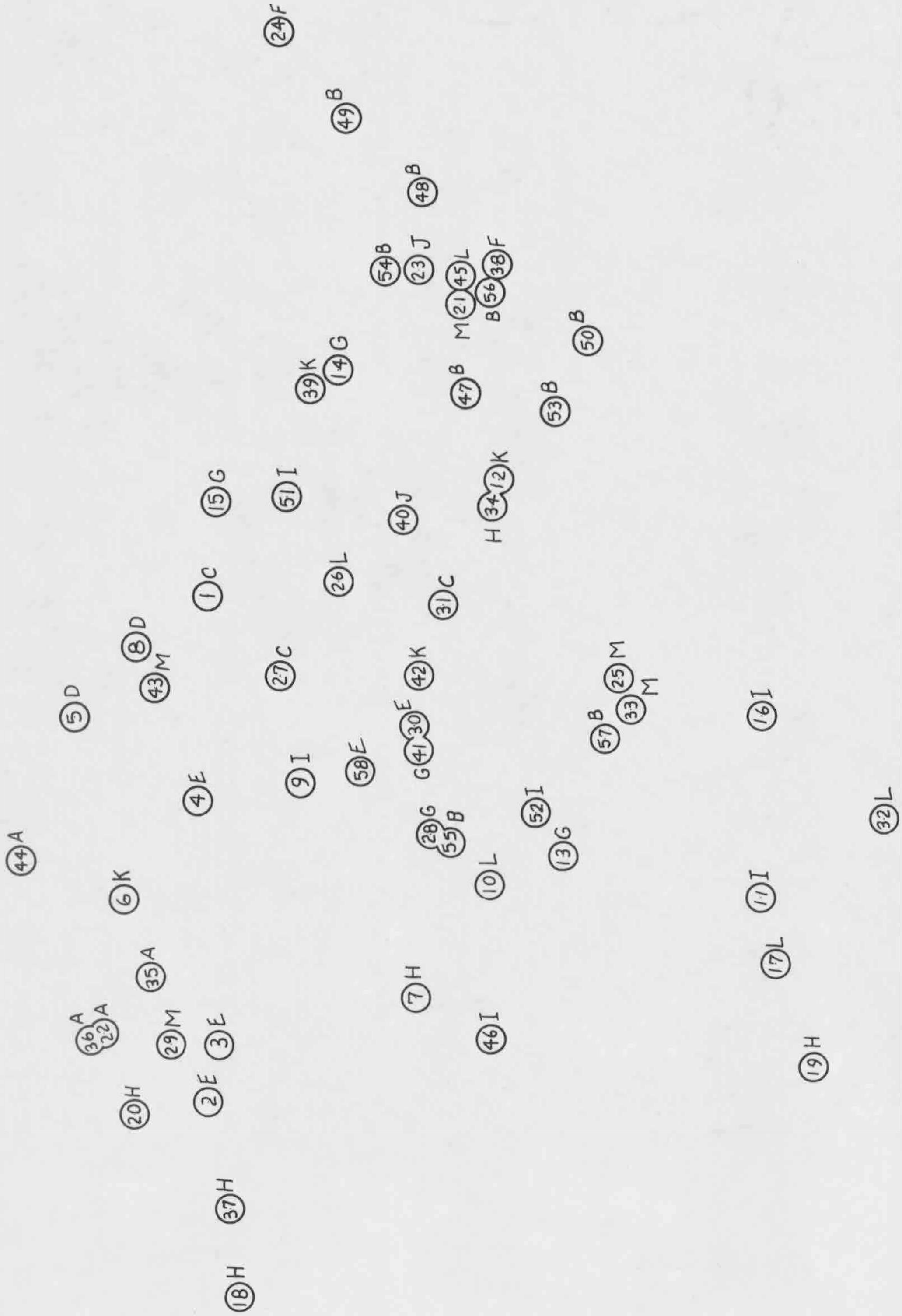

Figure 7. Results of Cluster and Ordination techniques. Clusters are indicated by the same letter.

study locations were divided into six groups with one group containing two subgroups. The groups were designated with Roman numerals and given names based on common plant species in the group. These plant species were merely common species in the groups. They did not necessarily indicate the dominance or aspects of their groups.

Site and soil data were summarized and related to the six groups. The groups are discussed individually below. Detailed site and soil data were arranged by groups and are presented in Appendix I.

Group I (*Artemisia*/*Poa* Group). This group includes study locations 11, 52, 16, 32, 51, 58, 6, 42, 8 and 9 (Table II).

The group was found only on gently sloping areas and on all exposures. All but two study locations had slopes of three percent or less and the remaining two had slopes of five and seven percent. Elevation at the study locations ranged from 2,800 to 3,325 feet.

The group occupied a harsh pan site. Where an A_1 horizon was present it was generally a sandy loam. Usually the A_1 was absent, exposing a relatively impermeable A_2 horizon. Seven of the nine soils had A_2 horizons. The B and C horizons generally were clayey. Soil structure was usually platy or structureless in the A horizon with a columnar B horizon. The soils normally did not effervesce in the surface horizon, but about half of the soils demonstrated a moderate effervescence in the subsurface layers. The pH was generally slightly acidic in the surface horizons increasing to slightly basic in the subsurface horizons. Electroconductivity values indicated low salinity in the surface horizons increasing to moderately salty with depth.

Vegetation of Group I (9 locations) (Figure 8 and 9) -

Ubiquitous Species 1/	Number of locations where present
Poa secunda	9
Agropyron smithii	8
Bouteloua gracilis	8
Lepidium densiflorum	8
Opuntia polyacantha	8
Lichen	8
Agropyron dasystachyum	7
Plantago spinulosa	7
Gutierrezia sarothrae	6
Ubiquitous Species not Common in this group	
Stipa viridula	0
Draba nemorosa	0
Sphaeralcea coccinea	1

The absence of any differentiating species 2/ and the lack of some of the ubiquitous species characterized the vegetation of this group (Table II).

Big sagebrush frequency varied from eight to 80 percent and its canopy cover ranged from 0.5 to 12 percent, with an average six percent cover. Big sagebrush exhibited a stunted appearance on most of the study locations of this group.

Group II (*Artemisia*/*Agropyron smithii*/*A. dasystachyum* group). This group includes study locations 25, 33, 26, 45, 41, 10, 17 and 15 (Table II).

The group was found only on gently sloping areas ranging from one to

1/ Ubiquitous species are defined here as species generally present throughout the entire study area.

2/ Differentiating species are those whose presence is indicative of a particular group.

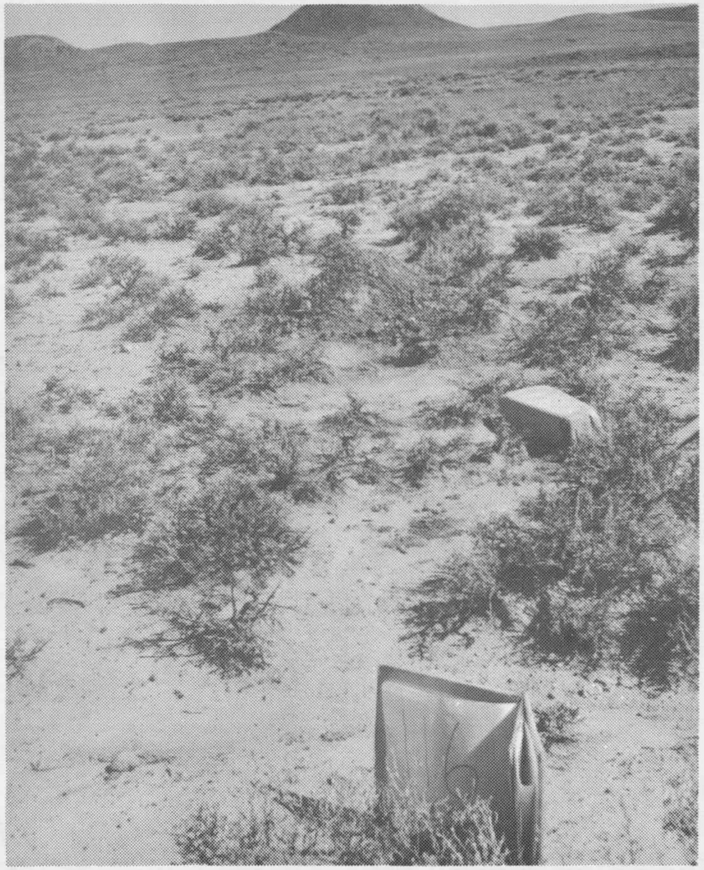

Figure 8. Location 16, representative of Group I (<u>Artemisia</u>/<u>Poa</u> group). Note the sparse vegetation and light colored A_2 horizon.

Figure 9. Location 9, representative of Group I (<u>Artemisia</u>/<u>Poa</u> group). Note the slickpan aspect.

six percent slope. The group occurred on all exposures. Elevations at the locations varied from 3,000 to 3,375 feet.

This community has a very characteristic soil type. The surface horizon was generally an A_1 with a B_2 or B_{2t} subsurface horizon. Every location occurred on a clay-textured soil. The moderately structured soil was normally granular or blocky in the surface horizon and prismatic in the B horizon. Consistence was usually hard when dry, firm when moist, and sticky and very plastic when wet. Most of the soils effervesced in the subsoil and indicated slightly alkaline pH values. Electroconductivity values were generally low except in some of the C and one of the B horizons (Appendix Table I).

Vegetation of Group II (8 locations) (Figures 10 and 11) -

Ubiquitous Species	Number of locations where present
Poa secunda	8
Vicia americana	8
Agropyron smithii	7
A. dasystachyum	7
Koeleria cristata	7
Stipa viridula	7
Lepidium densiflorum	7
Sphaeralcea coccinea	7
Opuntia polyacantha	7
Allium textile	6
Draba nemorosa	6
Artemisia frigida	6
Phlox sp.	5

The vegetation of this group had a characteristic rhizomatous wheatgrass aspect. The group generally lacked plant species other than ubiquitous ones (Table II).

The frequency of big sagebrush varied from 10 to 70 percent and its canopy cover ranged from 1.5 to 21 percent and averaged nine percent. This

Figure 10. Location 33, representative of Group II (*Artemisia*/*Agropyron smithii*/*A. dasystachyum* group). Note the rhizomatous wheatgrass aspect.

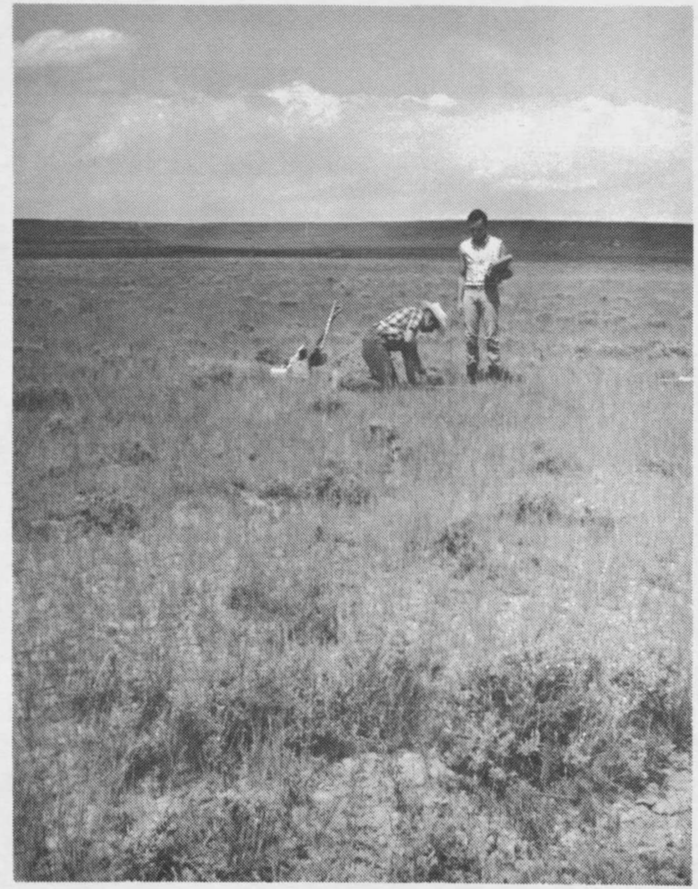

Figure 11. Location 10, representative of Group II (*Artemisia*/*Agropyron smithii*/*A. dasystachyum* group).

average cover value was higher than in Group I but lower than in any of the other groups.

Group III (Artemisia/Bouteloua group). This group includes study locations 28, 30, 13, 18, 37, 20, 19 and 7 representing subgroup a. (Bromus subgroup) and locations 3, 29, 35, 2, 36, 4, 44 and 22 representing subgroup b. (Carex subgroup) (Table II).

The group occurred on gentle to moderate slopes ranging from two to 15 percent. Study locations were found on all but west facing exposures. Elevations varied from 2,825 to 3,350 feet.

Favorable agricultural soils were characteristic of this group. There usually were well developed A and B horizons. The loamy soils were lighter textured than those of Group II. Soil structure was weak granular, blocky or platy in the A horizon with moderate prismatic B horizons. Consistence was slightly hard when dry, friable when moist, and slightly sticky and slightly plastic when wet. Few soils in this group demonstrated any effervescence. The surface horizons were acidic while the subsoils were slightly alkaline. Electroconductivity values were extremely low except at one study location (Appendix Table I).

Vegetation of Group III Subgroup a. (8 locations) (Figures 12 and 13)

Ubiquitous Species	Number of locations where present
Agropyron smithii	8
Plantago spinulosa	8
Stipa comata	7
Bouteloua gracilis	7
Poa secunda	7
Sphaeralcea coccinea	7
Lichen	7
Artemisia frigida	7
Opuntia polyacantha	7
Vicia americana	6
Lepidium densiflorum	6
Other Common Species	
Festuca octoflora	7
Carex eleocharis	7
Moss	7
Ubiquitous Species Not Common in this group	
Draba nemorosa	3
Phlox sp.	0
Agropyron spicatum	2
Differentiating Species	
Bromus japonicus	8
B. tectorum	8
Moss	7
Hedeoma hispida	6

Subgroup a. was much more complex vegetationally than either Group I or II (Table II).

The frequency of big sagebrush varied from four to 80 percent. A canopy cover ranged from 1.8 to 45 percent with an average value of 21 percent. This group had the highest average cover of big sagebrush of any of the groups.

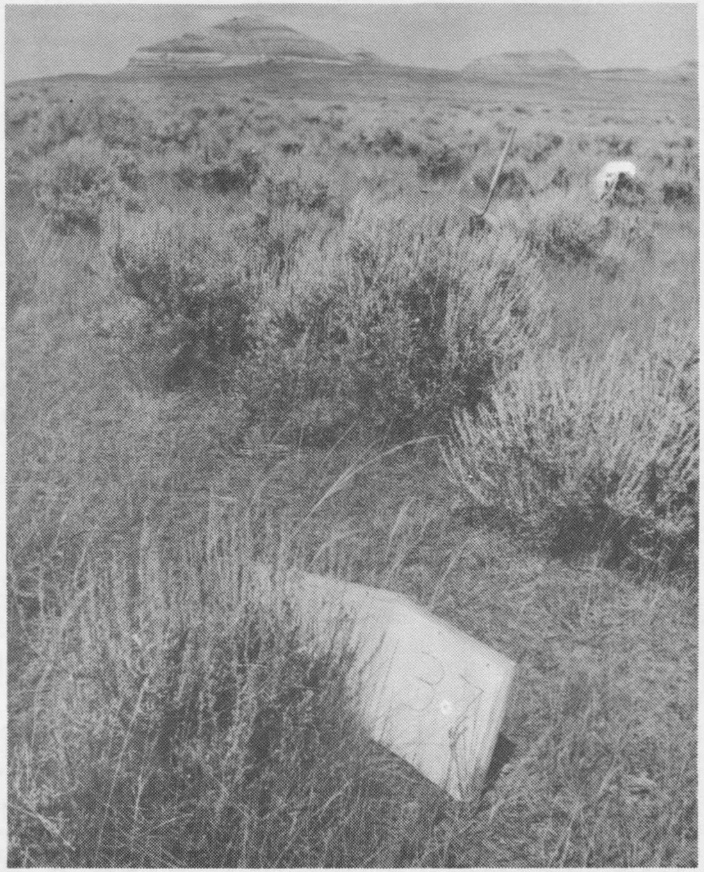

Figure 12. Location 37, representative of Group III Subgroup a. (Artemisia/Bouteloua group, Bromus subgroup).

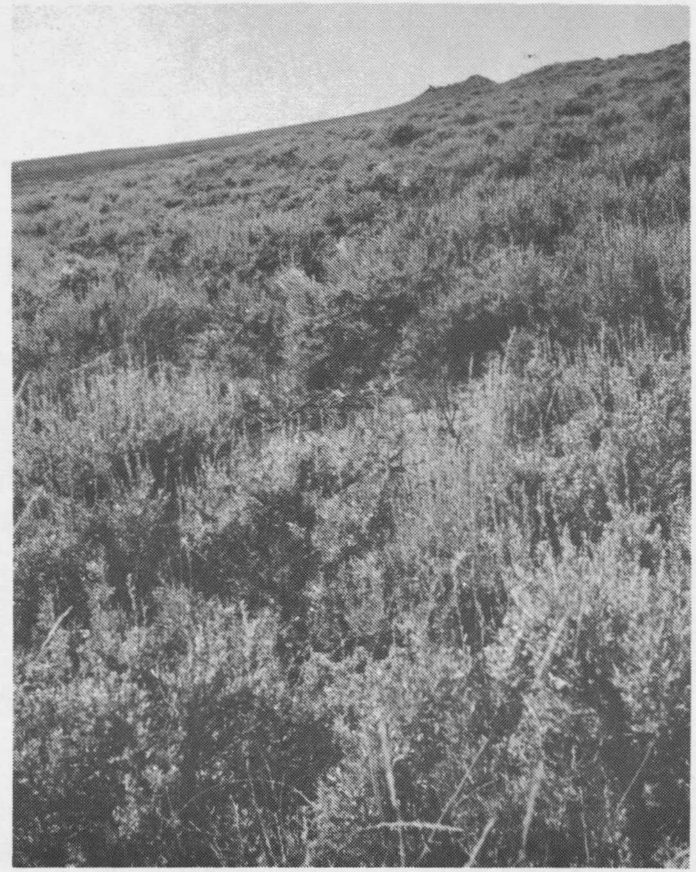

Figure 13. Location 7, representative of Group III Subgroup a. (Artemisia/Bouteloua group, Bromus subgroup). Note the robust big sagebrush.

Vegetation of Group III Subgroup b. (8 locations) (Figures 14 and 15)

Ubiquitous Species	Number of locations where present
Agropyron smithii	8
Bouteloua gracilis	8
Koeleria cristata	8
Poa secunda	8
Lichen	8
Opuntia polyacantha	8
Stipa comata	7
Lepidium densiflorum	7
Artemisia frigida	7
Agropyron dasystachyum	6
Sphaeralcea coccinea	6
Other Common Species	
Carex eleocharis	8
Festuca octoflora	7
Hedeoma hispida	6
Chenopodium leptophyllum	6
Erigeron pumilus	6
Ubiquitous Species Not Common in this group	
Stipa viridula	2
Draba nemorosa	3
Agropyron spicatum	3
Distinguishing Species	
Bromus japonicus	2
B. tectorum	0
Camelina microcarpa	0

Subgroup b. was very similar to subgroup a. except for the distinguishing species. This subgroup also was very complex vegetationally (Table II).

Big sagebrush frequency varied from 12 to 60 percent in the subgroups. Canopy cover ranged from two to 60 percent and averaged 12 percent.

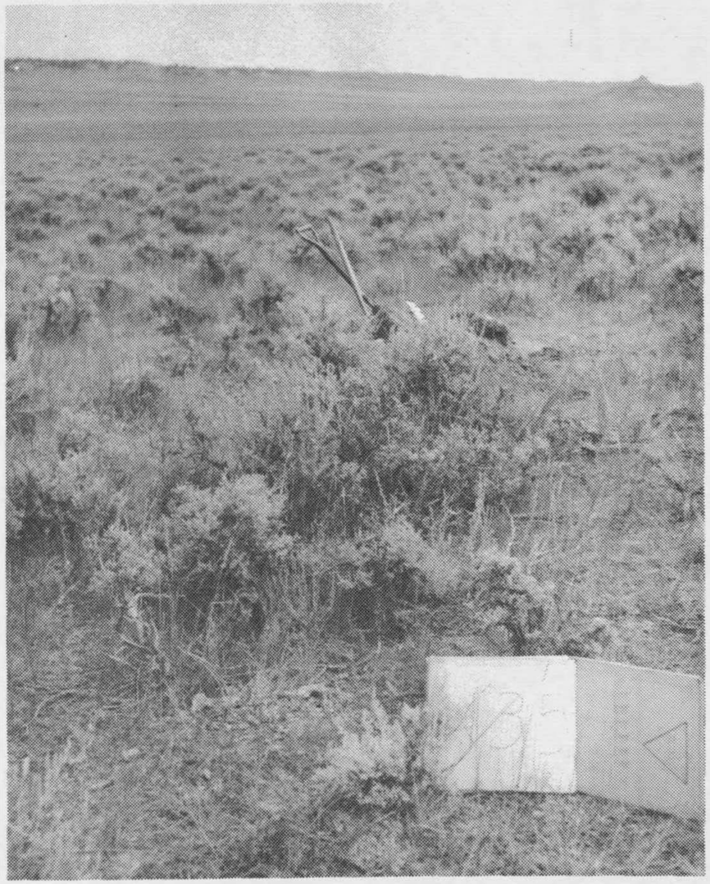

Figure 14. Location 35, representative of Group III Subgroup *b*. (*Artemisia*/*Bouteloua* group, *Carex* subgroup).

Figure 15. Location 22, representative of Group III Subgroup *b*. (*Artemisia*/*Bouteloua* group, *Carex* subgroup. Note the abundance of short sod forming grasses.

Group IV (Artemisia/Koeleria/Bouteloua group). This group includes study location 8, 43, 5, 27, 31, 1, 38 and 24 (Table II).

The community occurred on gentle to steep slopes ranging from two to 39 percent. None of the study locations were on east exposures. Elevations ranged from 2,850 to 3,250 feet.

The soils of this group were somewhat similar to those of Group III. The A and B horizons often were not well developed. The loamy soils were moderately well structured. Structure of the A horizon was variable while the B horizon was either blocky or prismatic. Consistence was slightly hard when dry, very friable when moist and variable when wet. The soils were usually calcareous. The pH was slightly alkaline. Electroconductivity values were very low except at one study location (Appendix Table I). The soils in this unit were quite variable.

Vegetation of Group IV (8 locations) (Figure 16 and 17) -

Ubiquitous Species	Number of locations where present
Bouteloua gracilis	8
Koeleria cristata	8
Vicia americana	8
Phlox sp.	8
Lichen	8
Opuntia polyacantha	8
Agropyron dasystachyum	7
Poa secunda	7
Sphaeralcea coccinea	7
Agropyron smithii	6
Stipa viridula	6
S. comata	6
Allium textile	6
Lepidium densiflorum	6
Plantago spinulosa	6
Artemisia frigida	6

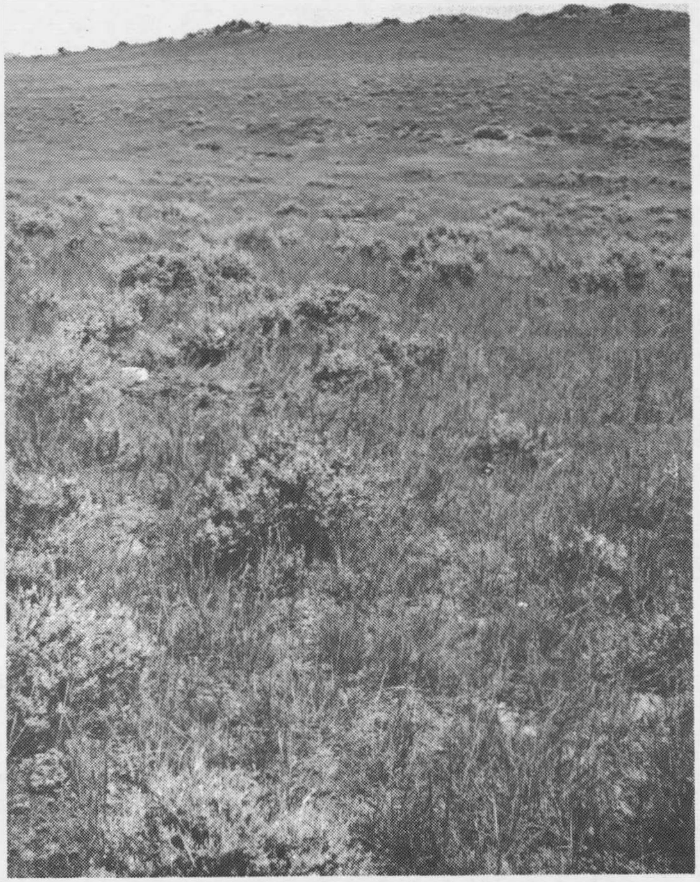

Figure 16. Location 8, representative of Group IV (Artemisia/Koeleria/Bouteloua group.

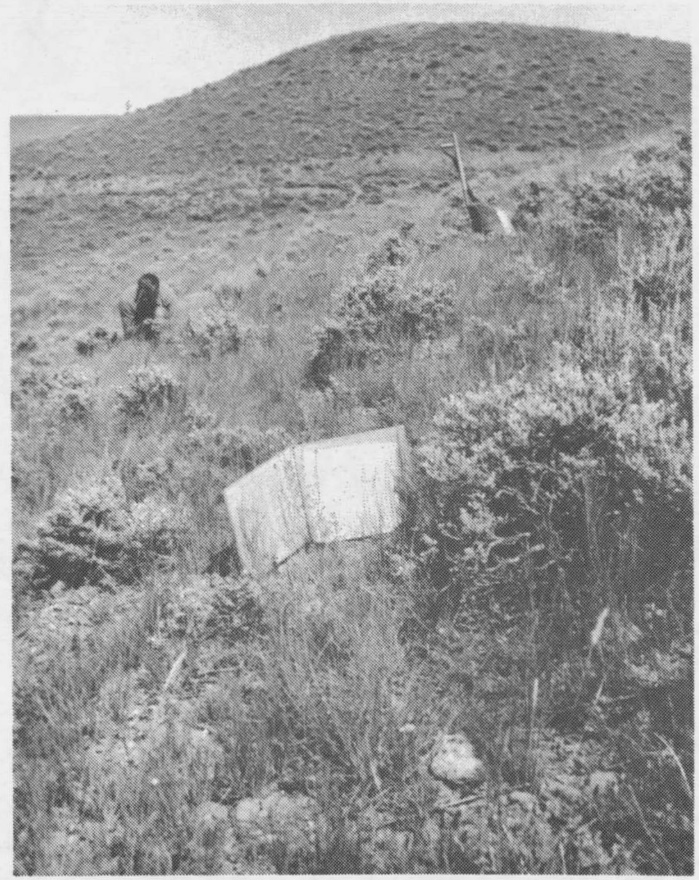

Figure 17. Location 24, representative of Group IV (Artemisia/Koeleria/Bouteloua group.

Other Common Species	Number of locations where present
Gutierrezia sarothrae	7
Erigeron pumilus	6

Many other plant species were present in half or less of the study locations in this group (Table II).

Big sagebrush frequency ranged from 22 to 72 percent. Cover of big sagebrush varied from five to 20 percent and averaged 12 percent.

This group was similar to Group III. Most of the ubiquitous species common to Group III and V were common in this group also. The species helpful in differentiating Group III, however, were not common in this group. Group IV's relationship with Groups III and V or validity as a separate unit needs further study for clarification.

Group V (*Artemisia/Stipa/Koeleria* group). The group includes locations 14, 34, 39, 21, 40, 12 and 23 (Table II).

This unit was found on moderate to steep slopes ranging from six to 35 percent. As in Group III, study locations occurred on all but west facing slopes. Elevations varied from 3,100 to 3,350 feet.

The soils of this group were variable. The surface horizon was A_1 horizon with a B_{2t} horizon developed below the A_1. The soils were heavier than those of either Group III or IV and were usually clay loam. The structure varied in the A horizon and there was a prismatic B horizon. Consistence was commonly hard when dry, firm when moist, and sticky and plastic when wet. The soils showed moderate effervescence and alkaline pH values. The variable nature of the soils of this group indicates a need for further research.

Vegetation of Group V (7 locations) (Figures 18 and 19) -

Ubiquitous Species	Number of locations where present
Agropyron smithii	7
Stipa viridula	7
Koeleria cristata	7
Poa secunda	7
Sphaeralcea coccinea	7
Opuntia polyacantha	7
Stipa comata	6
Bouteloua gracilis	6
Vicia americana	6
Draba nemorosa	6
Plantago spinulosa	6
Artemisia frigida	6
Lichen	6
Lepidium densiflorum	5
Phlox sp.	5
Other Common Species	
Carex eleocharis	6
Muhlenbergia cuspidata	5

The frequency of big sagebrush ranged from 10 to 82 percent. Canopy cover of big sagebrush varied from six to 35 percent and averaged 15 percent.

The group was rich floristically and contained nearly all of the ubiquitous species. The unit lacked, however, a group of species that would clearly differentiate it as a separate community. Perhaps data from more study locations or more detailed data from the present locations would help clarify both Groups IV and V.

Group VI (Artemisia/Agropyron/Poa group). This group includes locations 55, 49, 50, 56, 48, 54, 57, 53, 47 and 46 (Table II).

The group was found on very gentle to moderate slopes. Slope percentages ranged from one to 16 percent. Study locations of this group were

Figure 18. Location 39, representative of Group V (<u>Artemisia</u>/<u>Stipa</u>/<u>Koeleria</u> group).

Figure 19. Location 23, representative of Group V (<u>Artemisia</u>/<u>Stipa</u>/<u>Koeleria</u> group).

found on all exposures. Elevations at the study locations ranged from 2,700 to 2,925 feet.

The study locations of this unit occurred only on the heavy-textured soils developed from the Bearpaw shale parent material. The surface horizon was always an A_1 with a B_2 or B_{2t} horizon beneath the A_1. The soils were uniform in color. Colors were a 2.5Y5/2 (Munsell Chart) when dry and 2.5Y4/2 when wet. Soil textures were clayey. Structure was moderately strong and either blocky or granular in the A horizon with a prismatic B horizon. Consistence was commonly very hard when dry, firm when moist, and sticky and very plastic when wet. The soils generally did not indicate any effervescence. The pH of the unit was nearly neutral and electroconductivity values were low.

Vegetation of Group VI (10 locations) (Figures 20 and 21) -

Ubiquitous Species	Number of locations where present
Agropyron smithii	10
Vicia americana	10
Sphaeralcea coccinea	10
Draba nemorosa	10
Stipa viridula	9
Poa secunda	9
Opuntia polyacantha	9
Allium textile	8
Koeleria cristata	7
Agropyron spicatum	6
Ubiquitous Species Not Common in this group	
Bouteloua gracilis	3
Lepidium densiflorum	3
Plantago spinulosa	1
Taraxicum officinale	1
Artemisia frigida	1
Agropyron dasystachyum	0
Stipa comata	0

Figure 20. Location 50, representative of Group VI (Artemisia/Agropyron/Poa group).

Figure 21. Location 53, representative of Group VI (Artemisia/Agropyron/Poa group). Note the taller aspect of the vegetation.

Differentiating Species	Number of locations where present
Poa canbyi	10
Phacelia linearis	9
Collomia linearis	9
Lomatium foeniculaceum	9
Comandra umbellata	8
Melilotus officinalis	8
Tragopogon dubius	8

Big sagebrush frequency ranged from 22 to 76 percent in this unit. Big sagebrush cover varied from four to 25 percent and averaged 11 percent.

The species composition in this group differed greatly from that of the other groups (Table II). These differences indicate that this group represents a discrete plant community.

SUMMARY AND CONCLUSIONS

Research was initiated in 1966 to study big sagebrush rangelands in central Montana. A reconnaissance of the area was conducted and 58 study locations were chosen. Site, soil, and vegetation data were collected and analyzed. The study locations were classified into six groups, one with two subgroups, and described.

Based upon this research the following conclusions are presented:

1) Geological substrate in this area strongly influenced the density and distribution of big sagebrush. Big sagebrush was found on soils derived from shales but was generally absent from two sandstone-derived soils.

2) More emphasis should be placed on initially studying undisturbed sites.

3) A broader area should have been included in this initial study.

4) The use of several complementary methods of data analysis should be continued.

5) Further research needs to be conducted to separate Group IV and V into more meaningful units or to clarify their validity as groups.

6) Research is needed into the factor or factors in the geological materials which cause the difference in big sagebrush distribution.

APPENDIX

APPENDIX I

SITE AND SOIL DATA:

The site and soil data from the 58 study locations were coded when necessary and presented in Appendix Table I. The codes for texture, structure, consistence, effervescence and horizon boundaries are as follows:

Texture.

C - clay	SiL - silty loam
SiC - silty clay	L - loam
SyC - sandy clay	SyL - sandy loam
SiCL - silty clay loam	Si - silt
CL - clay loam	LSa - loamy sand
SyCL - sandy clay loam	Sa - sand

Structure.

- structureless	VFi - very fine	Platy - platy
VWk - very weak	Fi - fine	Prism - prismatic
Wk - weak	Med - medium	Colum - columnar
Mod - moderate	Co - coarse	An Blk - angular blocky
Str - strong	VCo - very coarse	Sub Blk - subangular blocky
		Gran - granular
		Crumb - crumb
		Mass - massive

Consistence.

Dry	Moist
Los - loose	Los - loose
Sof - soft	VFr - very friable
SlH - slightly hard	Fr - friable
H - hard	Fi - firm
VH - very hard	VFi - very firm
EH - extremely hard	EFi - extremely firm

Wet:

Stickiness	Plasticity
Non - non sticky	Non - non plastic
Sl - slightly sticky	Sl - slightly plastic
Stk - sticky	Pla - plastic
V - very sticky	V - very plastic

Effervescence.

Non - none
VSl - very slight
Sl - slight
Mod - moderate
Str - strong
Vio - violent

Boundary.

A - abrupt		S - smooth	
C - clear		W - wavy	
G - gradual		I - irregular	
D - diffuse		B - broken	

Appendix Table I. Topography and soil data arranged by association table groupings.

Location Number	Exposure (degrees)	Slope (percent)	Altitude (feet)	Horizon	Depth (inches)	Color (Munsell Chart)	Texture	Structure	Consistence				Effervescence	pH	Electroconductivity (mmhos/cm at 25° C)	Boundary
									Dry	Moist	Stickiness	Plasticity				
11	172	7	3025	B2t	0-2	10YR6/2-3/2	C	Str Med An Blk	EH	Fi	Stk	V	Non	6.0	1.30	CW
				C	2-18	10YR5/2-4/2	C	Mass	VH	Fi	Stk	V	Non	5.2	1.12	
52	164	3	2900	A1	0-1	2.5Y5/2-4/2	SyL	Structureless	Sof	VFr	Non	Non	Non	6.3	.85	CW
				A2	1-2	2.5Y7/2-4/2	SyL	Mass	SlH	Fr	Non	Non	Non	5.9	.36	AW
				B2t	2-8	10YR5/3-4/3	SiC	Wk Med Colum	H	Fi	Stk	Pla	Mod	7.7	1.30	GW
				B3	8-12	10YR6/3-5/3	SiC	Wk Med Colum	H	Fi	Stk	Pla	Mod	7.7	3.10	GW
				C	12-20	2.5Y5/2-4/2	SiCL	Mass	VH	Fi	Stk	Pla	Sl	7.5	6.60	GW
				R	20-24											
16	180	1	3325	A2	0-2	10YR7/2-5/2	L	Str Med Platy	SlH	VFr	Non	Sl	Non	6.5	.34	CW
				B2t	2-9	10YR5/2-4/2	CL	Wk Med Colum	H	Fi	Sl	Pla	Non	6.5	1.40	CW
				Cca	9-13	10YR5/2-4/2	CL	Mass	H	Fi	Sl	Pla	Non	7.1	2.20	DW
				R	13-24											
32	242	1	3200	A1	0-2	10YR6/3-4/3	LSa	Structureless	Sof	VFr	Non	Non	Non	8.2	.90	CB
				B2t	2-5	10YR5/3-4/3	SyCL	Mass	VH	Fr	Sl	Sl	Non	8.3	3.20	CI
				IIC	5-24	10YR5/3-3/3	C	Mass	H	Fi	V	V	Non	7.3	10.00	
51	0	1	2925	A1	0-2	2.5Y5/2-3/2	SyL	Structureless	Los	VFr	Non	Non	Non	6.0	.24	CW
				A2	2-3	10YR7/2-4/2	SyL	Wk Med Platy	SlH	VFr	Non	Non	Non	6.9	.50	AW
				B2t	3-12	2.5Y5/2-4/2	C	Wk Med Colum	VH	VFi	Stk	Pla	Mod	8.2	1.90	GW
				C	12-24	5Y6/3 -5/3	C	Mass	VH	VFi	Stk	Pla	Sl	7.7	6.80	
58	50	2	2800	A1	0-2	10YR5/3-3/3	L	Structureless	Sof	VFr	Non	Sl	VSl	6.1	.50	CW
				A2	2-4	10YR7/2-4/2	SyL	Mass	SlH	VFr	Non	Non	Non	5.9	.28	AW
				B2t	4-10	10YR5/3-4/3	SiCL	Mod Med Colum	SlH	Fr	Stk	Pla	Mod	7.8	8.00	GW
				C	10-20	10YR5/2-4/2	CL	Mass	H	Fi	Stk	Pla	Mod	7.7	7.50	
6	320	1	3100	A1	0-5	10YR6/4-3/3	SyL	Structureless	Los	VFr	Sl	Non	Non	5.6	.33	AW
				A2	5-6	10YR7/1-4/2	CL	Str Fi An Blk	H	Fi	Sl	Pla	Non	6.7	.44	AW
				B2t	6-13	10YR7/2-3/1	C	Mod Med Colum	EH	VFi	Sl	V	Non	7.4	.21	GI
				C	13-20	10YR6/3-4/3	C	Mass	VH	Fi	Sl	Sl	Non	7.6	9.00	

Location Number	Exposure (degrees)	Slope (percent)	Altitude (feet)	Horizon	Depth (inches)	Color (Munsell Chart)	Texture	Structure	Consistence				Effervescence	pH	Electroconductivity (mmhos/cm at 25° C)	Boundary
									Dry	Moist	Stickiness	Plasticity				
42	184	1	3000	A1	0-4	2.5Y6/2-4/2	SyL	Str Med Platy	SlH	VFr	Non	Non	VSl	6.6	.32	AI
				IIB2t	4-12	2.5Y5/2-4/2	C	Mod Med Colum	VH	Fi	Stk	Pla	VSl	7.4	.45	CW
				IICca	12-24	2.5Y6/2-4/2	CL	Mass	H	Fr	Sl	Pla	Str	7.6	9.50	
9	190	5	3100	A1	0-2	10YR5/2-3/2	LSa	VWk Med Sub Blk	SlH	VFr	Non	Non	Non	7.2	.61	CW
				A2	2-3	10YR6/2-3/2	SyL	Wk Med Platy	SlH	Fi	Sl	Sl	Non	6.8	.32	CW
				B2t	3-8	10YR6/3-3/3	C	Mod Med Colum	VH	VFi	Stk	Pla	Non	7.7	.20	CW
				Cca	8-24	10YR6/3-4/3	C	Mass	EH	VFi	Stk	Pla	Str	7.9	3.20	
25	55	6	3150	A1	0-3	10YR5/2-4/2	C	Str Med Gran	H	Fr	V	V	Non	6.7	.36	CW
				B2t	3-14	10YR5/2-4/2	C	Mass	VH	VFi	V	V	Non	7.5	.63	CW
				C	14-24	10YR5/3-3/3	C	Mass	H	Fi	V	V	Non	7.0	4.50	
33	348	2	3000	A1	0-3	10YR6/2-4/2	C	Str Co An Blk	H	Fr	Stk	Pla	Non	6.9	.44	CW
				B2t	3-14	2.5Y6/2-5/2	C	Mod Co Prism	VH	VFi	Stk	V	Mod	7.8	.62	GW
				C	14-24	5Y6/2 -5/2	C	Mass	VH	VFi	Stk	V	Str	7.8	1.40	
26	4	6	3050	A1	0-4	10YR5/2-4/2	C	Mod Fi Gran	H	Fr	V	V	Non	7.0	.40	CW
				B2	4-14	10YR5/2-4/2	C	Mod Co Prism	H	Fi	V	V	Str	7.8	1.00	GW
				C	14-24	10YR5/2-4/2	C	Mass	VH	VFi	V	V	Str	8.2	1.85	
45	10	4	3075	A1	0-3	2.5Y5/2-4/2	C	Mod Co An Blk	H	Fr	V	V	Sl	6.6	.35	CW
				B2t	3-16	2.5Y5/2-4/2	C	Str VCo Prism	EH	VFi	Stk	V	Mod	7.6	.67	GW
				C	16-24	2.5Y5/2-4/2	C	Mass	VH	VFi	V	V	Mod	7.6	2.10	
41	180	5	3100	A1	0-3	10YR5/2-3/2	C	Mod Med Platy	SlH	Fr	Stk	V	Sl	6.3	.45	CW
				B2t	3-14	2.5Y5/2-4/2	C	Str VCo Prism	VH	Fi	Stk	V	Mod	7.4	.42	GW
				B3ca	14-19	2.5Y5/2-4/2	C	Wk VCo Prism	EH	VFi	Stk	V	Str	7.6	.95	CW
				IICca	19-24	2.5Y6/2-4/2	CL	Mass	H	Fr	Sl	Pla	Str	7.4	6.50	
10	195	2	3100	A1	0-2	10YR7/2-4/2	SiCL	VWk Fi Platy	SlH	VFr	Stk	Sl	Non	7.8	.68	CW
				B2	2-8	5Y6/2 -4/2	C	Mod Co Prism	EH	VFi	V	V	Str	8.0	9.00	GW
				C	8-24	5Y6/2 -4/2	C	Mass	EH	VFi	Stk	V	Str	8.3	9.50	

Location Number	Exposure (degrees)	Slope (percent)	Altitude (feet)	Horizon	Depth (inches)	Color (Munsell Chart)	Texture	Structure	Consistence				Effervescence	pH	Electroconductivity (mmhos/cm at 25° C)	Boundary
									Dry	Moist	Stickiness	Plasticity				
17	268	1	3075	A1	0-5	10YR6/2-4/2	C	Mod Co Sub Blk	H	Fr	Stk	Pla	Mod	7.7	.31	CW
				B2	5-11	10YR6/2-4/2	C	Mod Med Prism	VH	Fi	Stk	Pla	Str	8.1	.26	GW
				C	11-24	10YR6/2-4/2	C	Mass	H	Fi	Stk	Pla	Str	8.1	.24	
15	164	2	3375	A1	0-5	10YR4/3-4/2	C	Mod Med Sub Blk	H	VFr	V	Pla	Non	6.8	.80	GW
				B2	5-11	10YR4/3-3/3	C	Wk Med Prism	VH	Fr	V	V	Non	6.7	.79	DW
				Cca	11-24	10YR5/1-3/1	C	Mass	EH	Fr	V	V	Str	7.9	.30	
28	85	5	3410	A1	0-3	10YR5/2-3/2	CL	Mod Fi Gran	Sof	Fr	Sl	Sl	Non	6.9	.58	AW
				B2t	3-8	10YR4/3-3/3	C	Mod Med Prism	H	Fi	V	V	Non	6.6	.33	GW
				Cca	8-24	10YR5/2-3/2	C	Mass	H	Fi	V	Pla	Vio	7.9	.28	
30	78	3	3350	A1	0-2	10YR6/2-4/2	SyL	Wk Fi Gran	Sof	Fr	Non	Sl	Non	7.2	.41	CW
				B2t	2-6	10YR5/2-3/2	CL	Mod Med Platy	SlH	Fi	Stk	Pla	Non	7.4	.44	CW
				B3ca	6-10	10YR5/2-3/2	CL	Mod Med Platy	SlH	Fi	Stk	Pla	Str	7.7	.80	GW
				Cca	10-20	10YR7/2-5/2	CL	Mass	SlH	Fr	Stk	Pla	Vio	7.6	2.40	GW
				R	20-26											
13	180	2	3300	A1	0-4	10YR5/2-3/2	C	Mod Co An Blk	SlH	Fi	V	V	Non	5.4	.14	GW
				B	4-12	10YR5/2-3/2	C	Mod Med Prism	H	Fi	V	V	Non	6.6	.22	CW
				C	12-19	10YR5/2-3/2	SiC	Mass	SlH	Fr	V	Pla	Non	7.3	.83	GW
				IIC	19-25	10YR5/2-3/2	SyC	Mass	Sof	VFr	Stk	Pla	Non	7.4	5.00	
18	70	5	3165	A1	0-5	10YR6/2-4/2	SyL	Wk Med Platy	SlH	VFr	Non	Sl	Non	6.4	.50	CW
				B2t	5-11	10YR5/3-4/2	CL	Wk Med Prism	VH	Fr	Stk	Sl	Non	6.9	.25	CW
				C	11-26	10YR6/3-4/3	LSa	Mass	Sof	VFr	Non	Non	VSl	7.9	.25	
37	145	4	2825	A1	0-3	10YR5/3-3/3	SyL	Wk Med Platy	Sof	VFr	Non	Non	Non	6.0	.18	CW
				B2t	3-8	10YR5/3-4/3	SyCL	Mod Med Prism	VH	Fi	Sl	Pla	Non	6.3	.21	CW
				B3	8-13	10YR6/3-4/3	SyL	Mod Med Prism	H	VFr	Non	Sl	Non	7.0	.25	CW
				Cca	13-24	10YR7/3-5/3	SyCL	Mass	VH	Fr	Sl	Pla	Str	7.7	.40	
20	125	7	3175	A1	0-3	10YR6/3-4/3	SyL	VWk Fi Gran	Sof	VFr	Non	Non	Non	6.4	.24	AW
				A2	3-4	10YR7/2-3/2	L	Mod Fi Platy	SlH	VFr	Sl	Sl	Non	6.4	.14	AW
				B2t	4-9	10YR5/3-3/3	C	Mod Med Colum	H	Fi	V	Pla	Non	6.7	.19	GW
				C	9-24	10YR5/3-4/3	CL	Mass	SlH	Fr	Sl	Sl	Str	8.0	.22	

Location Number	Exposure (degrees)	Slope (percent)	Altitude (feet)	Horizon	Depth (inches)	Color (Munsell Chart)	Texture	Structure	Consistence				Effervescence	pH	Electroconductivity (mmhos/cm at 25° C)	Boundary
									Dry	Moist	Stickiness	Plasticity				
19	120	3	3165	A1	0-4	10YR6/2-4/2	SyL	Wk Med Platy	SlH	VFr	Non	Non	Non	6.3	.21	CW
				B2t	4-11	10YR5/2-3/2	CL	Mod Co Platy	VH	Fr	Stk	Sl	Non	6.6	.12	GW
				C	11-24	10YR5/3-3/3	SyL	Mass	H	VFr	Non	Sl	Non	7.6	.24	
7	185	15	3050	A1	0-8	10YR5/3-3/3	LSa	VWk Med An Blk	Los	VFr	Non	Sl	Non	7.4	.23	CW
				B2	8-10	10YR4/3-3/3	L	Wk Med An Blk	Sof	VFr	Non	Sl	Non	7.0	.22	CW
				Cca	10-25	10YR5/4-4/3	SiL	Mass	SlH	VFr	Non	Sl	Str	8.1	.26	
3	150	4	3220	A1	0-2	10YR6/3-3/3	SyL	VWk Med Platy	Sof	VFr	Non	Sl	Non	5.6	.51	CW
				A3	2-5	10YR6/3-3/3	L	VWk Fi Prism	SlH	VFr	Non	Sl	Non	5.9	.23	CW
				B2t	5-8	10YR5/2-4/2	CL	Wk Fi Prism	SlH	VFr	Non	Sl	Non	6.0	.29	CW
				IICca	8-24	10YR7/2-4/3	C	Mass	VH	Fr	Stk	Pla	Mod	6.8	.90	
29	150	3	3400	A1	0-5	10YR5/3-3/3	CL	Mod Fi Gran	SlH	Fr	Stk	Pla	Non	7.2	.15	DW
				Cca	5-26	10YR5/2-3/2	C	Mass	H	Fi	V	V	Vio	7.6	.70	
35	10	3	2975	A1	0-3	10YR7/2-4/3	SiL	Mod Med Platy	SlH	Fr	Non	Sl	Non	6.5	.27	CW
				B2	3-10	10YR5/3-3/3	SyCL	Mod Co Prism	H	Fr	Sl	Pla	Non	6.7	.25	GW
				B3	10-15	10YR5/3-3/3	LSa	Mod Co Prism	SlH	VFr	Non	Non	Non	6.4	.65	CW
				IIB2t	15-21	10YR6/3-4/3	SyC	Str Med Prism	EH	Fr	Stk	Pla	Non	7.5	.95	CW
				IIB2ca	21-23	10YR6/3-4/3	SyC	Str Med Prism	EH	Fr	Stk	Pla	Non	7.7	1.20	CW
				R	23-26											
2	135	2	3180	A1	0-7	10YR6/3-4/3	SyL	VWk Fi Gran	Sof	VFr	Non	Non	Non	5.8	9.50	CW
				B2t	7-12	10YR7/2-4/2	C	Str Med Colum	VH	VFi	Stk	Pla	Non	6.5	2.50	CW
				IIC	12-24	10YR7/2-4/2	C	Mass	VH	VFi	Non	Pla	Non	6.9	1.23	
36	35	15	2950	A1	0-4	2.5Y5/2-3/2	SyL	Wk Med Platy	SlH	VFr	Non	Non	Non	6.7	.28	CW
				B1	4-10	2.5Y5/2-4/2	SyL	Mod Co Prism	SlH	VFr	Non	Non	Non	6.6	.19	GW
				B2t	10-30	10YR6/3-4/3	SyCL	Mod Co Prism	H	Fi	Sl	Pla	Sl	7.2	.44	DW
				Cca	24-36	10YR6/3-5/3	CL	Mass	H	Fr	Sl	Pla	Str	7.8	.90	
4	18	6	3220	A1	0-5	10YR6/3-4/3	SyL	VWk Fi Gran	Sof	VFr	Non	Sl	Non	5.9	.15	CW
				B2t	5-8	10YR7/2-4/2	CL	Wk Fi An Blk	H	Fr	Sl	Pla	Non	5.2	.22	CW
				C	8-22	10YR7/2-3/3	C	Mass	H	Fr	Sl	Pla	Non	5.0	.96	

Location Number	Exposure (degrees)	Slope (percent)	Altitude (feet)	Horizon	Depth (inches)	Color (Munsell Chart)	Texture	Structure	Consistence: Dry	Consistence: Moist	Consistence: Stickiness	Consistence: Plasticity	Effervescence	pH	Electroconductivity (mmhos/cm at 25° C)	Boundary
44	18	12	3100	A1	0-3	10YR6/3-3/3	SyL	Mod Fi Platy	SlH	VFr	Non	Sl	Non	6.3	.28	CW
				B2t	3-19	2.5Y5/2-4/2	Cl	Mod Co Prism	H	Fr	Sl	Pla	Non	6.4	.20	CW
				Cca	19-26	2.5Y6/2-4/2	SyCL	Mass	H	Fr	Sl	Pla	Str	7.3	.33	
22	40	12	3200	A1	0-3	10YR6/2-4/2	SiL	VWk Fi Gran	Sof	VFr	Non	Sl	Non	6.5	.68	CW
				B2t	3-7	10YR5/3-4/3	SiC	Mod Med Prism	H	Fi	Stk	Pla	Non	7.0	.17	CW
				B3ca	7-10	10YR6/3-4/3	SiC	Mod Med Prism	H	Fi	Stk	Pla	Str	7.6	.44	GW
				Cca	10-26	10YR7/3-5/3	CL	Mass	H	VFr	Stk	Pla	Vio	8.1	.30	
8	10	10	3040	A1	0-5	10YR5/2-3/2	SiCL	Mod Med Sub Blk	H	Fi	Stk	Pla	Str	7.7	.31	CW
				B2t	5-7	10YR5/2-3/2	SiC	Mod Co Sub Blk	H	Fi	Stk	Pla	Str	7.9	.19	CW
				C	7-24	10YR5/1-3/1	C	Mass	VH	VFi	V	V	Str	7.9	.25	
43	190	2	3100	A1	0-3	10YR5/3-3/3	L	Mod Med Platy	SlH	VFr	Sl	Sl	Non	6.3	.50	CW
				B2t	3-14	10YR6/2-4/2	L	Mod Co Prism	SlH	Fr	Non	Sl	Non	7.5	.39	GI
				R	14-24									7.4	5.90	
5	0	11	3100	A1	0-5	10YR6/3-3/3	SiL	Mod Med An Blk	SlH	VFr	Sl	Pla	Non	6.1	.16	GW
				B2	5-11	10YR5/2-3/3	L	Mod Co An Blk	H	VFr	Sl	Sl	Non	6.9	.14	GW
				C	11-20	10YR6/2-4/2	L	Mass	H	VFr	Sl	Sl	Mod	7.4	.20	CW
				Cca	20-24	10YR6/2-4/2	CL	Mass	H	Fr	Stk	Pla	Str	7.9	1.06	
27	0	4	3040	A1	0-3	10YR6/2-4/2	LSa	Structureless	Sof	VFr	Non	Non	Non	7.2	.64	AW
				IIB2t	3-6	10YR5/2-3/2	C	Mod Med Prism	VH	VFi	V	V	Non	7.7	.25	CW
				IIC21	6-23	10YR5/2-3/2	SiC	Mass	H	Fr	Stk	Pla	Str	8.2	10.00	DW
				IIC22	23-26	10YR5/2-3/2	SiC	Mass	H	Fr	Stk	Pla	Str	8.2	22.50	
31	290	6	3250	A1	0-2	10YR6/2-4/2	L	Mod Fi Gran	SlH	Fr	Non	Sl	Non	6.8	.36	CW
				B2t	2-6	10YR5/2-3/2	C	Wk Med An Blk	H	Fi	V	V	Non	7.4	.23	GW
				C	6-24	10YR5/2-3/2	C	Mass	H	Fi	V	V	Mod	7.7	.90	
1	0	6	3220	A1	0-4	10YR6/2-4/2	SyCL	Wk Fi Gran	SlH	VFr	Sl	Sl	Non	6.1	.44	GS
				C	4-24	10YR5/2-4/2	SyCL	Mass	SlH	VFr	Sl	Sl	Non	7.0	.21	

Location Number	Exposure (degrees)	Slope (percent)	Altitude (feet)	Horizon	Depth (inches)	Color (Munsell Chart)	Texture	Structure	Consistence				Effervescence	pH	Electroconductivity (mmhos/cm at 25° C)	Boundary
									Dry	Moist	Stickiness	Plasticity				
38	210	6	2850	A1	0-2	10YR5/2-4/2	SiCL	Wk Med Platy	SlH	Fr	Sl	V	Mod	7.4	.35	CW
				B2t	2-7	2.5Y5/2-4/2	C	Mod Co Prism	H	Fi	Stk	V	Mod	7.3	.36	CW
				R	7-24								Sl	7.6	.43	
24	345	39	3100	A1	0-4	10YR5/2-4/2	C	Str VFi Gran	Sof	Fi	V	V	Mod	7.5	.22	CW
				B2t	4-12	10YR5/2-4/2	C	Wk Med Prism	SlH	Fi	V	V	Str	7.6	.19	DW
				C	12-24	10YR5/2-4/2	C	Mass	H	Fi	V	V	Vio	7.7	.18	
14	25	15	3350	A1	0-6	10YR5/2-3/3	C	Wk Co Sub Blk	EH	VFi	V	V	Mod	7.7	1.50	CW
				B2t	6-11	10YR5/2-4/2	C	Wk Med Prism	EH	VFi	V	V	Str	8.2	.43	CW
				C1	11-19	10YR6/2-4/3	C	Mass	EH	VFi	V	V	Str	8.2	1.40	CW
				C2	19-25	10YR7/2-4/2	C	Structureless	H	VFr	V	V	Mod	7.6	6.98	
34	186	10	3100	A1	0-4	10YR7/3-4/3	SiL	Wk Med Platy	SlH	Fr	Sl	Sl	Non	6.7	.30	AW
				B2t	4-14	10YR6/3-4/3	SiC	Mod Co Prism	VH	Fi	Stk	Pla	Non	6.7	.34	GW
				Cca	14-24	2.5Y6/2-4/2	SiCL	Mass	VH	Fi	Stk	Pla	Str	7.9	.50	
39	55	6	3125	A1	0-5	2.5Y5/2-3/2	L	Mod Med Platy	SlH	VFr	Non	Sl	Non	6.6	.23	AW
				B2t	5-11	2.5Y5/2-3/2	CL	Str Med Prism	H	Fi	Sl	Pla	Non	6.9	.35	CW
				B3ca	11-16	2.5Y6/2-4/2	L	Mod Med Prism	H	Fr	Sl	Pla	Mod	7.7	.60	CW
				Cca	16-26	2.5Y6/2-4/2	L	Mass	H	Fi	Sl	Pla	Str	7.8	.30	
21	120	8	3100	A1	0-2	10YR6/2-4/2	SiC	Str Fi Gran	SlH	Fr	Stk	Pla	Str	7.6	.38	CW
				B2t	2-7	10YR6/2-4/2	C	Mod Co Prism	SlH	Fr	V	V	Str	7.5	1.80	AW
				C	7-24	10YR6/1-4/2	SyCL	Mass	SlH	Fr	Stk	Pla	Vio	7.4	2.40	
40	188	7	3100	A1	0-5	10YR5/2-3/2	L	Mod Med Platy	SlH	Fr	Sl	Pla	Sl	7.5	.41	GW
				B2t	5-12	2.5Y6/2-5/2	CL	Wk Med Prism	H	Fr	Stk	Pla	Str	7.8	.33	GW
				C	12-24	2.5Y6/2-4/2	L	Mass	H	Fr	Sl	Pla	Str	8.1	.41	
12	190	35	3500	A1	0-9	10YR6/3-4/3	CL	Mod Fi Sub Blk	SlH	Fi	Stk	V	Str	7.4	2.20	GW
				B2t	9-15	10YR7/2-7/4	C	Wk Med Prism	H	Fi	Stk	V	Str	7.7	.42	CW
				C	15-24	10YR6/1-3/2	C	Mass	SlH	Fr	V	Pla	Str	7.7	.25	

Location Number	Exposure (degrees)	Slope (percent	Altitude (feet)	Horizon	Depth (inches)	Color (Munsell Chart)	Texture	Structure	Consistence				Effervescence	pH	Electroconductivity (mmhos/cm at 25° C)	Boundary
									Dry	Moist	Stickiness	Plasticity				
23	130	23	3100	A1	0-6	10YR5/2-3/2	SiC	Str Fi Gran	SlH	Fi	Stk	Pla	Mod	7.8	.21	CW
				B2t	6-17	10YR5/2-4/2	C	Str Co Prism	H	VFi	V	V	Str	8.2	.16	GW
				C	17-24	10YR5/2-3/2	C	Mass	VH	VFi	V	V	Vio	8.2	.40	
55	135	7	2800	A1	0-3	2.5Y5/2-3/2	SiCL	Mod Med Sub Blk	VH	Fr	Stk	Pla	VSl	7.0	.70	GW
				B2t	3-16	2.5Y5/2-4/2	C	Wk Co Prism	VH	VFi	V	V	Mod	7.6	.76	DW
				R	16-24									6.0	5.20	
49	355	10	2925	A1	0-3	2.5Y5/2-4/2	C	Mod Med Sub Blk	SlH	Fr	Stk	Pla	Sl	7.5	.33	CW
				B2t	3-14	2.5Y5/2-4/2	C	Mod Co Prism	VH	VFi	V	V	Mod	7.8	.34	GW
				C	14-24	2.5Y5/2-4/2	C	Mass	VH	VFi	Stk	Pla	Sl	7.5	5.50	
50	134	16	2900	A1	0-2	2.5Y5/2-4/2	SiC	Mod Med Sub Blk	H	Fr	Stk	V	VSl	6.3	.55	CW
				B2	2-6	2.5Y5/2-3/2	C	Wk Med Prism	VH	VFi	Stk	Pla	Non	5.9	.26	GW
				R	6-24									4.6	.30	
56	255	5	2900	A1	0-3	2.5Y5/2-4/2	SiCL	Mod Med Sub Blk	SlH	Fr	Stk	Pla	VSl	6.2	.40	CW
				B2t	3-7	2.5Y5/2-4/2	C	Mod Co Prism	VH	VFi	Stk	V	Non	6.3	.22	GW
				B3	7-14	10YR5/3-4/3	C	Wk Co Prism	H	Fi	Stk	Pla	VSl	6.5	2.80	GW
				R	14-24									4.9	4.90	
48	178	16	2900	A1	0-3	2.5Y5/2-4/2	C	Str Med Sub Blk	H	Fr	Stk	V	VSl	6.5	.80	GW
				B2t	3-10	2.5Y5/2-4/2	C	Wk Co Prism	VH	VFi	V	V	VSl	7.1	.36	GW
				C	10-22	2.5Y5/2-4/2	C	Mass	VH	Fi	Stk	Pla	Non	7.0	2.50	GW
				R	22-24									5.6	3.00	
54	0	9	2775	A1	0-3	2.5Y5/2-4/2	SiCL	Str Fi Gran	H	Fr	Stk	Pla	VSl	7.0	.48	GW
				B2	3-18	2.5Y5/2-4/2	SiC	Wk Co Prism	VH	VFi	Stk	V	Sl	7.3	.52	CW
				R	18-24								Sl	7.4	2.50	
57	9	2	2700	A1	0-2	2.5Y5/2-4/2	SiC	Mod Med Sub Blk	H	Fr	Stk	Pla	VSl	6.3	.24	CW
				B2t	2-8	2.5Y5/2-4/2	C	Mod VCo Prism	VH	VFi	V	V	VSl	6.9	.52	CW
				C	8-24	2.5Y5/2-4/2	C	Mass	VH	VFi	V	V	Sl	7.2	5.50	

Location Number	Exposure (degrees)	Slope (percent)	Altitude (feet)	Horizon	Depth (inches)	Color (Munsell Chart)	Texture	Structure	Consistence				Effervescence	pH	Electroconductivity (mmhos/cm at 25° C)	Boundary
									Dry	Moist	Stickiness	Plasticity				
47	20	15	2700	A1	0-2	2.5Y5/2-4/2	SiCL	Str Med Sub Blk	H	Fr	Sl	Pla	VSl	6.7	.32	CW
				B2t	2-9	2.5Y5/2-4/2	C	Mod Co Prism	VH	Fi	Stk	V	VSl	7.5	.50	GW
				C	9-24	2.5Y5/2-4/2	C	Mass	VH	Fi	Stk	V	Sl	7.5	4.50	
53	156	6	2750	A1	0-2	2.5Y5/2-4/2	SiCL	Mod Med Sub Blk	H	Fr	Stk	Pla	VSl	6.6	.43	GW
				B2t	2-11	2.5Y5/2-4/2	SiC	Mass	VH	VFi	Stk	V	Non	6.9	.40	GW
				C	11-24	2.5Y5/2-4/2	C	Mass	SlH	Fi	Stk	Pla	Sl	7.3	3.50	
46	103	1	2700	A1	0-2	2.5Y6/2-4/2	C	Str Med An Blk	SlH	Fr	V	V	VSl	6.6	.32	CW
				B2	2-13	2.5Y5/2-4/2	C	Wk Co Prism	VH	VFi	Stk	V	Sl	7.5	.55	GW
				C21	13-22	2.5Y5/2-4/2	C	Mass	VH	VFi	Stk	V	Sl	7.7	2.00	GW
				C22	22-26	2.5Y7/2-4/2	C	Mass	H	VFi	Stk	V	Mod	7.7	2.00	

APPENDIX II

PLANT LIST:

The following list contains species encountered in the study area:

Scientific Name	Common Name	Number of Sites Where Present (of 58)
Perennial Grasses.		
Agropyron dasystachyum	Thickspike wheatgrass	35
A. desertorum	Crested wheatgrass	*1/
A. smithii	Western wheatgrass	56
A. spicatum	Bluebunch wheatgrass	24
Aristida longiseta	Red threeawn	3
Bouteloua gracilis	Blue grama	45
Calamagrostis montanensis	Plains reedgrass	12
Distichlis stricta	desert saltgrass	2
Hordeum jubatum	Foxtail barley	*
Koeleria cristata	Prairie junegrass	52
Muhlenbergia cuspidata	Plains muhly	8
Oryzopsis hymenoides	Indian ricegrass	1
Poa canbyi	Canby bluegrass	23
P. pratensis	Kentucky bluegrass	2
P. secunda	Sandberg bluegrass	56
Schedonnardus paniculatus	Tumblegrass	14
Sitanion hystrix	Squirreltail	4
Sporobolus cryptandrus	Sand dropseed	4
Stipa comata	Needleandthread	34
S. viridula	Green needlegrass	37
Annual Grasses.		
Bromus japonicus	Japanese chess	22
B. tectorum	Cheatgrass brome or Downy chess brome	12
Festuca octoflora	Six-weeks fescue	24
Sedges.		
Carex eleocharis	Needleleaf sedge	31
C. filfolia	Threadleaf sedge	9

1/ Species collected in the study area but not encountered in the plots in 1967.

Scientific Name	Common Name	Number of Sites Where Present (of 58)
Annual Forbs.		
Aster tanacetifolia	Tansyleaf aster	1
Atriplex argentea	Silverscale saltbush	1
A. dioica	Annual saltbush	*1/
Camelina microcarpa	Littlepod falseflax	12
Chenopodium leptophyllum	Narrow-leaf goosefoot	15
Cirsium undulatum	Wavy-leaf thistle	*
Collomia linearis	Narrow breakleaved collomia	20
Descurainia pinnata	Pinnate tansy mustard	1
Draba nemorosa	woods draba	32
D. reptans	Draba	*
Epilobium paniculatum	Paniculed willow-herb	2
Euphorbia spatulata	Spatula-leaved spurge	*
Hedeoma hispida	Rough false pennyroyal	16
Lappula echinata	European stick tight	19
Lepidium densiflorum	Prairie pepperweed	44
Monolepis nuttalliana	Nuttall monolepis	*
Oenothera albicaulis	Whitestem evening primrose	1
Plantago elongata	Slender plantain	2
P. spinulosa	Spindle plantain	42
Polygonum ramosissimum	Brushy knotweed	2
Sisymbrium altissimum	Tumblemustard	*
Spergularia sp.	Sand spurry	2
Veronica peregrina	Purslane speedwell	1
Biennial Forbs.		
Grindelia squarrosa	Curlcup gumweed	3
Lactuca serriola	Wild lettuce	*
Lupinus pussillum	Rusty lupine	1
Melilotus officinalis	Yellow sweetclover	12
Tragopogon dubius	Common salsify	20
Perennial Forbs.		
Achillea millefolium	Western yarrow	16
Allium textile	Onion	40
Antennaria rosea	Rose pussytoes	9

1/ Species collected in the study area but not encountered in the plots in 1967.

Scientific Name	Common Name	Number of Sites Where Present (of 58)
Perennial Forbs (continued)		
Arabis holboellii	Holboell rockcress	2
Arenaria hookeri	Hooker sandwort	10
Artemisia longifolia	Longleaf sagebrush	1
Arnica sororia	Arnica	*1/
Aster foliaceus	Leafybract aster	*
Astragalus bisulcatus	Two grooved milkvetch	*
A. gilviflorus	Threeleaved milkvetch	2
A. missouriensis	Missouri milkvetch	2
Astragalus sp.	Milkvetch	*
Besseya wyomingensis	Kitten-tail	1
Calochortus nuttallii	Mariposa lily	2
Cirsium flodmani	Thistle	*
Comandra umbellata	Pale bastard toadflax	12
Crepis occidentalis	Western hawksbeard	1
Erigeron ochroleucus	Daisy	5
E. pumilus	Daisy	23
Eriogonum umbellatum	Sulfur eriogonum	2
Caura	Scarlet gaura	*
Haplopappus nuttallii	Nuttal goldenweed	1
H. spinulosus	Spiney goldenweed	1
Heuchera parvifolia	Littleleaf allumroot	1
Hymenoxys richardsonii	Pingue	*
Iva axillaris	Poverty weed	*
Lithospermum incisum	narrow leaf gromwell	1
Liatris punctata	Dotten blazingstar	1
Lomatium foeniculaceum		12
Lygodesmia juncea	Rush skeletonweed	1
Microseris nutans	Nodding microseris	22
Penstemon albertinus	Alberta penstemon	*
P. albidus	White penstemon	*
P. nitidus	Waxleaf penstemon	3
Petalostemon purpureum	Purple prairie-clover	4
Phacelia linearis	Linear-leaf phacelia	12
Phlox sp.	Phlox	34
Potentilla hippiana	Horse cinquefoil	3
Psoralea argophylla	Silverleaf scurfpea	10
P. esculenta	Breadroot scurfpea	*
P. tenuiflora	Slim flower scurfpea	2

1/ Species collected in the study area but not encountered in the plots in 1967.

Scientific Name	Common Name	Number of Sites Where Present (of 58)
Perennial Forbs (continued)		
Rumex sp.	Dock	7
Sphaeralcea coccinea	Scarlet globemallow	47
Taraxicum officinale	Common dandelion	24
Thermopsis rhombifolia	Prairie thermopsis	2
Townsendia hookeri	Hooker's townsendia	*1/
Vicia americana	American vetch	48
Half shrubs.		
Artemisia frigida	Fringed sagewort	43
Gutierrezia sarothrae	Broom snakeweed	28
Shrubs.		
Artemisia cana	Silver sagebrush	2
A. tridentata vaseyana	Mountain big sagebrush	58
Atriplex nuttalii	Nuttal saltbush	8
Chrysothamnus nauseosus	Rubber rabbitbrush	10
Juniperus horizontalis	Creeping juniper	2
Mamillaria vivipara	Pink pincushion cactus	3
Opuntia polyacantha	Plains prickly pear	56
Rosa woodsii	Wood's rose	1
Sarcobatus vermiculatus	Greasewood	4
Clubmoss and Lichen.		
	Lichen	52
	Moss	20
Selaginella densa	Clubmoss	20

1/ Species collected in the study area but not encountered in the plots in 1967.

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