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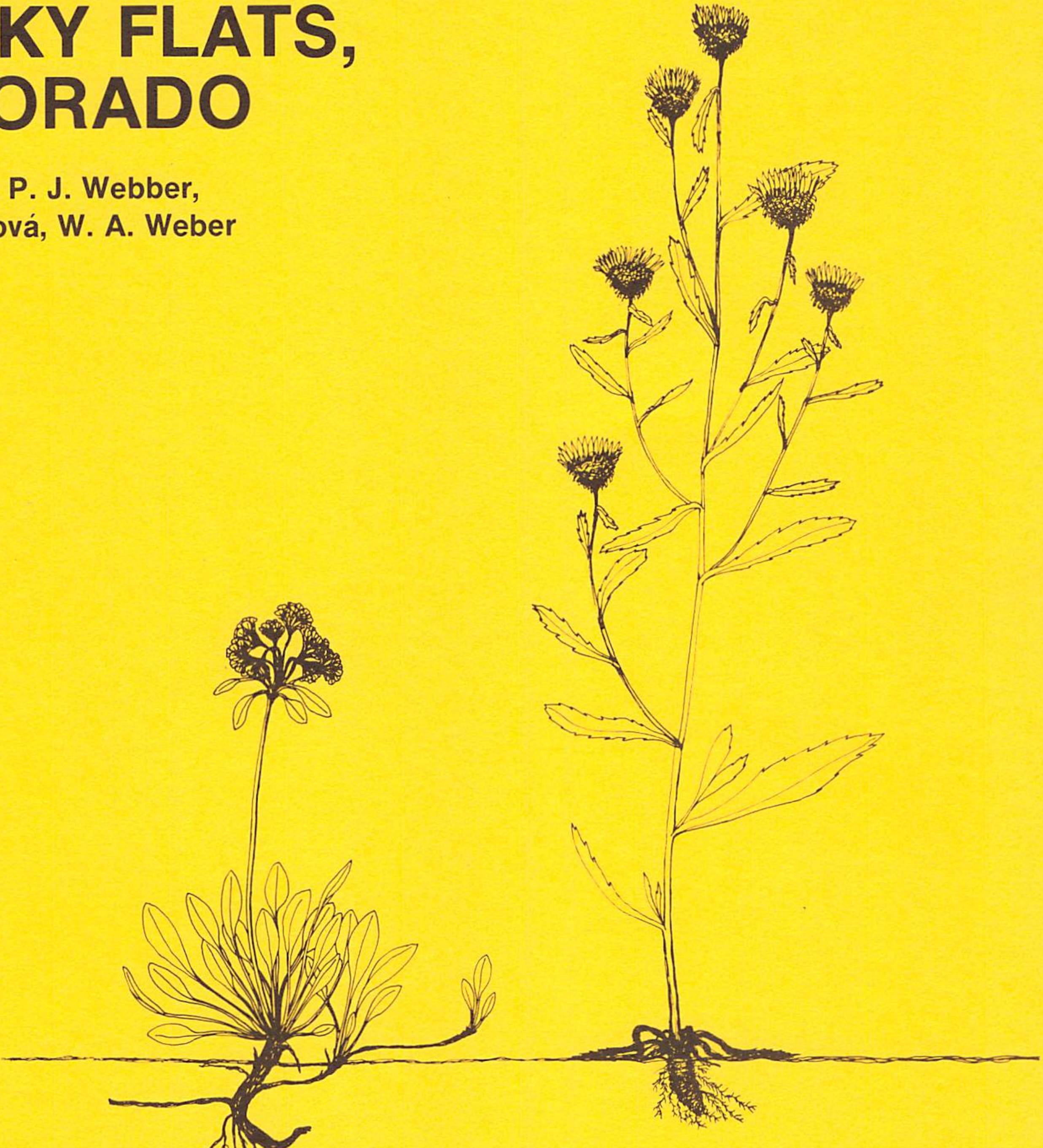

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MAP OF MIXED PRAIRIE GRASSLAND VEGETATION

ROCKY FLATS, COLORADO

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PREFACE

The publication of this paper as an Institute of Arctic and Alpine Research Occasional Paper is the product of the continuing efforts by the Institute to contribute and involve its expertise in two directions not necessarily related to arctic or alpine environments: (1) local geoecological problems, related to the well-being of the people of Colorado, and (2) informed development and management of resources.

Prudent development and management of local resources has to be based on detailed field information. Understanding and prediction of short- and long-term changes in ecosystems are necessary prerequirements of management decisions and formulation of future management policies. Vegetation is one of the key elements in ecosystems and is of particular importance as an indicator and agent of ecosystem recovery after disturbance. It is hoped that land management and land-use planning will be based in part on detailed field vegetation studies in the future, and that the present paper will make a contribution to applied ecology.

The vegetation research presented in this paper was supported by a U.S. Energy Research and Development Administration contract no. E(11-1)-2371. We would like to thank Dr. William S. Osburn, Jr., Department of Energy, for his general support of this project. The personnel of the Rocky Flats, Rockwell International Plant were very helpful during the course of this study. Most of the former private owners of the land surrounding the plant kindly gave us permission to enter their properties. Vicki Dow drafted the map and some of the figures, and prepared the color map copy. Ken Bowman also drafted some of the figures. Tewell Printing and Lithographing Company of Denver printed the map. Rolf H. Kihl, Sedimentology Laboratory, Institute of Arctic and Alpine Research, analyzed the soil samples. Assistance with computer programs was provided by James A. Clark and Margaret Eccles.

ABSTRACT

A color vegetation map at the scale of 1:12,000 of the area surrounding the Rocky Flats, Rockwell International Plant near Boulder, Colorado, provides a permanent record of baseline data which can be used to monitor changes in both vegetation and environment and thus to contribute to future land management and land-use policies. Sixteen mapping units based on species composition were identified, and characterized by two 10-m^2 vegetation stands each. These were grouped into prairie, pasture, and valley side on the basis of their species composition. Both the mapping units and these major groups were later confirmed by agglomerative clustering analysis of the 32 vegetation stands on the basis of species composition. A modified Bray and Curtis ordination was used to determine the environmental factor complexes controlling the distribution of vegetation at Rocky Flats. So that a great number of zero similarities between stands would not occur, a growth-form data matrix was used as ordination input; this proved to be a satisfactory alternative to input of species data to ordination programs. It was determined during ordination trials that the above-mentioned ordination technique was more efficient and successful in interpreting the vegetation at Rocky Flats than principal components analysis when growth-form data input was used. Three environmental factor complexes correlated significantly with the ordination axes: percentage of nonvegetated area (X axis), moisture regime (Y axis), and grazing regime (Z axis). This correlation agreed well with the observations made during field work and during map analysis. The growth forms were shown to have a significant relationship with the controlling environmental factors. Recommendations are made for future policies of environmental management and predictions of the response to environmental change of the present vegetation at the Rocky Flats site.

INTRODUCTION

The present study was part of a project which documented the plant life in the vicinity of the Rocky Flats Plant between Boulder and Denver, Colorado. The plant is owned by the U.S. Department of Energy (formerly U.S. Atomic Energy Commission and U.S. Energy Research and Development Administration), operated by Rockwell International; it is concerned with plutonium processing and recovery. We initiated this analysis of natural vegetation, including plant species inventory, vegetation inventory, and identification of major environmental control factors, at the Rocky Flats site to provide a data base on which future environmental decisions could be made (cf. Kessell, 1979). This study was not directed toward assessing any past or present industrial impacts of plutonium processing.

A botanical inventory of the vascular plants, bryophytes, and lichens present in the vicinity of the Rocky Flats Plant site was completed during the first stage of the project (Weber et al., 1974). In subsequent stages, vegetation has been the primary subject of study (Webber and Clark, 1976; Clark, 1977; Webber et al., 1977). In addition to the color map included here (in pocket), five detailed maps of selected areas were produced (Webber and Clark, 1976). During the last stage of the project, an attempt was made to establish normal morphological characteristics of two vascular plant species (*Alyssum alyssoides* and *Paronychia jamesii*) common at the Rocky Flats site (Webber and Werbe, 1977); these plants are potential indicators of mutagenic hazards. This last stage of the project will enable development of a vegetation-based system for detection of possible changes in plant life induced by accidental plutonium release around the plant. Two of the authors of the present paper (P.J.W. and W.A.W.) were co-principal investigators on the project; the results presented here were, for the most part, included in greater detail in a M.A. thesis (Clark, 1977) under direction of P.J.W.; V.K. participated in the field work, vascular plant identification, and writing; W.A.W. identified bryophytes and lichens and verified the identification of vascular plants.

This paper focuses on the vegetation map of the Rocky Flats site, the associated phytosociological data, and the major environmental controls of the vegetation.

DESCRIPTION OF THE STUDY AREA

Abiotic Environment

The Rocky Flats vegetation map area (38.8 km^2) is located in a transition area between the Great Plains and the Rocky Mountains in Jefferson and Boulder Counties, Colorado. The foothills of the Front Range rise 5 km to the west. The elevations range from 1707 m s.m. in the valleys of the southeastern part to 1905 m s.m. on the plains of the southwestern part. The area slopes towards the east.

The rocks in the map area, which range in age from Precambrian to Holocene, include the Arapahoe Formation, the Laramie Formation, Fox Hills Sandstone, and Pierre Shale, and are composed of shales, clays, sandstones, siltstones, claystones, and sands (Figure 1; Van Horn, 1972; Hurr, 1976). The surficial deposits range in age from Pleistocene to Holocene. The source of these deposits is primarily the Precambrian quartzite from the mountains to the west, but also includes the sedimentary bedrock and older surficial deposits. The oldest is the pre-Rocky Flats Alluvium, which caps some hills and terrace remnants to the west. The topography is dominated by the younger Rocky Flats Alluvium which is a broad alluvial fan and uncomformably overlies all older bedrock formations. The resistant sandstone beds in the Laramie Formation form a north-south oriented hogback; streams cutting through the hogback form broad, shallow, east-west oriented valleys. Locally two Wisconsin-age terraces are associated with the present drainage (Malde, 1955; Hurr, 1976). Valley fill occupies the bottom of the valleys, while colluvium deposits form on the sides and at the base of steep slopes in the stream valleys. All streams in the area are ephemeral. The hydrology of the area is described by Hurr (1976).

The soils of the map area are loams which belong to the Larimer, Fort Collins, Cass, and Terry series (Figure 2). Forty percent of the area is classified by Harper et al. (1932) as rough, broken land,

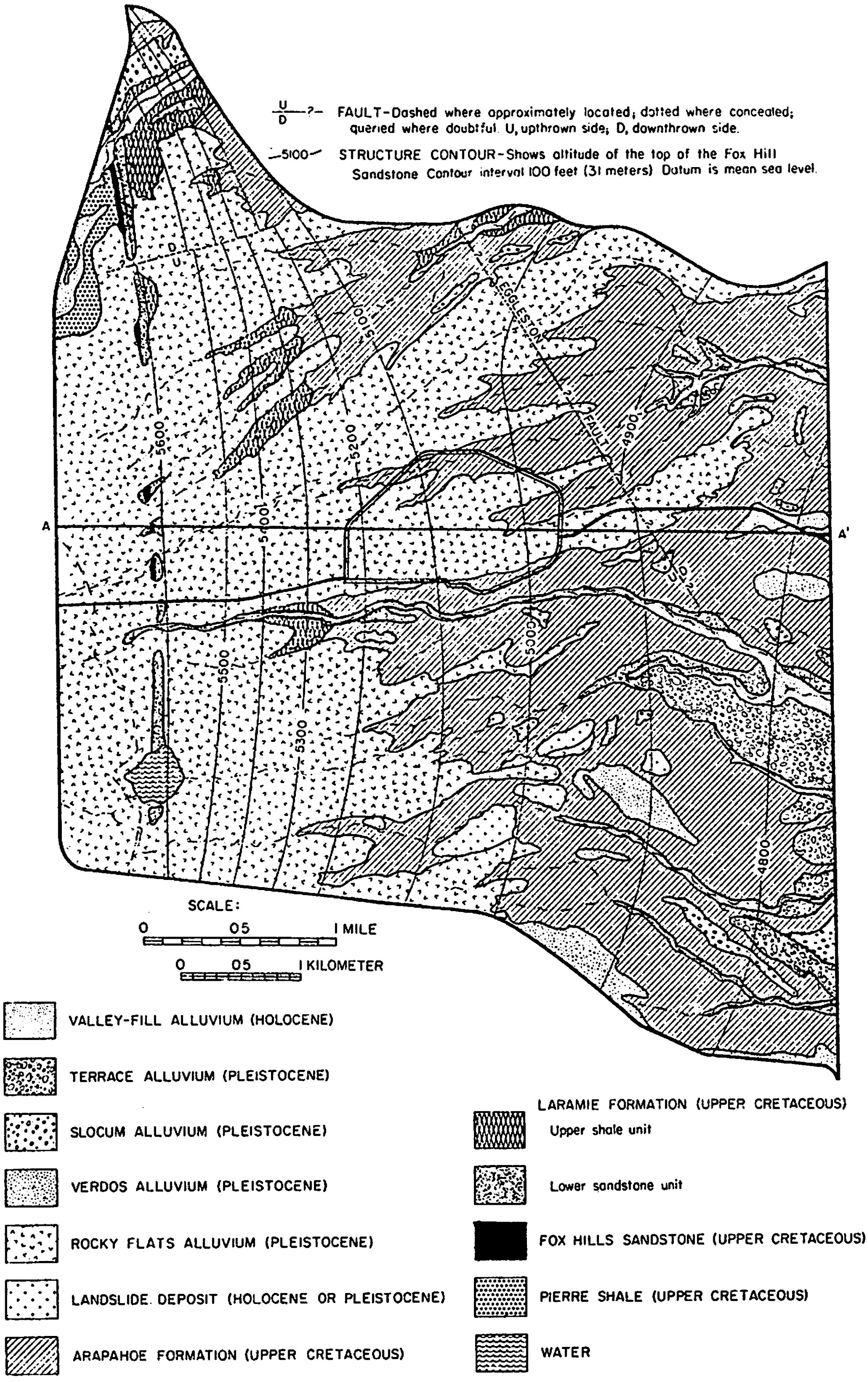


Figure 1. The bedrock and surficial geology of the map area. Adapted from Hurr (1976, plate 1) and Malde (1955).

suitable only for pasture because of its steepness or large amounts of surface boulders. Rocky Flats soils are believed to be of pre-Wisconsin age (Malde, 1955); they have well-developed profiles with columnar structure in B horizons (Branson et al., 1965; Hadley and Branson, 1965). Among soils in the northwestern corner of the map area, identified by the soil survey of Boulder County (Moreland and Moreland, 1975), are Valmont cobbly clay loam (Aridic Argiustolls, Mollisols), Nederland very cobbly sandy loam (Aridic Argiustolls, Mollisols), Niwot soils (Typic Haplaquolls, Mollisols), Kutch clay loam (Torrertic Argiustolls, Mollisols), and terrace escarpments. Samsil-Shingle complex (Ustic Torriorthents, Entisols) and Nunn clay loam (Aridic Argiustolls, Mollisols), common on similar landforms in Boulder County, probably also occur in the study area.

The climate of Rocky Flats is similar to that of the Great Plains although it is tempered by the proximity of the Front Range. The winters are cold and dry, and the maximum precipitation occurs in May (Figure 3; Livingston, 1952; Bradley, 1973). According to Paddock (1964), generally low precipitation, a large daily temperature range, low humidity, and high radiation receipts characterize the climate of this region. The frost-free season at Boulder is about 152 days (Bradley, 1973). The winds prevail from the west, and strong downslope winds often referred to as chinooks or föhns are a significant component of the climate. Brinkmann (1973a, 1973b) discussed the origin of downslope windstorms and their physical characteristics. These windstorms exhibit hurricane-force velocities, extreme gustiness, rapid and frequent fluctuation in speed, and an associated extremely low relative humidity. The annual mean wind speed at Rocky Flats is 3.68 m/sec, and annual peak gust 41.3 m/sec (24-year period; Hornbacher, 1980, personal communication); the wind speeds are usually higher than those in the Boulder area (Madole et al., 1973).

Land Use and Herbivores

The Rocky Flats area was probably forested in the past (Weber et al., 1974), the forest having been removed by burning and cutting by

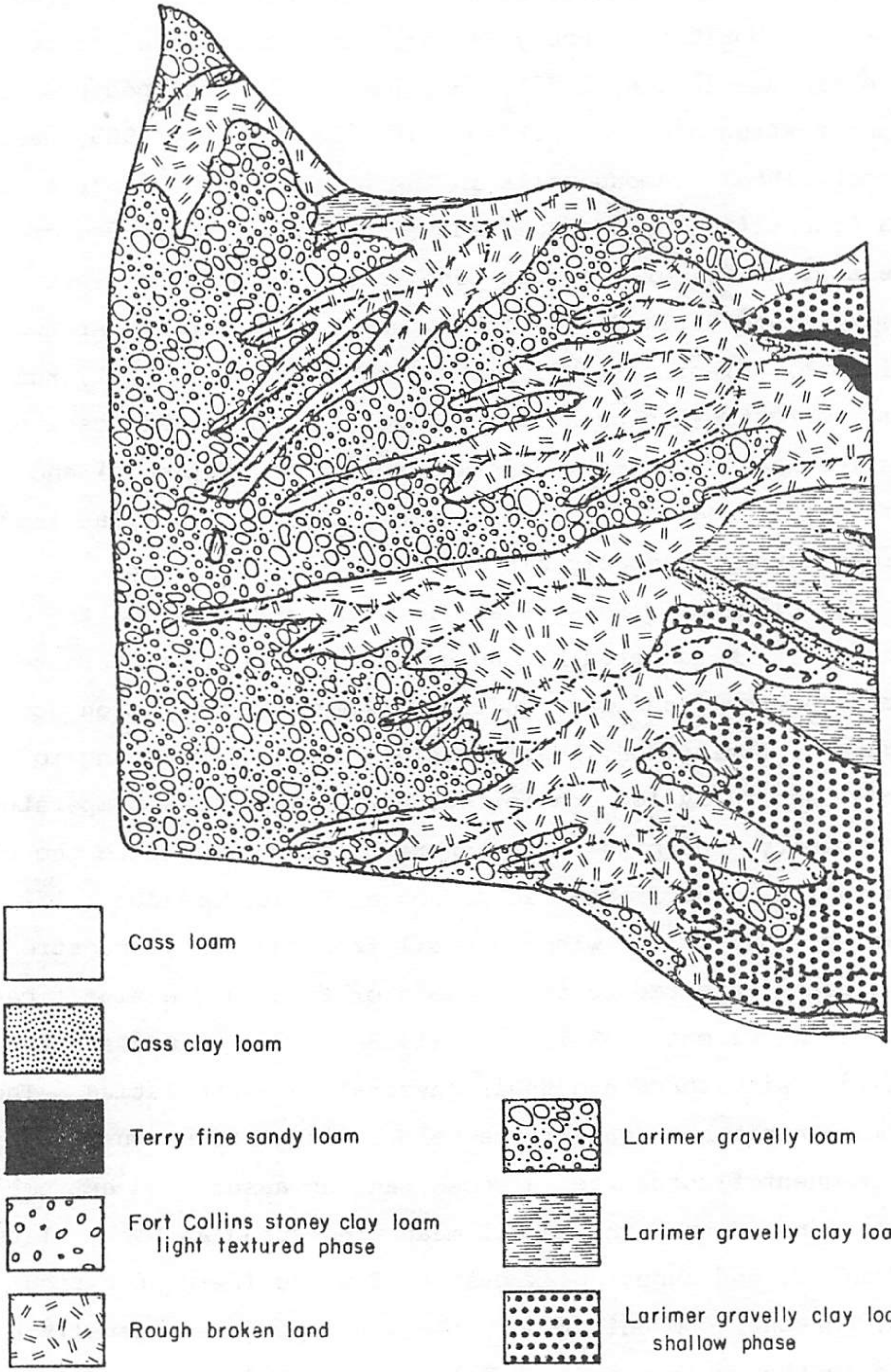


Figure 2. The soils of the map area. Adapted from Harper et al. (1932).

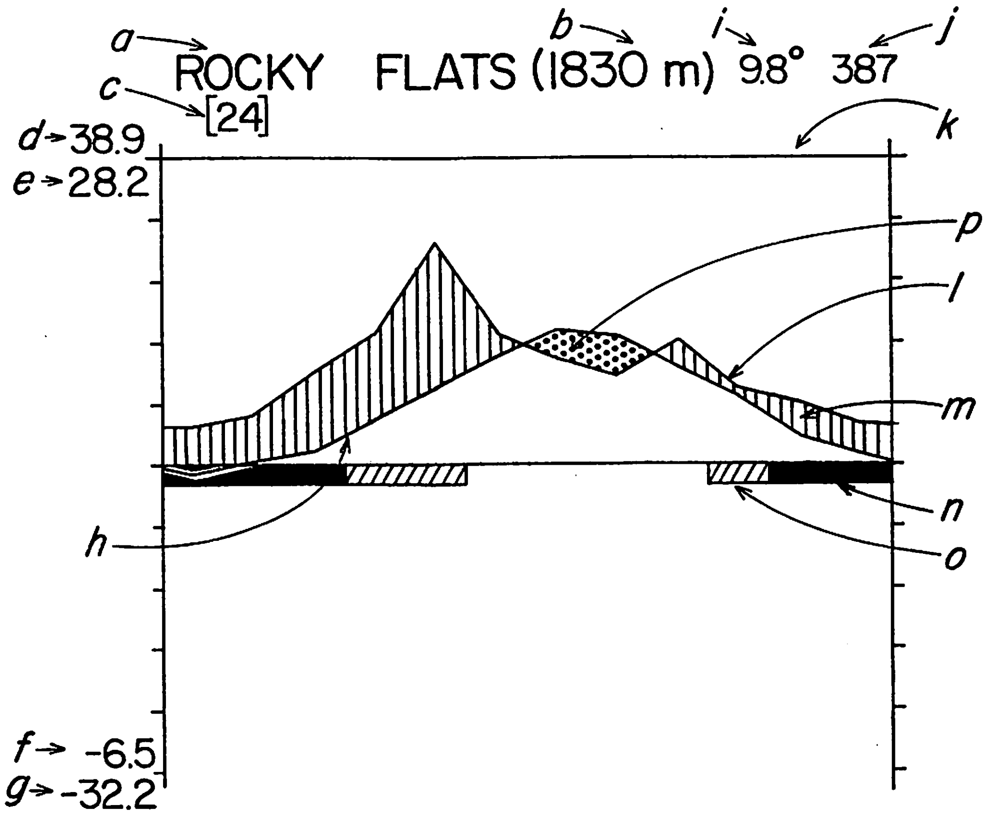


Figure 3. Climatic diagram for Rocky Flats. After Walter and Lieth (1967) on the basis of the Rocky Flats Plant data (West, 1978, personal communication).
Abscissa: months (January-December), ordinate: one division - 10°C or 20 mm precipitation.
a - station name, b - elevation in meters, c - duration of observation in years, d - highest recorded temperature in °C, e - mean daily maximum temperature of the warmest month, f - mean daily minimum temperature of the coldest month, g - lowest recorded temperature, h - curve of mean monthly temperature, i - mean annual temperature, j - mean annual precipitation in mm, k - line of 100 mm precipitation, l - curve of mean monthly precipitation, m - the relative humid season, n - months with mean daily minimum temperature below 0°C, o - months with absolute minimum below 0°C, p - relative period of drought (after Walter, 1973).

Indians and white settlers. Unlike in some areas just to the northeast, which were protected from logging since the 1870s, the forest in the Rocky Flats area has not recovered, apparently because the area has been exposed to the strong winter winds by the deforestation and because of its dryness. Cattle have overgrazed the Rocky Flats area for a long time.

The grazing was first discontinued approximately 25 years ago in the land sections immediately adjacent to and owned by the Rocky Flats plant. An outer, main wire fence surrounds this land, which serves as a buffer zone around the plant. In 1974 when this vegetation study was initiated, this buffer zone constituted about one-fourth of the study area. The remainder of the area was privately owned and utilized as pasture for range animals and as agricultural fields. The intensity of grazing differed in various sections and properties.

Today, much of the area is partially barren or heavily disturbed from the combined effects of an exposed windy location, nutrient-poor soil, bulldozing of fire-breaks, small-mammal burrowing, and cattle and horse grazing. Branson et al. (1965) attributed the formation of pebble mounds at Rocky Flats to the activities of the mountain pocket gopher. In small parts of the area, soil is contaminated by radioactive waste and hence soil erosion and subsequent redistribution could produce an environmental hazard. This subject is discussed by Caine and Morin (1975) and by Whicker and Staff (1975).

Flora and Vegetation

Three-hundred and eighty-five plants, 21 bryophytes, 44 lichens, and 1 macroscopic green alga have been identified during the botanical inventory and vegetation studies. The plant nomenclature in this study follows Weber et al. (1974) and Weber and Johnston (1976). According to Weber et al. (1974), the floristic spectrum of vascular plants represents residual tall-grass prairie, short-grass plains, ponderosa pine woodland, and foothill ravine flora all of which have been extremely depauperated by human activity. Introduced Eurasian weeds constitute a significant percentage of the flora. Most of the very few bryophytes and lichens present today represent remnants of the forest vegetation; the area is generally too dry for bryophytes and lichens to flourish today. The remainder of bryophytes and lichens are common floodplain species of the surrounding piedmont valleys. The elements of the forest flora and remnants of woody vegetation persist on north-facing slopes in ravines and gulches. *Pinus ponderosa* remains on rocky ridges. Species that indicate forest conditions are *Agrimonia striata*, *Campanula rotundifolia*, *Carex interior*, *Galium boreale*, and *Physocarpus monogynus* (Weber et al., 1974).

The mid grasses (Weaver and Clements, 1938) reached the foot of the mountains during the Pleistocene when a general depression of timberline and cooler, moister climate permitted migration of the Cordilleran forest eastward (on the higher areas) and migration of the midwestern prairie flora westward (along the river valleys and adjacent slopes). Degeneration of the Pleistocene climate and the accompanying dryness isolated a number of prairie species in mesic pockets in the protection of the Front Range and left some Cordilleran elements stranded far to the east of their present major ranges (Weber, 1965). Livingston (1952) proposed that true prairie species occurring in the Black Forest area near Colorado Springs, Colorado, have persisted on the high mesas since the retreat of the glaciers. This may partially explain their presence on Rocky Flats (Branson et al., 1965). *Andropogon gerardi*, *Sporobolus heterolepis*, and *Schizachyrium scoparium* are among prairie species still present at Rocky Flats (Weber et al., 1974).

The Rocky Flats vegetation resembles the native prairie vegetation to some degree, as evidenced by comparison with the descriptions of prairie grassland on the Great Plains (e.g., Weaver and Fitzpatrick, 1934; Weaver and Clements, 1938) and with the Colorado relict prairie communities studied by Livingston (1952). Most of the present Rocky Flats vegetation in mesic areas belongs to the mixed prairie association of the grassland or prairie formation (Weaver and Clements, 1938). Short-grass plains vegetation occurs in dry sites and areas of compacted soil; according to Weaver and Clements (1938), the dominance of short grasses, *Bouteloua* and *Buchloë* in particular, is a result of over-grazing. Weaver and Clements also pointed out that when grazing is prevented by fenced exclosures, the mid grasses return in a few years. Branson et al. (1965) concluded that the presence of the prairie grasses on stony soil and their absence on shale-derived soil at Rocky Flats are largely due to greater soil moisture availability, and perhaps higher soil temperatures in summer. The vegetation of the area near Boulder, including Rocky Flats, has previously been described by Vestal (1914), who recognized a number of plant associations and presented several perceptive insights into relationships between vegetation and environment. He emphasized the transitional character of the environment in this area and identified grazing as an important factor disturbing vegetation. He also observed that *Bouteloua gracilis* replaces *Agropyron smithii* in the presence of grazing. Hyder et al. (1966), who studied vegetation-soils and vegetation-grazing relationships in grassland vegetation near Nunn, Colorado (where grazing has been controlled at various intensities since 1939), found that *Stipa comata* importance decreased with increasing grazing intensity. The most important effect of heavy grazing, however, has been a reduction in herbage yields.

METHODS

A modification of Küchler's comprehensive method of vegetation mapping (Küchler, 1967) was used to construct the vegetation map (see pocket). As in the course of other mapping projects, we found that it was more expedient to draw unit boundaries on black and white photographs in the field rather than beforehand in the laboratory. In black and white photographs, different shades of gray represent the differences in percentage of vegetated area rather than floristic differences between mapping units (cf. Komárková and Webber, 1978). Field mapping provides considerably more information than remote sensing methods (cf. Komárková and Webber, 1978). The diameter of the smallest mapped area was approximately 50 m, except for the above mentioned pebble mounds, which were often smaller but were retained on the map. In the few sections of the map area that were privately owned and to which we were not granted access, the unit boundaries were drawn onto the photographs from a distance.

Sixteen mapping units were defined in the course of field mapping on a combination floristical-physiognomical basis (Figures 4-19). The mapping units were named according to the two main dominant plants in each. The moisture regime of each mapping unit is characterized in the unit name (dry, moist, wet), as is the physiognomy of the unit (pasture, prairie, savannah, barrens, low scrub, streambank, marsh, field, scrub). The mapping units were grouped into two classes (well vegetated vs. barren, disturbed, and cultivated units) which were distinguished on the basis of bare soil cover. The area occupied by each mapping unit was determined by cutting the map and weighing the accumulated pieces of each unit.

The field mapping was done at a scale of 1:7920. The 1:12,000 scale of the final color version was determined by standard press and paper sizes and by the production costs. The colors for the mapping units were chosen in order to convey additional information about the mapping units (Küchler, 1967; Unesco, 1973), in this case, to illustrate moisture and disturbance regimes of the mapping units. (These regimes were judged to be the most important for their distribution during the fieldwork.) The evaluation of the moisture factor was based on soil water absorption values and on subjective scale estimates. Moisture regime is represented by orange (dry), yellow (moist), and blue (wet) colors. The evaluation of the disturbance was based on bare soil percentage and is represented by red (least disturbance), yellow (intermediate disturbance), and gray (greatest disturbance). The moisture and disturbance color sequences were combined when determining the color of each mapping unit. The base map was redrawn from the U.S. Geological Survey 1:24,000 maps (Golden and Louisville, Colorado, quadrangles) and enlarged. The copy of the map for reduction was prepared according to standard methods used in the Plant Ecology Laboratory, Institute of Arctic and Alpine Research, University of Colorado, Boulder, Colorado (see Komárková and Webber, 1978).

Each mapping unit was characterized by two vegetation samples. The sites for these samples were subjectively selected for uniformity and representativeness of each mapping unit in areas geographically separated, in order to attempt to cover the variability of each mapping unit within the map. Ten individual 1-m square quadrats were sampled in each stand and percentage crown cover of each vascular plant, bryophyte, and lichen species was estimated. Total percentage cover of vascular plants, bryophytes, and soil and rock lichens was also estimated.

Species index (Webber, 1971) values were computed and averaged for both stands of each mapping unit. Table 1 (see pocket) presents the species index values for five major dominant plants in each mapping unit. Complete species lists for each stand including the percentage cover values are available (Clark, 1977). Homogeneity within each mapping unit was determined and is also presented by Clark (1977).

The environment of each stand was characterized by estimating percentage rock, bare soil, and surface water cover; the intensity of three types of disturbance (small mammal, cattle and horse grazing, and man-caused disturbances such as bulldozing) and of site moisture regime was estimated using 10-part subjective scales. A soil sample of surface soil horizon was collected in each stand and analyzed according to standard methods in the Sedimentology Laboratory, Institute of Arctic and Alpine Research, University of Colorado, Boulder, Colorado.

The collected vegetation quadrat data matrix was viewed as a simplified geometrical model which can be analyzed for ecological gradients and for clustering of the stands (Orlóci, 1966). The agglomerative clustering average linkage method of Sokal and Sneath (1963), which produces polythetic, hierarchical dendrograms, was used to provide the classification of the 32 vegetation stands in the map area. Vegetation types are represented by clusters of stands in the dendrograms. Unfortunately, because of the constraints of having to accomplish the principal field work in one summer, it was not possible to finish vegetation analysis prior to field mapping. When this analysis was subsequently completed, it was found that this fact did not represent a serious problem in the interpretation of the map. However, this practice requires considerable prior experience with vegetation mapping and classification; we would like to point out the desirability of using vegetation units supported by vegetation analysis as mapping units.

The determination of environmental factor complexes controlling the vegetation at the Rocky Flats site was approached by means of indirect ordination, in which the vegetation stands are visualized as points in space with their attribute scores as coordinates (Orlóci, 1966). The axes of the ordination space represent environmental gradients along which the stands of vegetation are ordered. Correlation of environmental factors with the axes is a means of determining which environmental factors probably influence the distribution of the vegetation and to what extent they control it (Whittaker, 1967).

The range of vegetation types among the mapping units was such that the stand similarity matrix contained a number of zero values. Ordination of such a data matrix is not usually successful (Swan et al., 1969), as was the case in two trial ordinations of the Rocky Flats species data matrix. In order to avoid this problem, the species data were transformed into growth-form data. The species in the data set were reduced to a few growth form categories, which are a means of describing the vegetation in terms of its physiognomic structure and life cycle (Cain, 1950). The system of the growth forms used was approximately that of Mueller-Dombois and Ellenberg (1974). Ordination using growth forms rather than species data has been tried elsewhere. For example, Knight (1965) studied Wisconsin prairie vegetation and Knight and Loucks (1969) studied Wisconsin upland forest using stand ordinations based on groupings of species into growth forms based on structural and functional criteria.

During ordination trials, the growth form data proved to be a satisfactory alternative to species data as input to ordination programs; i.e., they produced ordinations that were more efficient and successful than those based on species data. This was determined by performing a modified Bray and Curtis ordination (Bray and Curtis, 1957; Beals, 1960) on four species and growth-form data matrices (see Clark, 1977, p. 60-74, 101-109, for further details). An ordination is efficient if the data can be summarized effectively within the spatial framework of three or fewer dimensions. An ordination can be considered successful if it exhibits three properties: 1) a high negative correlation between interstand distances within the ordination and interstand percentage similarities in terms of vegetation composition, 2) a nonrandom distribution of species within the spatial framework of ordination, and 3) some clear correlations between stand coordinates and stand environments (Austin and Orlóci, 1966; Webber, 1971).

Another objective of the ordination trials was to determine which of the available types of ordination programs was the most efficient and successful aid in interpreting the vegetation at Rocky Flats. This problem has been discussed in many papers concerned with ordination methods and is summarized by Beals (1973). Principal components analysis has been considered by some to be the most successful ordination technique (e.g., Austin and Orlóci, 1966; Gittins, 1969). To compare the performance of various ordination techniques, a modified Bray and Curtis ordination (Bray and Curtis, 1957; Beals, 1960), a principal components analysis or ordination using a standard Pearson's product-moment correlation matrix, a principal components ordination using a Spearman's rank correlation matrix (Nie et al., 1975), and the Swan, Dix, and Wehrhahn ordination (Swan et al., 1969) were all performed on the complete growth form data matrix.

A three-dimensional Bray and Curtis ordination with orthogonal axes proved to be the best method of analyzing the Rocky Flats vegetation data. This method was efficient in that the data were summarized within three dimensions. The correlation of growth-form data with interstand distances and interstand percentage similarity of the vegetation was negative and highly significant ($r_s = -.85$); there was a nonrandom distribution of species within the spatial framework (when plotted on the ordination, the distribution of *Buchloë dactyloides*, a native short-grass prairie species, was restricted to a narrow ecological range whereas the distribution of *Bromus tectorum*, a weedy species, was widespread); and there were high, significant correlations of several environmental factors with the ordination axes (see Clark, 1977, p. 74-80, 101-109, for further details). This is consistent with the results of Beals (1973), who found that the Bray and Curtis ordination comes closer to the preferable model of vegetation defined by changes in vegetation from point to point than does principal component analysis. As observed in the present study, Beals (1973) concluded that the former method has given results that are equally satisfactory ecologically to those of more sophisticated methods. Similarly, Gauch and Whittaker (1972) and Whittaker and Gauch (1973) suggested that Bray-Curtis ordination, using the complemented coefficient of community as a distance measure, is the best general ordination method, superior to principal components analysis. Kessell and Whittaker (1976) also concluded that the Bray-Curtis ordination technique gave the best ordinations when compared to the principal components analysis; however, they found that the complements of percentage similarity was a better distance measure than Euclidean distance and coefficient of community. Noy-Meir and Whittaker (1977), who reviewed the use of continuous multivariate methods in community analysis, also discuss this problem.

Correlation of environmental variables themselves and with the ordination axes was done with Spearman's rank correlations. Since some of the environmental variables were measured at the ordinal level, Spearman's rank correlations were applicable rather than Pearson's product-moment correlations.

MAP ANALYSIS: DESCRIPTION AND RELATIONSHIPS OF THE MAPPING UNITS

The mapping units, established during the field mapping, are described and illustrated in Figures 4-19; the general floristic, physiognomic, and ecological characteristics of each unit are found in the figure legends. Table 1 gives the species index for the five most important plants in each unit. Figure 20 shows the similarity among the mapping units based on their species composition. Three major groups of mapping units apparent in this diagram include pasture, prairie, and valley side vegetation. Inspection of Figure 20 reveals the obvious trends of the most important environmental factors, which agree well with the controlling environmental factor complexes observed in the field and later determined by ordination.

The prairie group consists of the three mapping units: DRY, *Stipa comata-Koeleria macrantha*, PRAIRIE (mapping unit 5); DRY, *Koeleria macrantha-Agropyron trachycaulum*, PRAIRIE (mapping unit 3); and DRY, *Hypericum perforatum-Paronychia jamesii*, PASTURE (mapping unit 12). These units have both the largest number of species and show the greatest homogeneity. Units 5 and 3 occur either inside the principal wire fence (where cattle grazing has not occurred for approximately 20 years), or outside this fence on properties that were grazed only very lightly. These units probably most closely approximate the native prairie at Rocky Flats. Mapping unit 12 represents the first step between the mapping units 5 and (in particular) 3 and the grazing-controlled mapping units of the pasture group. The mapping units 5 and 3 generally correspond to the prairie-grass association of Vestal (1914). They are also related to the *Stipa comata-Bouteloua gracilis-Bouteloua curtipendula* association described by Hanson (1955) from northern Colorado. Stands with open vegetation cover on elevated surfaces, in which *Schizachyrium scoparium*, *Muhlenbergia montana*, *Bouteloua curtipendula*, and *Liatris punctata* become more prevalent, correspond to Vestal's (1914) bunch-grass association. The mapping

Figure 4. Mapping unit 1. DRY, *Buchloë dactyloides-Medicago sativa*, PASTURE. Stands 28 (pictured) and 27.
This mapping unit is related to the mapping unit 2, DRY *Buchloë dactyloides-Arnica fulgens*, PASTURE, which occurs in less grazed and more moist habitats. Mapping unit 1 is found in very dry and heavily grazed habitats, and it covers approximately 2.5 percent of the map area. The dominant plants are *Buchloë dactyloides* (5 cm high in stature), *Medicago sativa*, and *Gutierrezia sarothrae* (both about 0.5 m high).

Figure 5. Mapping unit 2. DRY, *Buchloë dactyloides-Arnica fulgens*, PASTURE. Stands 29 (pictured) and 30.
This mapping unit occurs in dry, heavily grazed habitats, which are less grazed and more moist than the habitats of the related mapping unit 1, DRY, *Buchloë dactyloides-Medicago sativa*, PASTURE. Mapping unit 2 covers much of the extensive pastures in the eastern part of the map area. Its total percentage cover is high, 16.4 percent of the map. It occurs both on elevated surfaces and on valley sides. *Buchloë dactyloides* forms an almost continuous sod, through which *Arnica fulgens* and *Bromus tectorum* are scattered.

Figure 6. Mapping unit 3. DRY, *Koeleria macrantha-Agropyron trachycaulum*, PRAIRIE. Stands 5 (pictured) and 6.
This mapping unit occurs only on elevated surfaces in the western part of the map area where grazing is absent (inside the main wire fence) or limited. It covers approximately 7.8 percent of the map area. Grasses dominate the vegetation cover, which ranges from 0.25 m to nearly 1 m in height. Common grasses include *Koeleria macrantha*, *Agropyron trachycaulum*, *Muhlenbergia montana*, and *Schizachyrium scoparium*, which is an indicator of true prairie. *Artemisia ludoviciana*, *Heterotheca villosa*, and *Antennaria parviflora* are common herbs, and *Sedum lanceolatum* and *Opuntia compressa*, common succulents. The mapping unit 5, DRY, *Stipa comata-Koeleria macrantha*, PRAIRIE and the mapping unit 3 probably represent the vegetation closest to the original prairie grassland.

Figure 7. Mapping unit 4. DRY, *Carduus nutans-Bromus tectorum*, BARRENS. Stands 9 (pictured) and 10.
This mapping unit occurs in patches on disturbed sites on valley sides throughout the study area, especially in its middle section. It covers a relatively small area, approximately 3.2 percent of the map. This mapping unit is related to the mapping unit 8, MOIST, *Agropyron trachycaulum-Poa compressa*, MEADOW, with which it forms mosaics and intermediate stands. The mapping unit 4 has two distinct facies. One is dominated by *Carduus nutans*, which may reach over 1 m in height, has a dense understory of *Bromus tectorum*, and occurs in dry sites. *Cirsium arvense* forms more dense, shorter stands on moist valley sides and in meadows.

Figure 8. Mapping unit 5. DRY, *Stipa comata-Koeleria macrantha*, PRAIRIE. Stands 25 (pictured) and 26.
This mapping unit most closely approximates the former native prairie. It is related to the mapping unit 3, DRY, *Koeleria macrantha-Agropyron trachycaulum*, PRAIRIE. The mapping unit 5 constitutes approximately 7.1 percent of the map area; it occurs in the middle section, on relatively undisturbed elevated surfaces. It does not occur on valley sides and in the intensely grazed eastern portion of the map. Under heavy grazing pressure, this mapping unit and the mapping unit 3 are replaced by the mapping units 6 and 12, and, in part, by the mapping units 1 and 2. The dominant and most conspicuous species is *Stipa comata*, a native prairie grass which may reach 1 m in height. Other indigenous grasses include *Koeleria macrantha*, *Andropogon gerardii*, and *Sitanion longifolium*.

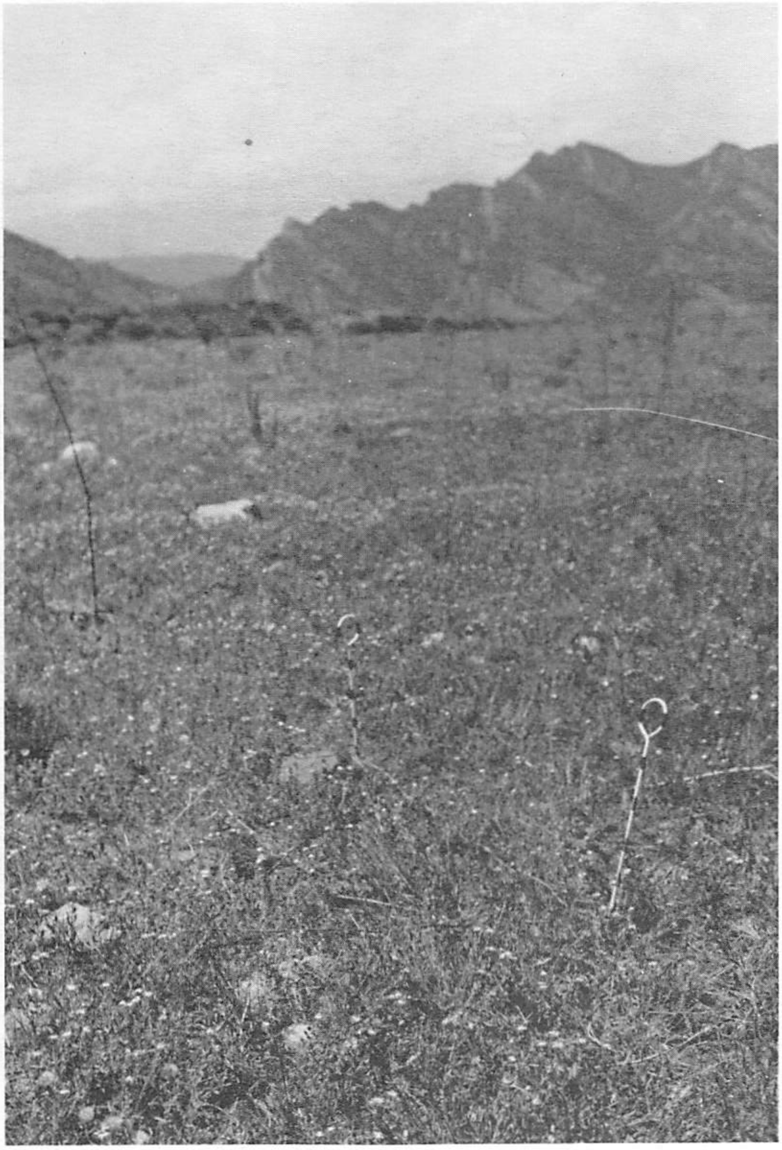


Figure 9. Mapping unit 6. DRY, *Heterotheca villosa-Buchloë dactyloides*, PASTURE. Stands 31 (pictured) and 32.
This mapping unit is found in grazed areas on elevated surfaces outside of the main wire fence; it covers approximately 8.4 percent of the map area. It is related to the mapping unit 12, DRY, *Hypericum perforatum-Paronychia jamesii*, PASTURE, with which it forms mosaics and intermediate stands. The vegetation cover in the stands of the mapping unit 6 is open, formed largely by the conspicuous yellow composite *Heterotheca villosa* which grows to a height of about 0.25 m. The most frequent grasses include *Buchloë dactyloides*, *Bouteloua curtipendula*, and *Bromus tectorum*.

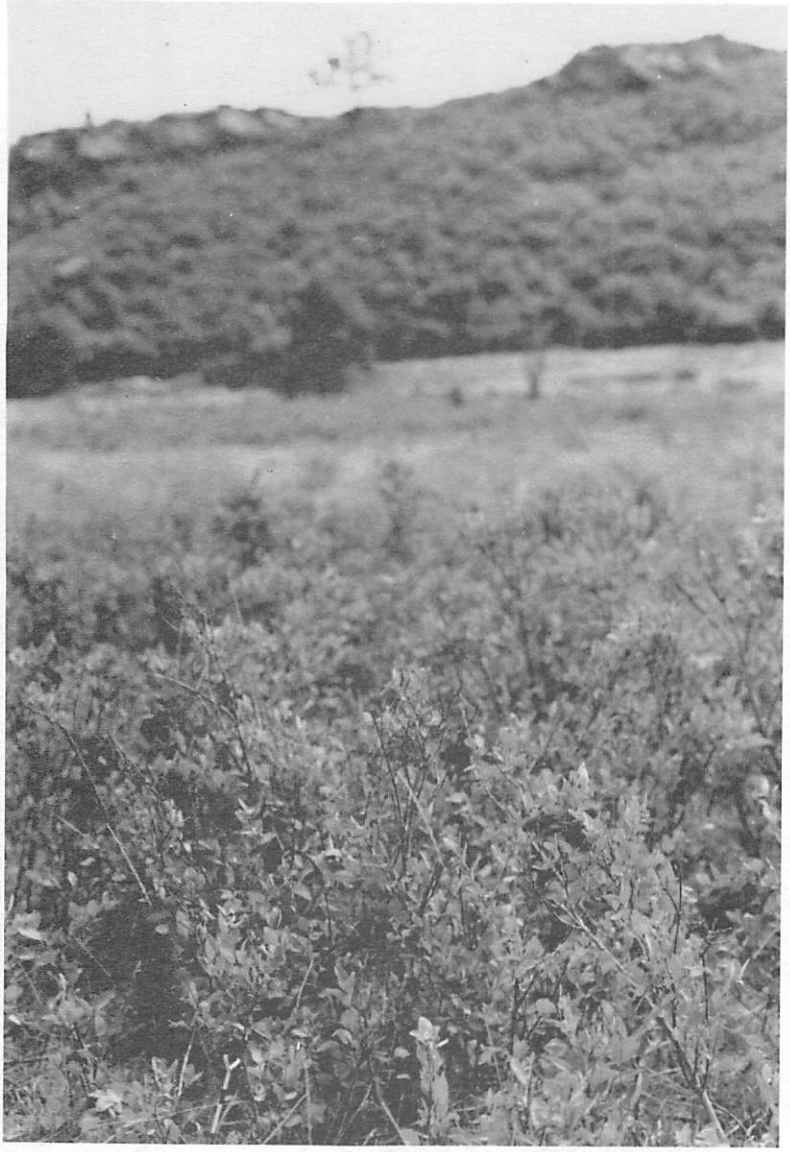


Figure 10. Mapping unit 7. MOIST, *Symphoricarpos occidentalis-Poa compressa*, LOW SCRUB. Stands 23 (pictured) and 24.
This mapping unit occurs in small stands along many of the valley sides and bottoms throughout the area. Its total area is small, approximately 0.7 percent of the map. The stands are often surrounded by the stands of the mapping unit 8, MOIST, *Agropyron trachycaulum-Poa compressa*, MEADOW (the predominant mapping unit on valley sides and bottoms); mosaics and mixed stands between these two units also occur. *Symphoricarpos occidentalis* and *Symphoricarpos oreophilus* form a dense scrub about 0.5 m high. Grasses, including *Poa compressa*, *Agropyron trachycaulum*, and *Bromus tectorum*, grow at the margins of the stands, but there is very little understory.

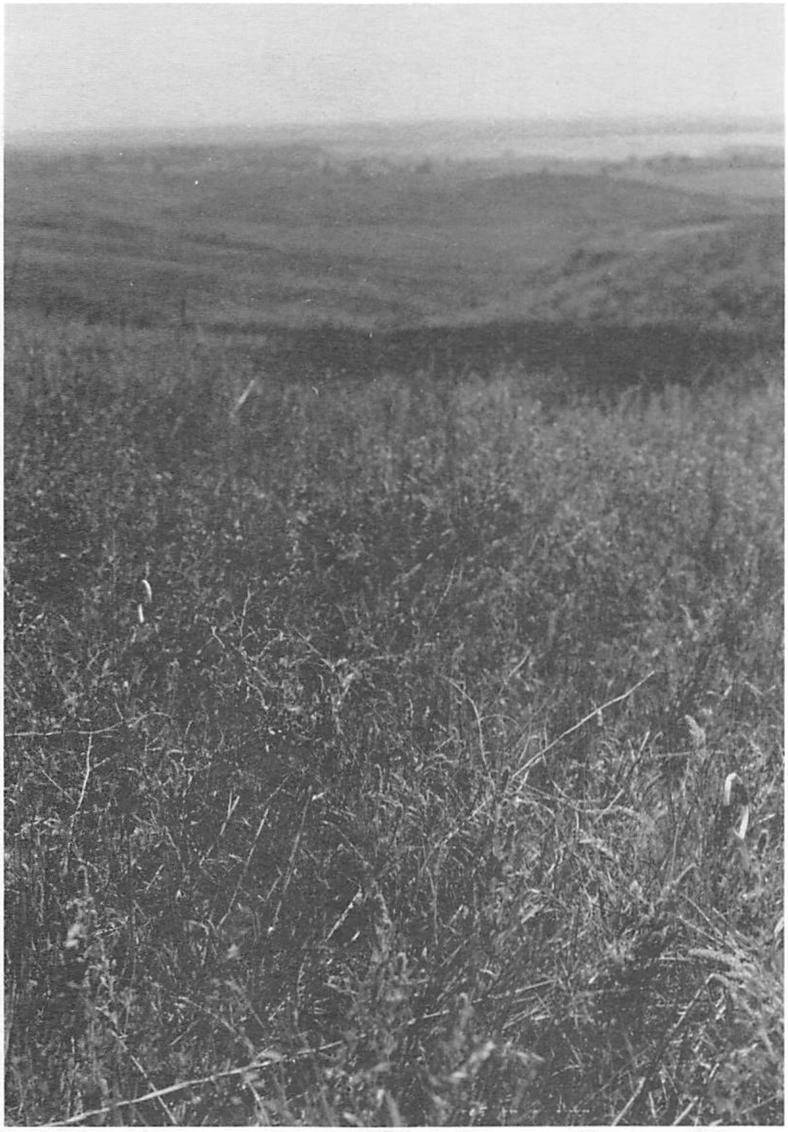


Figure 11. Mapping unit 8. MOIST, *Agropyron trachycaulum-Poa compressa*, MEADOW. Stands 11 (pictured) and 12.
This is a very common mapping unit, which covers approximately 22.9 percent of the study area. It dominates most of valley sides and bottoms in less grazed areas. Under the pressure of intensive grazing it is replaced by the mapping units 1 and 2. The mapping unit 8 forms mosaics and intermediate stands with most of the less grazed mapping units that occur in the valleys (mapping units 4, 7, 9, 10, 16). The stands of this mapping unit are dominated by grasses. *Agropyron trachycaulum* grows to nearly 1 m in height in drier areas, where *Bromus tectorum*, *Poa pratensis*, and *Tragopogon dubius* are also prominent. *Poa compressa* often dominates in moist stands and on valley bottoms.

Figure 12. Mapping unit 9. WET, *Salix exigua-Barbarea orthoceras*, STREAMBANK. Stands 13 (pictured) and 14.
This mapping unit accompanies larger streams. Its total area is small, only 0.7 percent of the total map. *Salix exigua* grows to a height of 2 m and, along with other shrub communities in the study area, provides shelter for deer. *Cirsium arvense* often forms a dense understory. Other common understory species include *Barbarea orthoceras*, *Epilobium adenocaulon*, and *Fallopia convolvulus*.

Figure 13. Mapping unit 10. WET, *Carex nebraskensis-Juncus arcticus*, MARSH. Stands 15 (pictured) and 16.
This mapping unit occurs in floodplains of streams and along wet valley bottoms. Its total area is 3.5 percent of the map. The percentage cover of *Carex nebraskensis* is greater along streams, where it forms dense stands high about 0.5 m. *Juncus arcticus* dominates in slightly drier sites and forms taller, more open stands with a thick litter layer through which small mammals tunnel. Small dense stands of *Typha latifolia* which occur in very wet areas such as pond margins are also included in this mapping unit.

Figure 14. Mapping unit 11. DRY, *Polygonum aviculare-Ambrosia psilostachya*, BARRENS. Stands 3 (pictured) and 4.
This mapping unit includes very little vegetated, heavily disturbed sites, e.g., bulldozed areas, fire breaks, and old road beds. Its total area is only 1.5 percent of the map. The vegetation cover consists mainly of decumbent annuals except for *Ambrosia psilostachya* which often grows to 0.5 m in height. Wind erosion is especially high in the stands of this mapping unit.

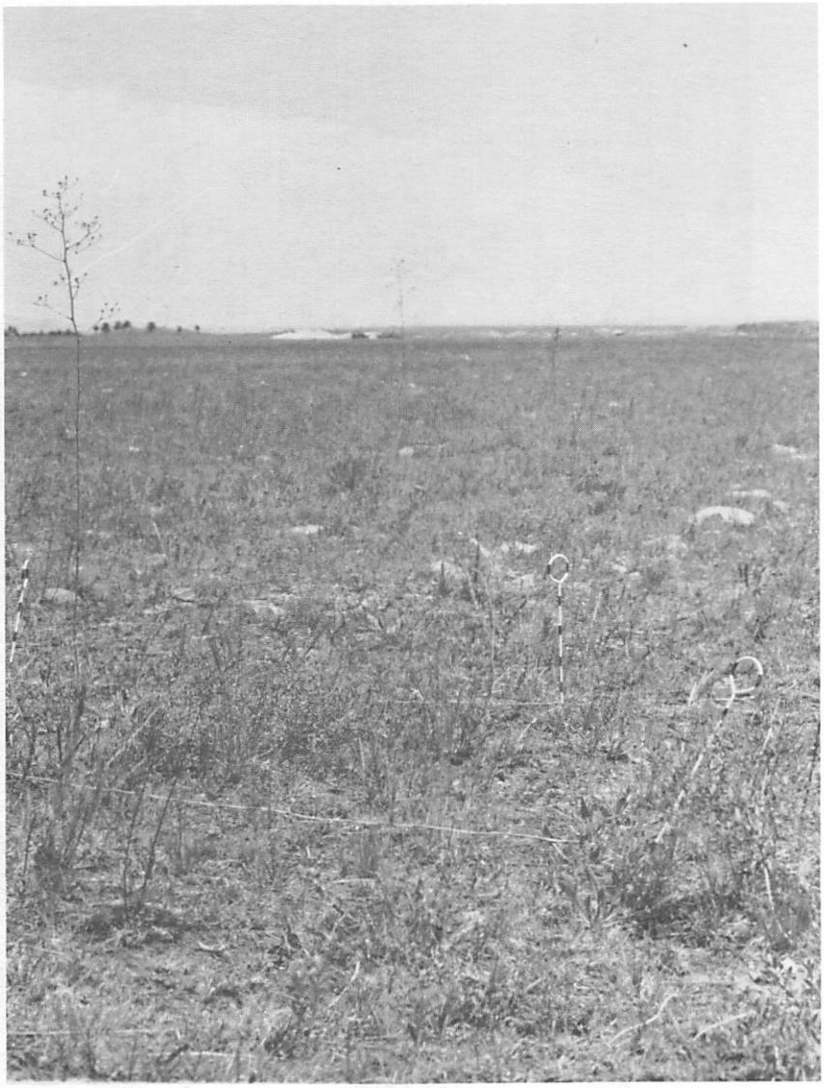


Figure 15. Mapping unit 12. DRY, *Hypericum perforatum-Paronychia jamesii*, PASTURE. Stands 18 (pictured) and 17.
This mapping unit is common on over-grazed elevated surfaces. It covers 11.5 percent of the map area and it only rarely occurs inside the principal wire fence. This mapping unit is related to the mapping unit 6, DRY, *Heterotheca villosa-Buchloë dactyloides*, PASTURE, with which it forms mosaics and intermediate stands. The stands of the mapping unit 12 have open vegetation cover, in which dominant and conspicuous herbs include *Hypericum perforatum* (0.5 m high), *Eriogonum alatum* (often over 0.7 m high), *Paronychia jamesii* (10 cm high), and *Liatris punctata*. Grasses are represented by *Koeleria macrantha* and *Buchloë dactyloides*.

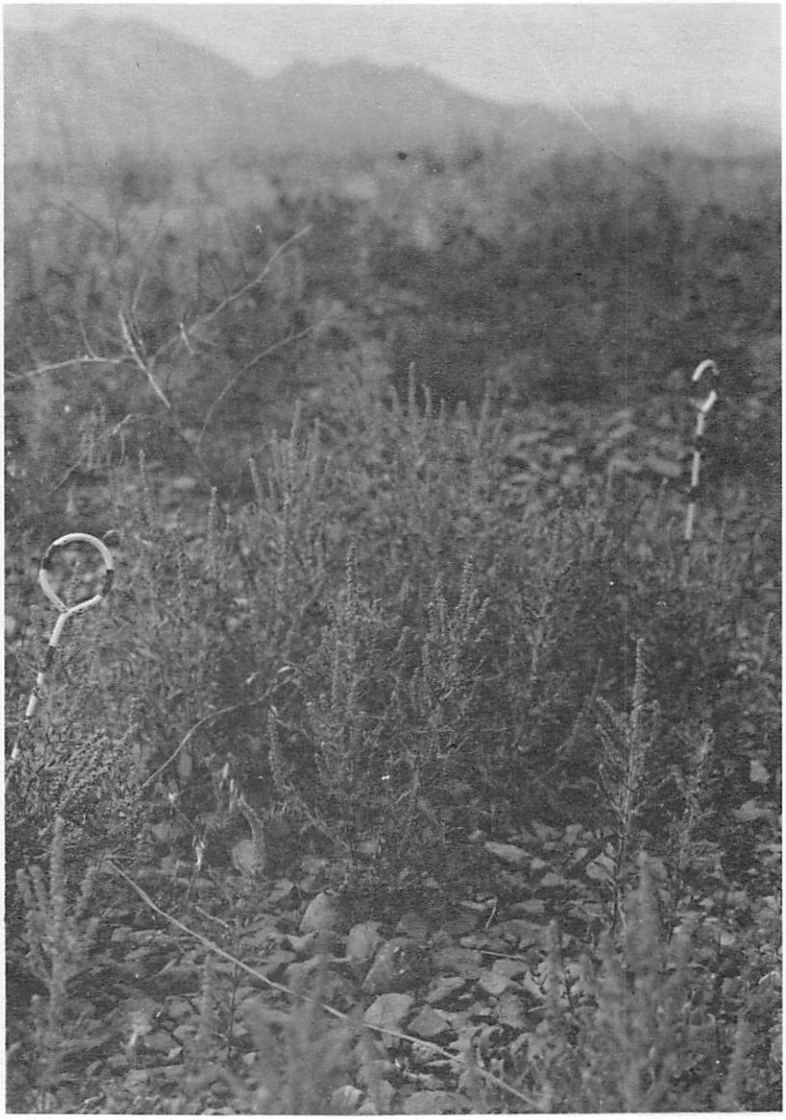


Figure 16. Mapping unit 13. DRY, *Hypericum perforatum-Ambrosia psilostachya*, BARRENS. Stands 8 (pictured) and 7.
This mapping unit is found on disturbed roadsides, extremely heavily grazed pastures, and on mounds. Its total area is 3.3 percent of the map. The surface in the stands of this mapping unit is considerably more stabilized and vegetated than surface in the stands of the mapping unit 11, DRY, *Polygonum aviculare-Ambrosia psilostachya*, BARRENS, which, in most cases, includes surfaces disturbed only recently. The dominant herbs in the stands of the mapping unit 13 include *Ambrosia psilostachya* and other weedy perennials. Grasses are mainly represented by a weedy annual, *Bromus tectorum*, and an indigenous perennial, *Bouteloua hirsuta*. This vegetation often averages 0.25 m in height.

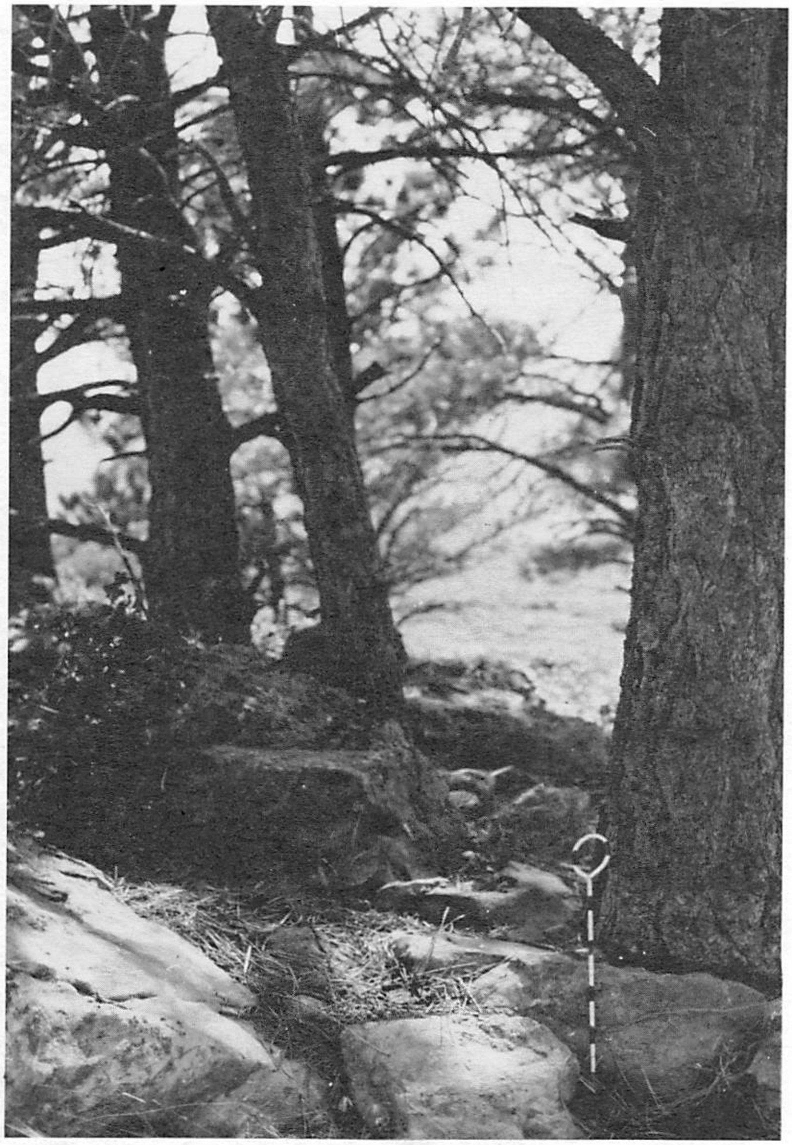


Figure 17. Mapping unit 14. DRY, *Pinus ponderosa-Bromus tectorum*, SAVANNAH. Stands 21 (pictured) and 22.
Stands of scattered trees on dry, rocky, north-south ridges in the northwest corner of the study area constitute this mapping unit. Its total area is only 0.04 percent of the map. The dominant tree *Pinus ponderosa* often grows to a height of 10 m. The stands are always overgrazed. *Bromus tectorum* and *Rhus trilobata* are typical understory species. Many species of rock lichens are present; among the more common ones are, for instance, *Lecanora muralis* and *Acarospora fuscata*. *Pinus ponderosa* needles form a litter layer on the surface.

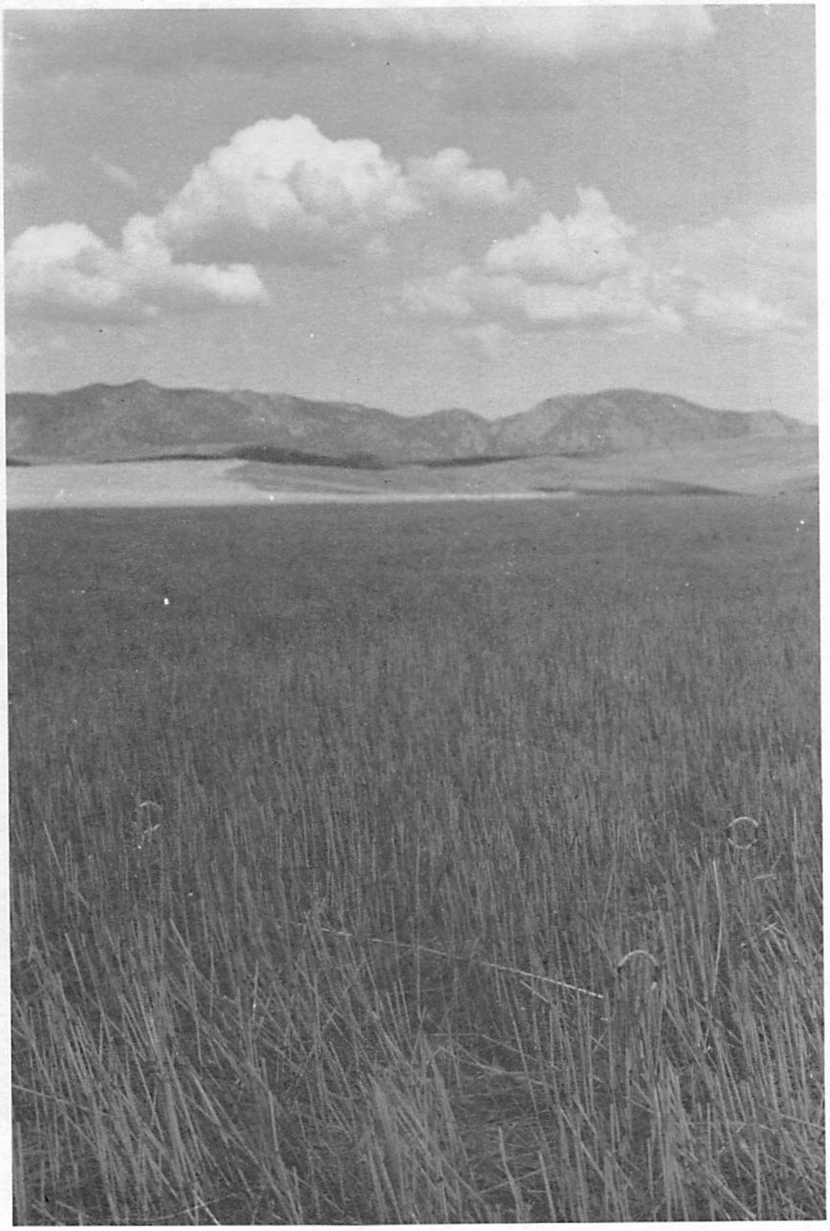


Figure 18. Mapping unit 15. DRY, *Secale cereale-Bromus tectorum*, FIELD. Stands 1 (pictured) and 2.
Both planted and fallow fields belong to this mapping unit which constitutes approximately 9.7 percent of the map area. Most fields are planted with *Secale cereale* and have an understory of weedy annuals such as *Bromus tectorum* and *Lactuca serriola*. Harvesting results in a layer of litter over the soil surface which may provide some degree of protection from wind erosion during the winter.

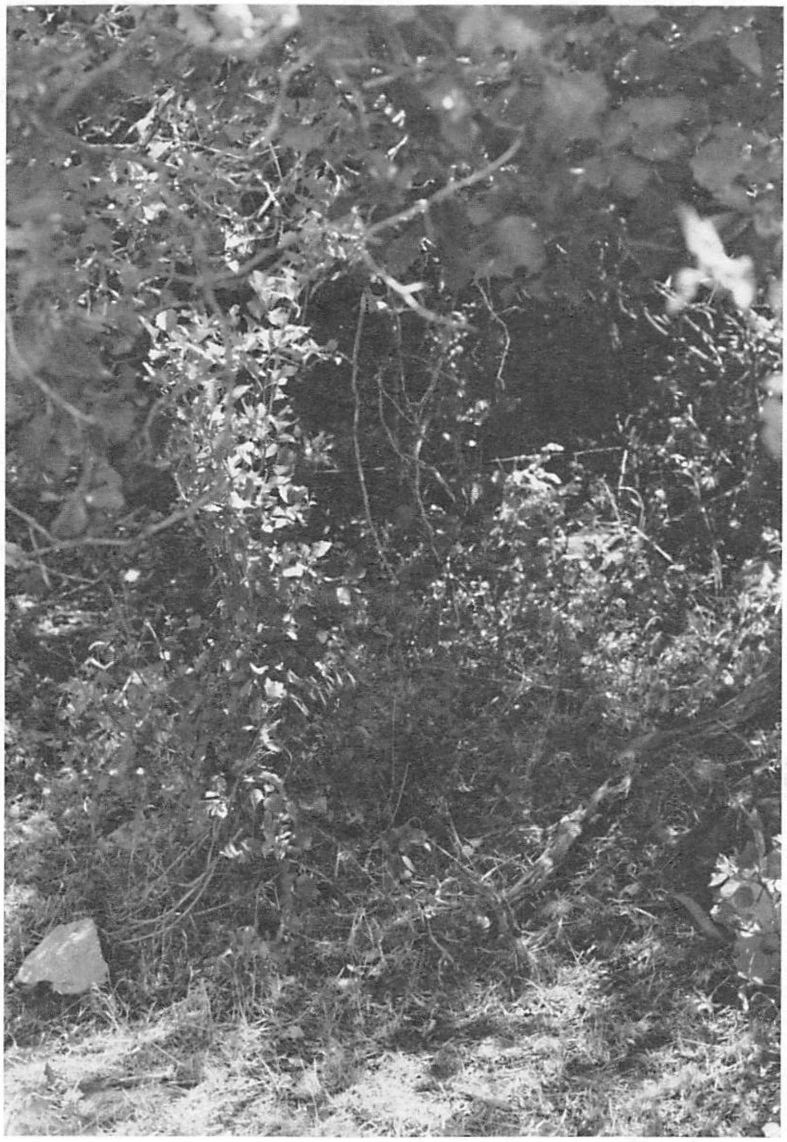


Figure 19. Mapping unit 16. MOIST, *Crataegus erythropoda-Galium aparine*, SCRUB. Stands 19 (pictured) and 20.
This mapping unit consists of small shrub stands on north-facing valley sides and in gulches. Its total area is only 0.9 percent of the map. The dominant shrub species, *Crataegus erythropoda*, often grows to 2 m in height and provides shelter for deer. Understory species include *Galium aparine*, *Bromus tectorum*, *Arctium minus*, and *Hydrophyllum fendleri*. *Rhus trilobata* dominates in some stands of this mapping unit, which are usually lower in stature. All the stands are very dense, and thus little grazed by cattle.

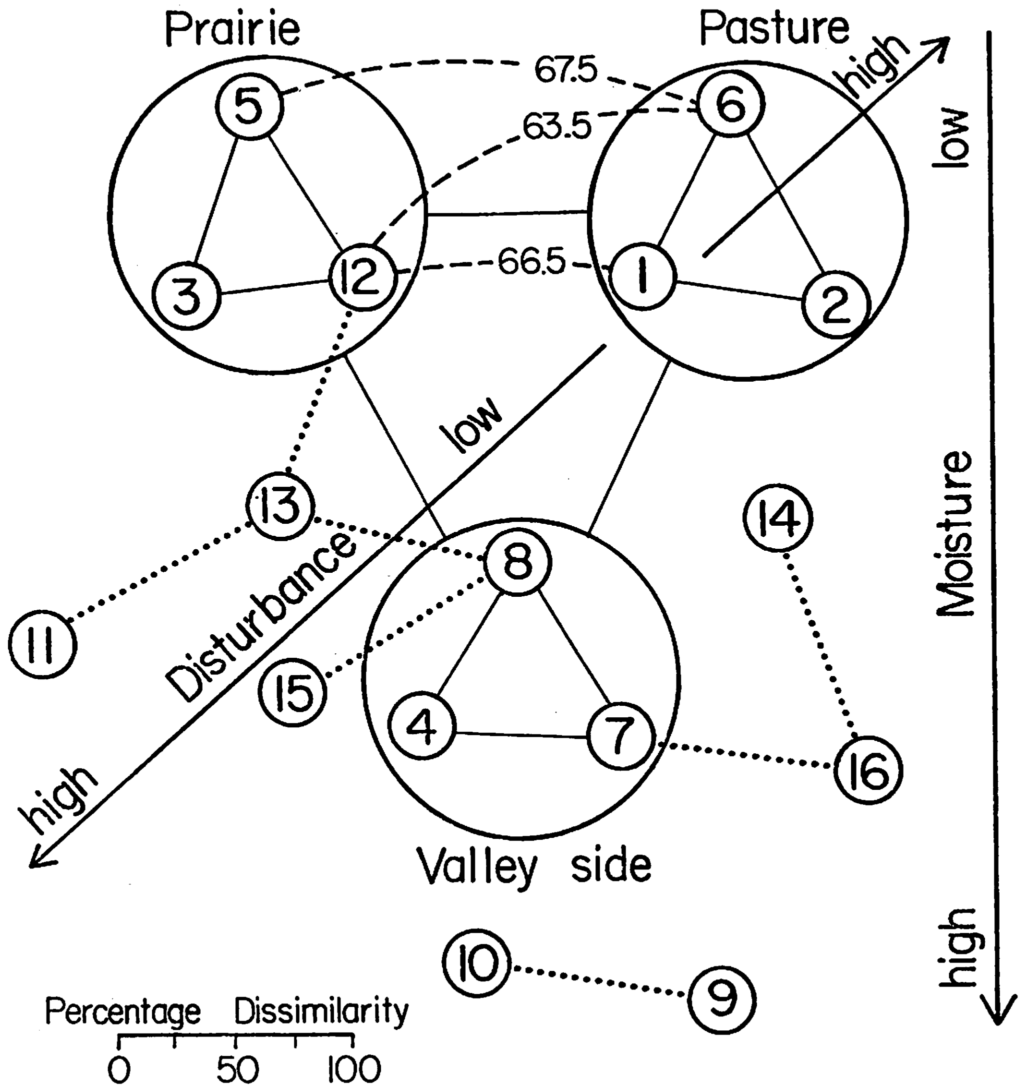


Figure 20. Similarity among the mapping units based on their species composition. The lengths of lines connecting the mapping units are scaled to represent their percentage dissimilarity. Where percentage dissimilarity values between mapping units in different groups were lower than those between mapping units within the same group, the lines connecting the mapping units of different groups are curved, broken, and the percentage dissimilarity values are indicated. Three major groups of mapping units can be recognized: pasture, prairie, and valley side. Mapping units which do not fit into any of these groups are connected with dotted lines only to the most similar mapping unit. Major trends of the most important environmental factors are indicated. The mapping units are identified by their number.

unit 5 is related to the *Stipa-Aristida* association of Vestal (1914).

The three pasture units form a homogeneous group: DRY, *Buchloë dactyloides-Medicago sativa*, PASTURE (mapping unit 1); DRY, *Buchloë dactyloides-Arnica fulgens*, PASTURE (mapping unit 2); and DRY, *Heterotheca villosa-Buchloë dactyloides*, PASTURE (mapping unit 6). These mapping units occur only outside of the main wire fence, on elevated surfaces that have been overgrazed. Some native prairie species, especially short grasses, are present. *Buchloë dactyloides* forms a continuous sod over a large portion of the area in the mapping units 1 and 2. It does not dominate the stands of the mapping unit 6, which occurs in less grazed areas than the mapping units 1 and 2. The mapping unit 6 has lower percentage vegetation cover than mapping units 1 and 2 because of wind erosion rather than grazing. These three mapping units fit the description of the short-grass association of Vestal (1914), although one stand of the mapping unit 1 can be considered intermediate between this association and the *Gutierrezia-Artemisia* association of Vestal (1914).

The third, that is the valley side group, consists of the mapping unit 4, DRY, *Carduus nutans-Bromus tectorum*, BARRENS; mapping unit 7, *Symphoricarpos occidentalis-Poa compressa*, LOW SCRUB; and mapping unit 8, *Agropyron trachycaulum-Poa compressa*, MEADOW. These mapping units are limited to valleys and never occur on the elevated flat surfaces. The mapping unit 4 occurs mainly on valley sides, while the mapping units 7 and 8 occur both on valley sides and bottoms. Although each of these mapping units is dominated by a different plant growth form and therefore has a physiognomy very different from the other two mapping units, they have many other species in common. The mapping unit 8 is the least homogeneous mapping unit at Rocky Flats. One of its stands appears to belong to the wheat-grass association of Vestal (1914), and the other one to the short-grass association (Vestal, 1914).

Two mapping units which often occur together on valley bottoms are WET, *Carex nebraskensis-Juncus arcticus*, MARSH (mapping unit 10), and WET, *Salix exigua-Barbarea orthoceras*, STREAMBANK (mapping unit 9). The mapping unit 10 is limited to poorly drained areas, while the mapping unit 9 occurs on streambanks and gravel in streambeds. They have only a few insignificant species in common. A similar hydric meadow community dominated almost exclusively by *Carex nebraskensis* was observed in prairies near Colorado Springs by Livingston (1952). The remaining five mapping units are only slightly related to the above groups in terms of species composition. The mapping units 11, DRY, *Polygonum aviculare-Ambrosia psilostachya*, BARRENS, and 13, DRY, *Hypericum perforatum-Ambrosia psilostachya*, BARRENS appear to belong to the plains ruderal association of Vestal (1914).

The seven grass-dominated mapping units (numbers 1, 2, 3, 5, 6, 8, 12) together cover 76% of the vegetated area of the map. Agricultural fields (mapping unit 15) cover another 10% of the map. Eight percent of the area is covered by barrens (mapping units 4, 11, 13). The remaining five mapping units, including tree, shrub, and marsh vegetation (mapping units 14, 16, 7, 9, 10) cover the remaining 6 percent of the map area.

It is apparent from the overall map inspection that a differential amount of grazing between various sections and properties and between the area inside and outside of the main wire fence in many cases determines the mapping units. Prairie, pasture, and valley side mapping units, all with a high proportion of grasses, belong to the mapping units which show these distinct, intensity-of-grazing-related patterns. Other patterns obvious from the map are related to higher amounts of moisture seasonally available along ephemeral streams on valley bottoms.

CLASSIFICATION OF VEGETATION AND RELATIONSHIP OF VEGETATION TYPES TO THE MAPPING UNITS

The clustering technique identified eight vegetation types or noda in the map area. These were named according to their physiognomy or habitat: valley side, scrub, field, marsh, streambank, barrens, savannah, and pasture-prairie (Figure 21). Nodum A contains the two stands of the mapping unit 10, WET, *Carex nebraskensis-Juncus arcticus*, MARSH, which is very well separated from the rest of the mapping units at 32% of similarity. The same is true for the mapping unit 9, WET, *Salix exigua-Barbarea orthoceras*, STREAMBANK (nodum B); mapping unit 14, DRY, *Pinus ponderosa-Bromus tectorum*, SAVANNAH (nodum F, 28% of similarity); mapping unit 16, MOIST, *Crataegus erythropoda-Galium aparine*, SCRUB (nodum G, 31% of similarity); and mapping unit 11, DRY, *Polygonum aviculare-Ambrosia psilostachya*, BARRENS (nodum D, 22% of similarity). The mapping unit 15, DRY, *Secale cereale-Bromus tectorum*, FIELD, is also well separated (nodum H, 26% of similarity), but it clustered with one stand of the mapping unit 13, DRY, *Hypericum perforatum-Ambrosia psilostachya*, BARRENS, the second stand of which is contained in nodum E. Otherwise, nodum E consists of the mapping units 4, DRY, *Carduus nutans-Bromus tectorum*, BARRENS; 8, MOIST, *Agropyron trachycaulum-Poa compressa*, MEADOW; and 7, MOIST, *Symphoricarpos occidentalis-Poa compressa*, LOW SCRUB, and is thus equivalent to the valley side group of mapping units identified in the preceding section. The other two groups of mapping units, prairie (mapping units 3, 5, 12) and pasture (mapping units 1, 2, 6) are also well separated within the cluster of nodum C (28% of similarity). Only the two stands of the mapping unit 1, DRY, *Buchloë dactyloides-Medicago sativa*, PASTURE, are separated within this cluster.

The good agreement between this objective, quantitative classification and the groups of mapping units in the preceding section (which were determined subjectively) is not surprising, since both were derived from species composition of stands. Especially encouraging is

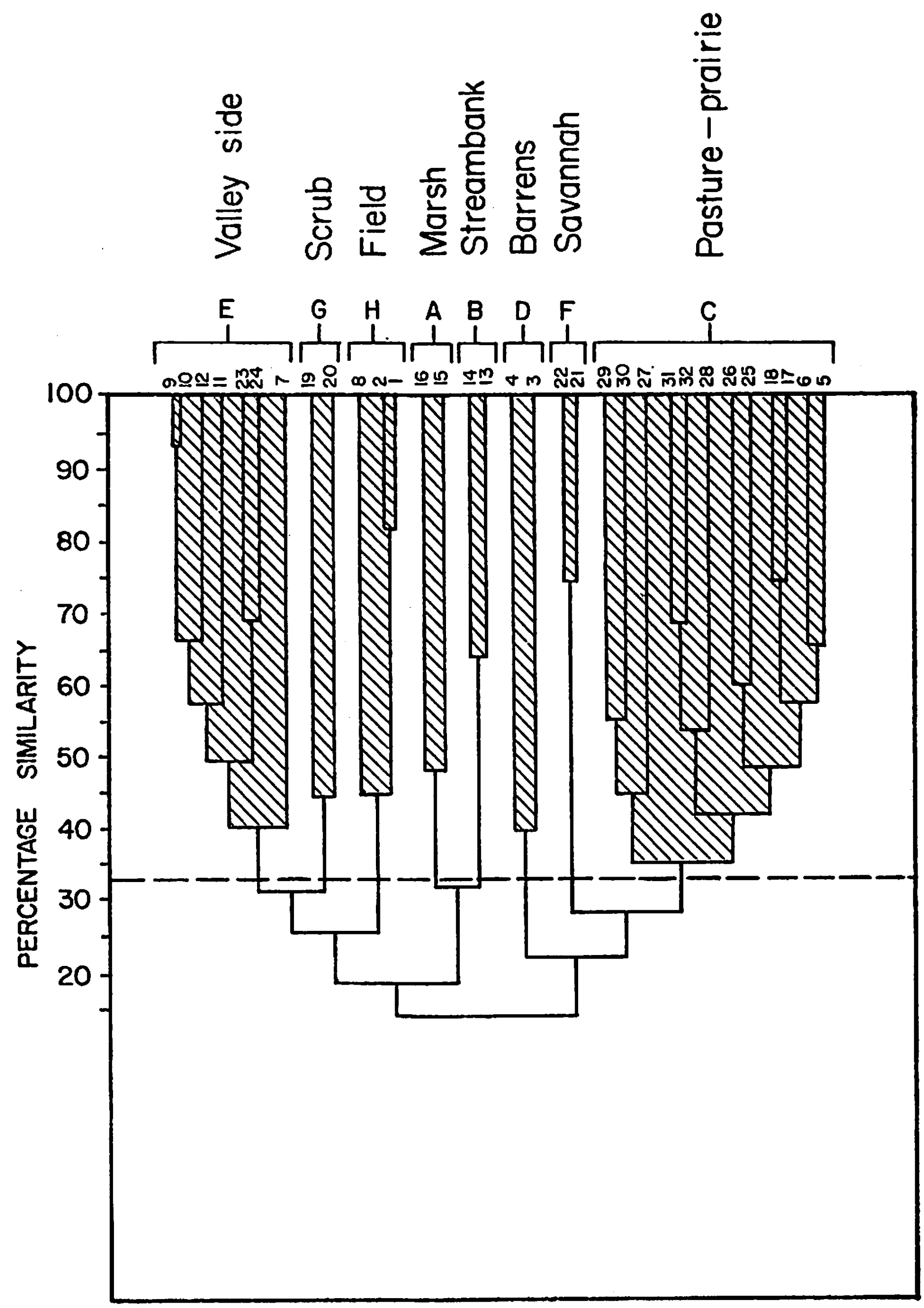


Figure 21. A hierarchical dendrogram of 32 vegetation stands representing 16 mapping units, based on species composition and constructed according to the average linkage method (Sokal and Sneath, 1963). Eight clusters identifying the vegetation types were produced at the 33% similarity level.

the fact that both stands of every mapping unit with the exception of mapping units 13 and 1 clustered together and were, in most cases, well separated from the rest of the stands. It appears then that despite the fact that mapping units were defined in the course of field mapping prior to vegetation classification, they are meaningful in terms of vegetation units, arrived at by classification later.

DETERMINATION OF THE ENVIRONMENTAL FACTOR COMPLEXES CONTROLLING THE DISTRIBUTION OF VEGETATION

The growth forms recognized at Rocky Flats that were used as ordination input are shown in Figure 22. Table 2 (in pocket) gives the "species" index values for the growth form categories in mapping units. Herbaceous, narrow-leaved, perennial and herbaceous, broad-leaved, perennial are the dominant growth forms in the Rocky Flats vegetation. A three-dimensional indirect Bray and Curtis stand ordination based on percentage similarity and ten growth forms is shown in Figure 23. Eight clusters (noda) group the stands, mapping, and vegetation units which have similar growth form composition (Figure 24) and which were plotted on the ordination planes. Growth forms appear as a useful and meaningful alternative to species in classifying the vegetation; they can be of particular importance in impact assessment of future management decisions because they can be readily evaluated by personnel with limited training.

It appears that the noda based on growth forms are meaningful in terms of both vegetation and mapping units. Nodum I includes a small compact cluster of all the prairie mapping units (mapping units 3, 5, 12), two of the pasture mapping units (1 and 2), one valley side mapping unit (8), marsh (mapping unit 10), and field (mapping unit 15). This nodum groups communities dominated by narrow-leaved plants belonging to Poaceae and Cyperaceae. One pasture mapping unit (6) is separated into nodum II, which also contains one stand of the mapping unit 13, barrens (one of only two mapping units which have the two representative vegetation stands separated into two different noda). The other mapping unit 11, also belongs to barrens, and is separated between nodum III and V. Nodum IV (mapping unit 4) and VII (mapping unit 7) each consist of one valley side mapping unit. The tree-dominated savannah mapping unit (14) is separated in nodum VI, and shrub-dominated mapping units 16 and 9 are included in nodum VIII.

Plotting of noda on the ordination planes (Figure 23) reveals that while each nodum is limited to a fairly small portion of the X and Y axes, Noda I, II, V, VII, and VIII are spread over a large portion of the Z axis. This implies that the Z axis is not nearly as useful in separating these noda as are the X and Y axes.

Important correlations among measured environmental variables and ordination axes are listed in Table 3. The X axis of the ordination is significantly correlated to percentages of bare soil (r_s = -.55) and rock and to the disturbance caused by humans. The Y axis represents the moisture regime (r_s = .48), and the Z axis is related to the grazing regime (r_s = .36; this correlation is significant only to 5%).

The controlling effects of moisture and disturbance on the vegetation distribution at Rocky Flats had already been recognized during the formulation of mapping units, in the course of the selection of colors for the mapping units, and from an inspection of the map (sections Methods and Map Analysis). The ordination and environmental variable correlation results agree with these subjective preliminary results.

Figure 25 shows isolines representing the same values of environmental variables plotted within the framework of the three-dimensional ordination. The first two variables, percentage bare soil and percentage rocks, showed the highest correlation with the X axis of the ordination. These two variables were added to form a new variable, percentage nonvegetated area; the correlation of this new variable with the X axis was even higher than the correlation of the original variables. Human disturbance was also correlated with the X axis, while moisture regime and presence of soil lichens correlated most highly with the Y axis. Grazing regime and percentage moisture loss on ignition are correlated with the Z axis. As pointed out above, the significance of this last correlation is low; however, the distribution of some species is conspicuously related to grazing. For instance, the importance of *Opuntia compressa* is greatly increased in some of the heavily grazed stands and native prairie species like

Figure 22. Rocky Flats species representative for the growth form categories which were used as ordination input for the determination of controlling environmental complexes.
Among 227 species which occurred in the 32 stands, the following growth forms were recognized:
Woody - greater than 5 m in height (1 species)
Woody - less than 5 m in height (11 species)
Herbaceous, broad-leaved, perennial (57 species)
Herbaceous, broad-leaved, biennial (11 species)
Herbaceous, broad-leaved, annual (22 species)
Herbaceous, narrow-leaved, perennial (61 species)
Herbaceous, narrow-leaved, annual (14 species)
Succulent (5 species)
Bryophyte (9 species)
Lichen (34 species)
Pteridophyte (1 species)
Parasite (1 species)
The last two categories were dropped from the data set since they appeared in one stand only and with a low "species" index value.
(Drawing by S.V. Clark.)

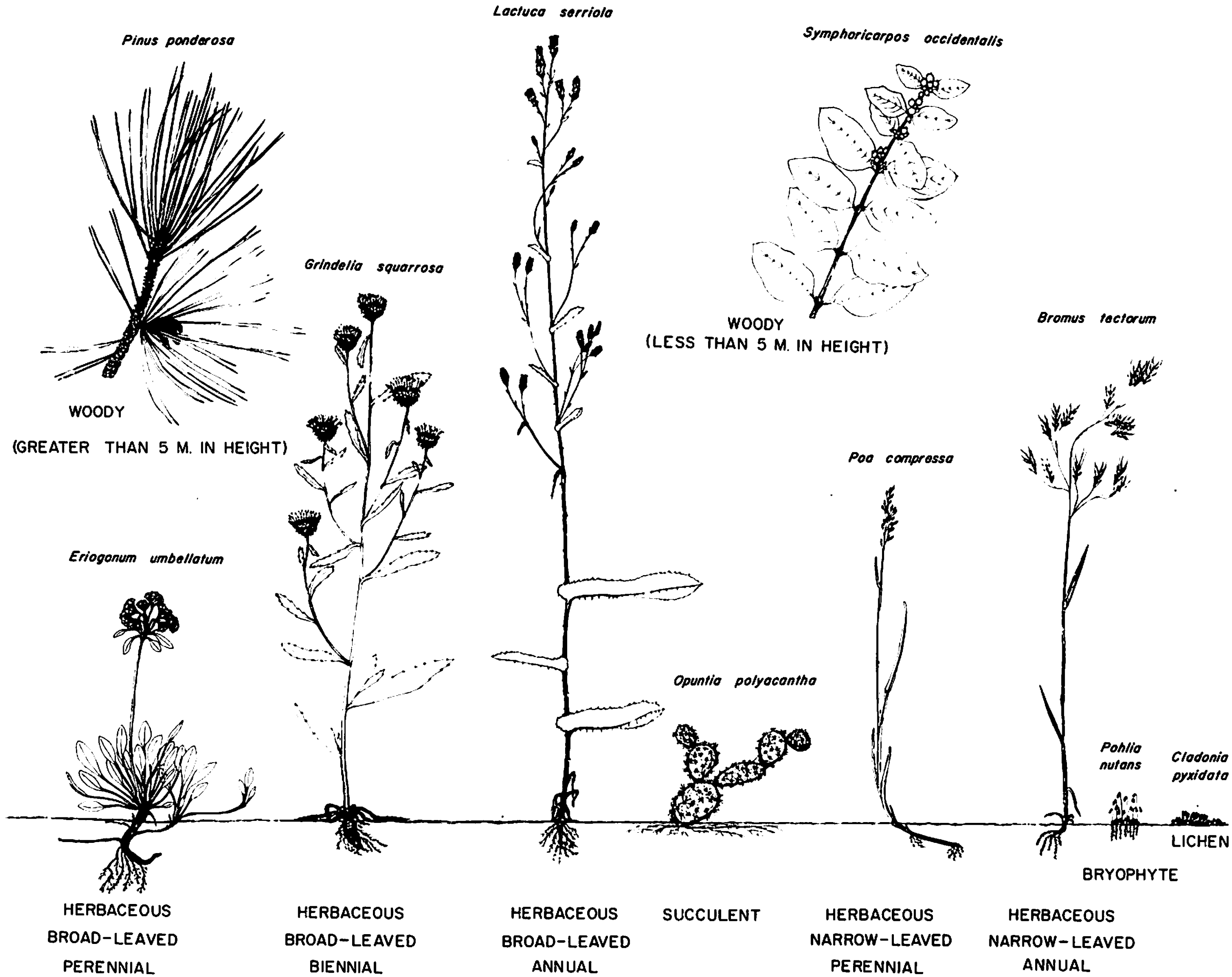

Pinus ponderosa
WOODY
(GREATER THAN 5 M. IN HEIGHT)
Grindelia squarrosa
Lactuca serriola
Symphoricarpos occidentalis
WOODY
(LESS THAN 5 M. IN HEIGHT)
Bromus tectorum
Poa compressa
Eriogonum umbellatum
Opuntia polyacantha
Pohlia nutans
Cladonia pyxidata
LICHEN
BRYOPHYTE
HERBACEOUS BROAD-LEAVED PERENNIAL
HERBACEOUS BROAD-LEAVED BIENNIAL
HERBACEOUS BROAD-LEAVED ANNUAL
SUCCULENT
HERBACEOUS NARROW-LEAVED PERENNIAL
HERBACEOUS NARROW-LEAVED ANNUAL

Figure 22.

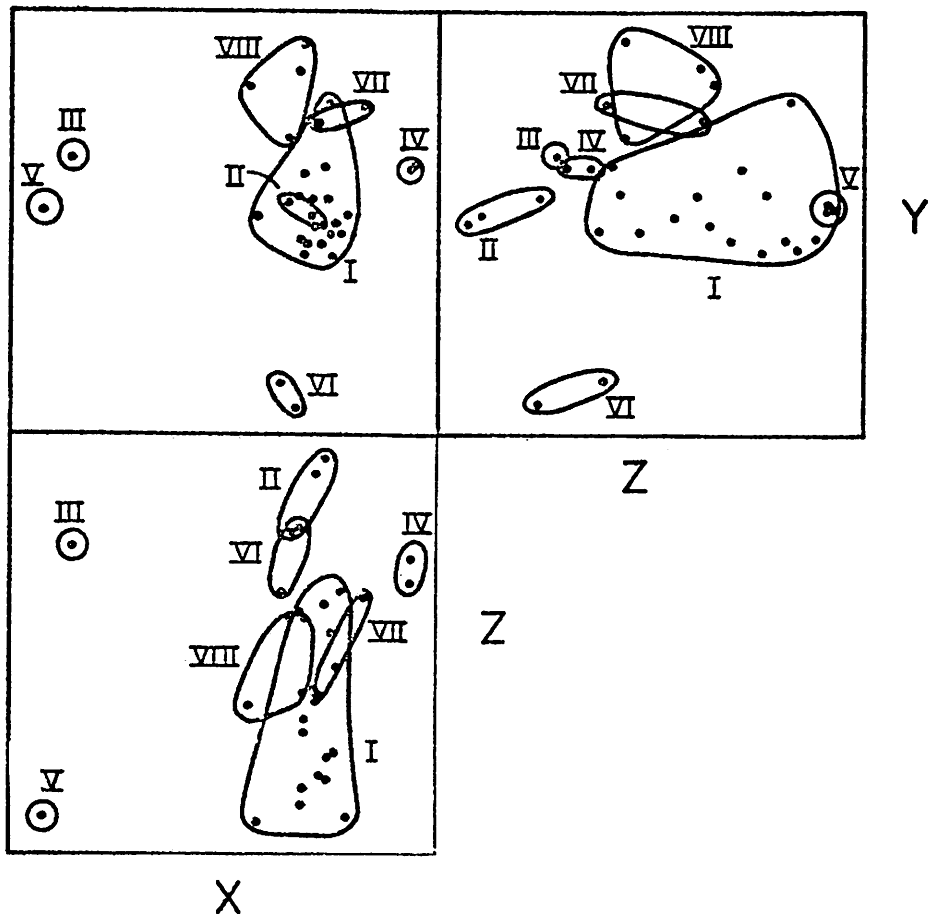


Figure 23. Bray and Curtis ordination (Bray and Curtis, 1957) of 32 vegetation stands representing 16 mapping units. Growth form input was used. Eight clusters of stands, grouping the mapping and vegetation units with similar growth forms, were identified by a hierarchical dendrogram (Figure 25) and plotted on the ordination planes. Stand numbers can be identified in Figure 25.

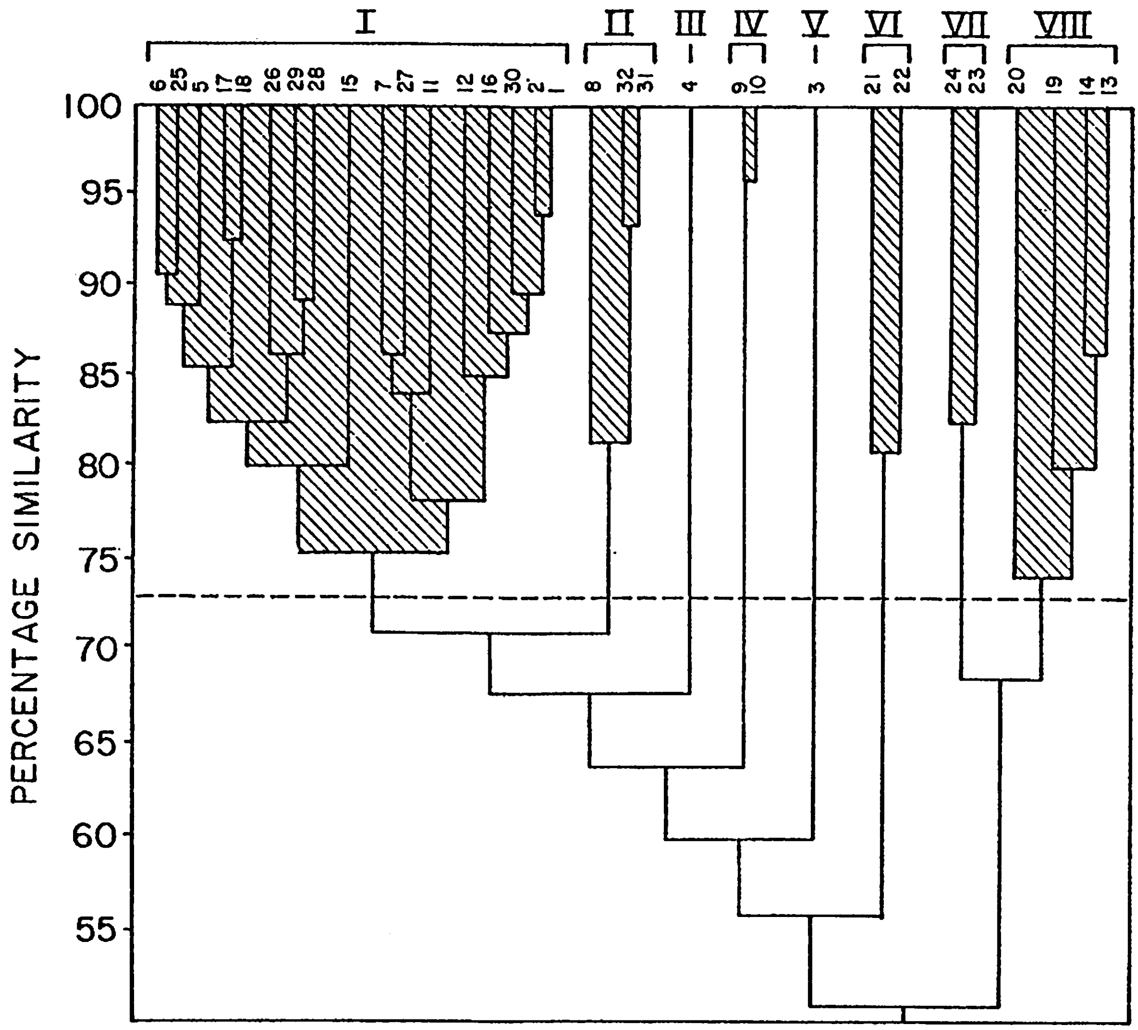


Figure 24. A hierarchical dendrogram of 32 vegetation stands representing 16 mapping units, based on ten growth forms and constructed according to the average linkage method (Sokal and Sneath, 1963). Eight clusters are identified at the 73% level of similarity.

TABLE 3

IMPORTANT CORRELATIONS AMONG MEASURED ENVIRONMENTAL VARIABLES AND ORDINATION AXES*

VARIABLES AND AXES	SIGNIFICANT CORRELATIONS
Percentage of pebbles and granules (PEBB)	ROCK, -WABS, -FCAP, -SILT, -ORGM, -HYGR, SAND, LICH.
Percentage of sand (SAND)	-SILT, -CLAY, -FCAP, -HYGR, -WABS, ROCK, -ORGM, -PEBB, -AWAT.
Percentage of silt (SILT)	-SAND, FCAP, WABS, HYGR, ORGM, CLAY, -ROCK, -PEBB, AWAT.
Percentage of clay (CLAY)	-SAND, SILT, HYGR, FCAP.
Percentage of hygroscopic moisture loss (HYGR)	FCAP, SILT, WABS, -SAND, CLAY, ORGM, -PEBB.
Percentage of water absorption (WABS)	ORGM, FCAP, SILT, HYGR, -PEBB, -SAND, -ROCK, -HUMA, MOIS.
Percentage of organic matter (ORGM)	WABS, FCAP, SILT, -HUMA, HYGR, -PEBB, -SAND, -ROCK.
Field capacity (FCAP)	WABS, SILT, ORGM, HYGR, -SAND, -PEBB, CLAY, ROCK, AWAT.
Available water (AWAT)	SILT, FCAP, -SAND.
Moisture regime (MOIS)	-ROCK, WABS, BCLFMY.
pH (pH)	
Grazing (GRAZ)	
Soil disturbance caused by small mammals (MAMM)	-ROCK, -SOIL.
Soil disturbance caused by humans (HUMA)	-ORGM, -WABS, -BCLFMX.
Percentage of bare soil (SOIL)	ROCK, -BCLFMX, -MAMM.
Percentage of rocks (ROCK)	PEBB, SOIL, -SILT, SAND, -WABS, -MOIS, -FCAP, -BCLFMX, -MAMM, -ORGM.
Percentage of soil lichens (LICH)	PEBB.
Bray and Curtis ordination, 10 growth forms, X axis (BCLFMX)	-SOIL, -HUMA, -ROCK.
Bray and Curtis ordination, 10 growth forms, Y axis (BCLFMY)	MOIS.
Bray and Curtis ordination, 10 growth forms, Z axis (BCLFMZ)	

*Underlined correlations are significant to 0.1%. All other correlations are significant to 1%. Negative correlations are indicated with a minus sign. The correlations are listed in order of significance, the highest correlations being listed first.

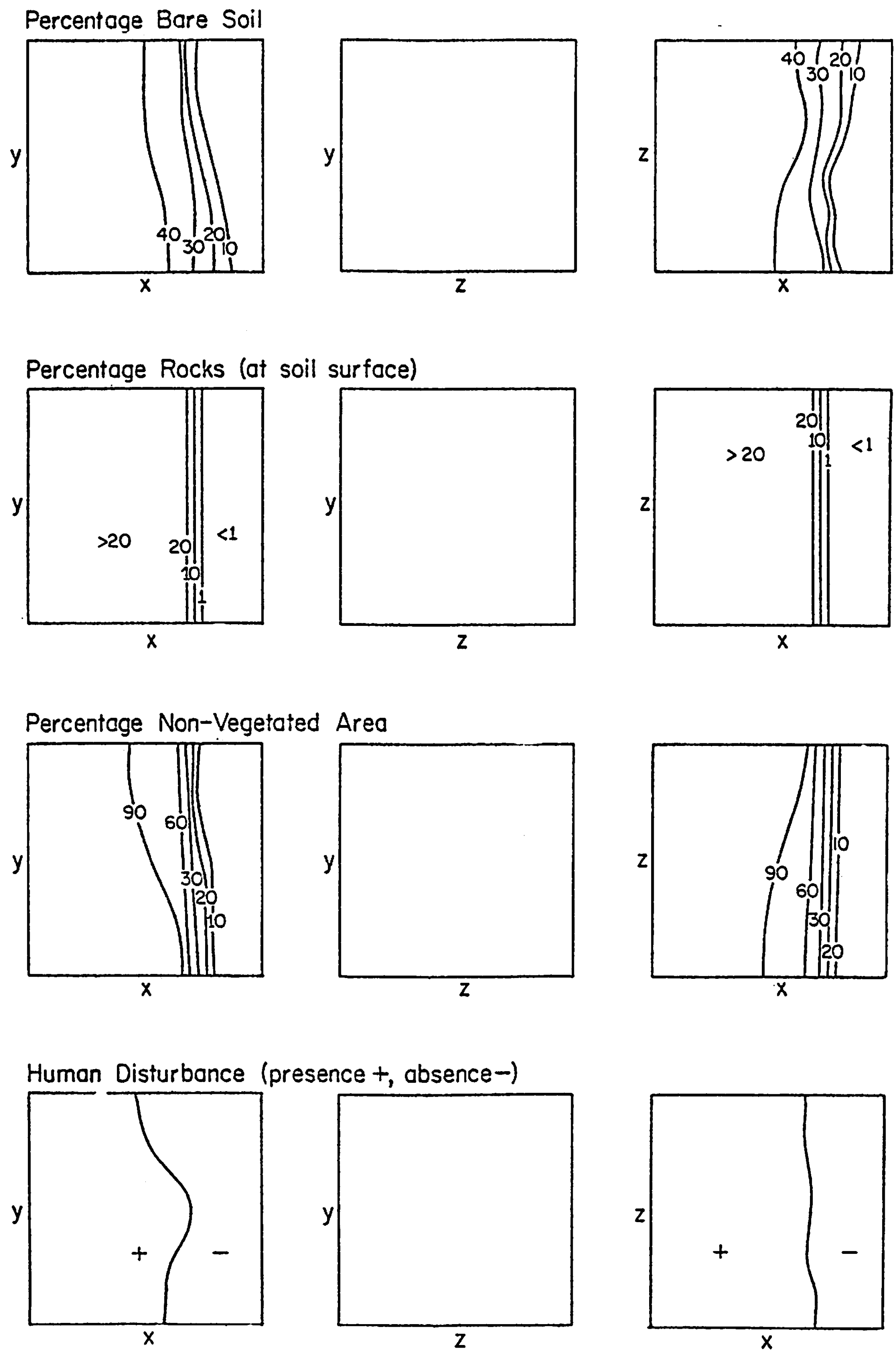


Figure 25. Isolines connect equal values of the environmental variables which showed the highest correlations with ordination axes on the three planes of the ordination.

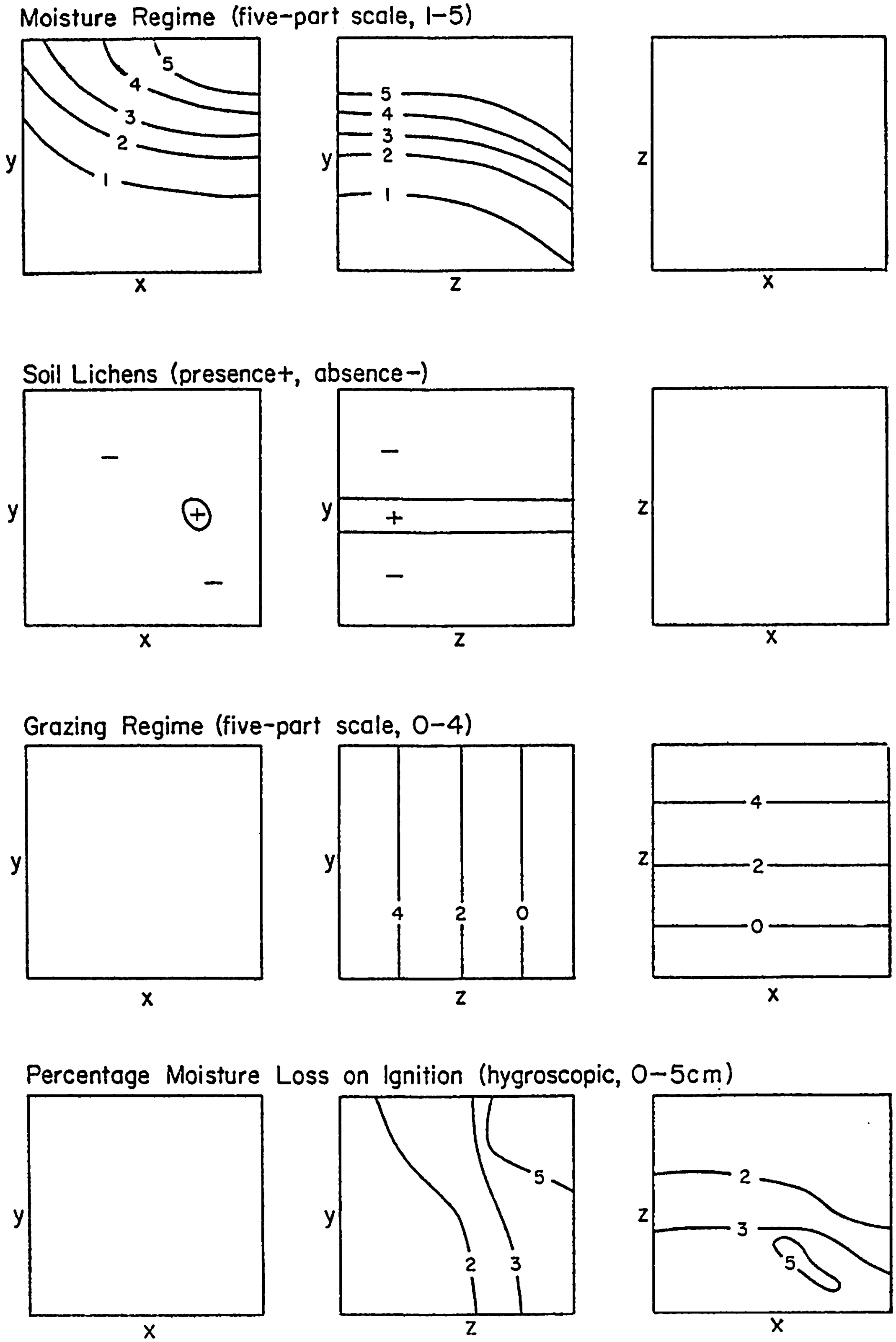


Figure 25 (cont.).

Stipa comata and *Agropyron trachycaulum* do not occur in heavily grazed areas.

A definite relationship between the importance and distribution of ten growth forms among the 32 vegetation stands, and the three controlling environmental factor complexes is shown in the context of the three ordination planes in Figure 26. It appears that growth forms have the same significant relationship with the controlling environmental factors as species; this can be expected, because growth forms represent the adaptation of plants to their environment. For instance, that numerous characters of plant structure and function showed trends along the moisture gradient in the Wisconsin prairie vegetation was observed by Knight (1965). Knight and Loucks (1969) found ordination useful means of determining which structural-functional features differentiate the upland forest communities in Wisconsin and showed that quantitative analysis on the basis of structural-functional features provides means by which the ecology of a plant community can be investigated.

DISCUSSION

Examination of the vegetation map and the results of the mathematical analysis indicate that as grazing increases, the DRY, *Hypericum perforatum-Paronychia jamesii*, PASTURE mapping unit replaces both the DRY, *Koeleria macrantha-Agropyron trachycaulum*, PRAIRIE and the DRY, *Stipa comata-Koeleria macrantha*, PRAIRIE mapping units. Where grazing is particularly severe or there has been, in the past, human-caused disturbance such as bulldozing, the DRY, *Hypericum perforatum-Ambrosia psilostachya*, BARRENS mapping unit is found in place of the DRY, *Hypericum perforatum-Paronychia jamesii*, PASTURE. The DRY, *Polygonum aviculare-Ambrosia psilostachya*, BARRENS mapping unit is found on recently or continually disturbed areas. All of the mapping units which have been mentioned thus far are found almost exclusively on Rocky Flats Alluvium in the western half of the study area. A different succession occurs in the eastern, valley-dissected half of the study area where there is a larger portion of the clay fraction in the soil. The DRY, *Buchloë dactyloides-Arnica fulgens*, PASTURE and, in the southeastern quadrat, the DRY, *Secale cereale-Bromus tectorum*, FIELD cover most of this area, which is underlain by Arapahoe Formation. In isolated patches, probably where the soil is looser or where grazing is more severe, broad-leaved herbs are able to invade the DRY, *Buchloë dactyloides-Arnica fulgens*, PASTURE mapping unit and the mapping unit DRY, *Buchloë dactyloides-Medicago sativa*, PASTURE replaces it. Where the soil is gravelly and there is an even smaller portion of clay, the vegetation changes from being dominated by short-grasses to being dominated by broad-leaved herbs. In these areas, the DRY, *Heterotheca villosa-Buchloë dactyloides*, PASTURE mapping unit replaces the other two *Buchloë dactyloides*-dominated pasture mapping units. Unlike the latter two types, the DRY, *Heterotheca villosa-Buchloë dactyloides*, PASTURE mapping unit seems to be able to successfully invade the western half of the map area,

Figure 26. The relative importance of growth forms in the 32 vegetation stands plotted on the three ordination planes. The arrangement of the ordination planes is the same as in Figure 24. The ordination axes are labeled with the three controlling environmental complexes. The size of the circles, which has a relative meaning with respect to all values available in each case, is based on the "species" index of each growth form. The stands are located in circle centers.

A. Woody - greater than 5 m in height. This growth form is important in both stands of only one mapping unit (14). It includes one tree, *Pinus ponderosa*, and occurs on very dry, heavily grazed ridgetops.

B. Woody - less than 5 m in height. This growth form contains both shrubs and lianas and was found in only 9 out of 32 stands. It shows a very low importance in a few dry stands and a high importance in moist to wet stands. These stands are not grazed, but this growth form does not occur in stands which have a high percentage of nonvegetated area.

C. Herbaceous, broad-leaved, perennial. This is one of the most important growth forms in the study area which occurs nearly in every stand. It includes both native and non-native plants. Its importance increases with increasing grazing intensity. Its optimum is found in relatively dry stands, both barren and well vegetated.

D. Herbaceous, broad-leaved, biennial. Also this growth form includes both native and non-native plants. It occurs in nearly all stands like the preceding growth form, but with an exception of those that have a high percentage of nonvegetated area. Its optimum lies in moist to wet stands with a low percentage of nonvegetated area. Its distribution does not appear to be affected by grazing regime.

E. Herbaceous, broad-leaved, annual growth form category consists primarily of weeds. It occurs in almost every stand but its importance is high only in two fairly dry stands with a high percentage of nonvegetated area.

F. Herbaceous, narrow-leaved, perennial plants are most common at Rocky Flats. This growth form includes native grasses, narrow-leaved forbs, and a few weedy species. Its importance is high in nearly every stand, and in dry stands in particular. It is absent in stands with a high percentage nonvegetated area, and its importance decreases with increasing grazing intensity.

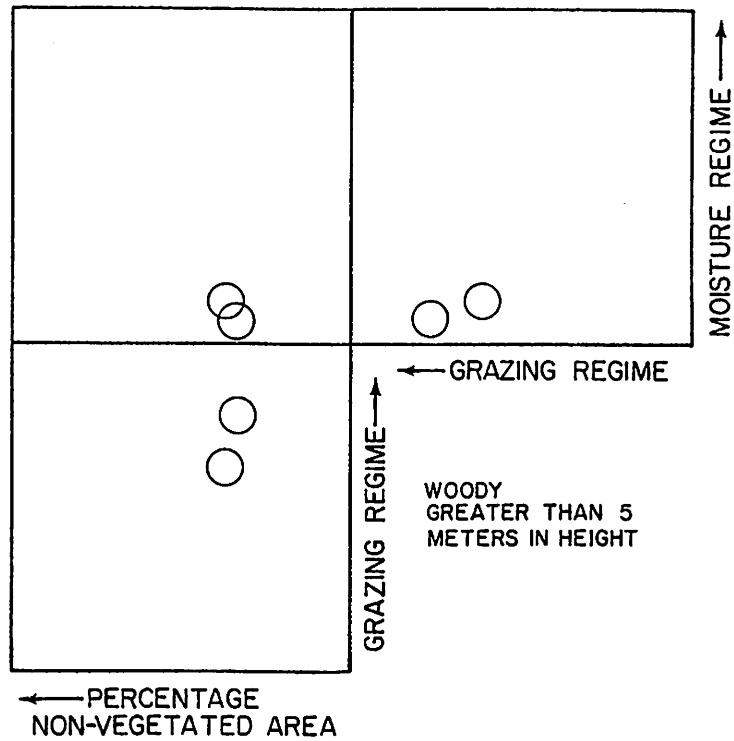
G. Herbaceous, narrow-leaved, annual growth form category includes mainly weedy grasses and narrow-leaved forbs. It occurs in nearly every stand except for those with a very high percentage of nonvegetated area. Its importance increases with increased grazing intensity and it has an optimum in dry to moist stands.

H. Succulent growth form consists of four species of cacti and one species of *Sedum*. It is absent in stands with a high percentage of nonvegetated area, and its importance decreases with increased grazing. It occurs in only 11 stands out of 32, which are dry to moist.

I. Bryophytes include both mosses and liverworts. They occur in only 11 out of 32 stands, avoiding places with a high percentage of nonvegetated area. They are found along the entire moisture gradient, but have an optimum in moist to wet sites. The importance of bryophytes decreases with increased grazing intensity.

J. Lichens, which are more important than bryophytes at Rocky Flats, include both saxicolous and terricolous species. They occur in 13 out of 32 stands, and their importance increases with increased grazing intensity. Lichens are absent in stands with a high percentage of nonvegetated area, and in moist to wet stands. They have an optimum in the driest stands.

A.


MOISTURE REGIME
GRAZING REGIME
GRAZING REGIME
WOODY
GREATER THAN 5
METERS IN HEIGHT
PERCENTAGE
NON-VEGETATED AREA

B.

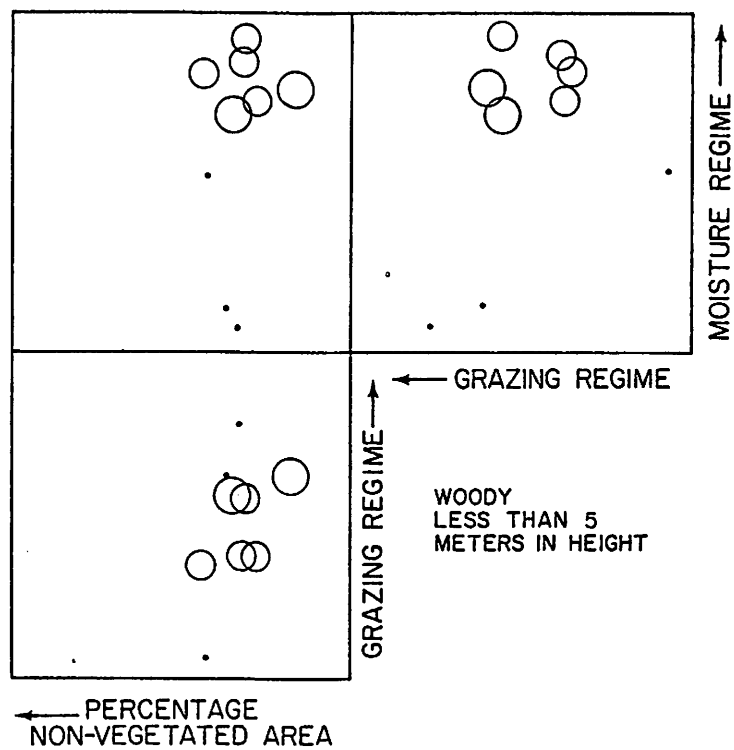
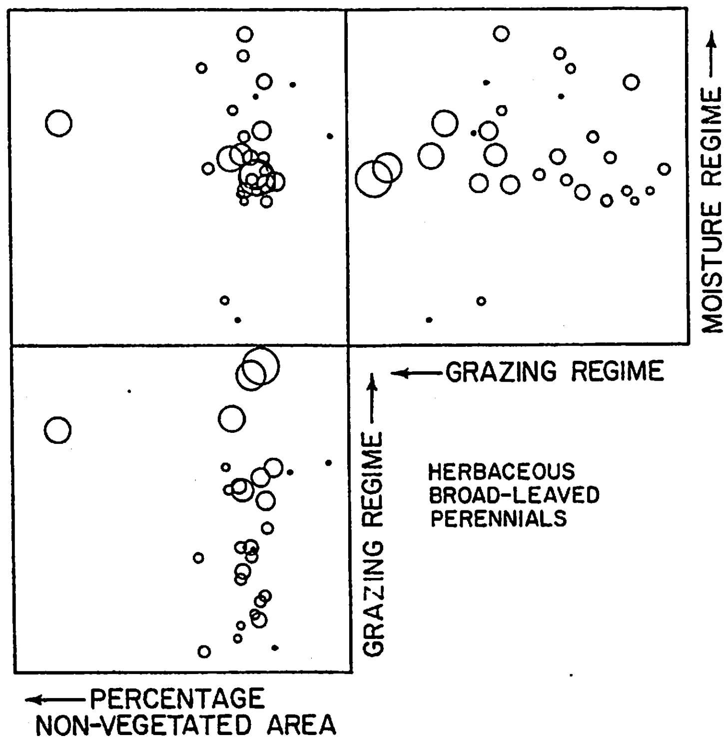
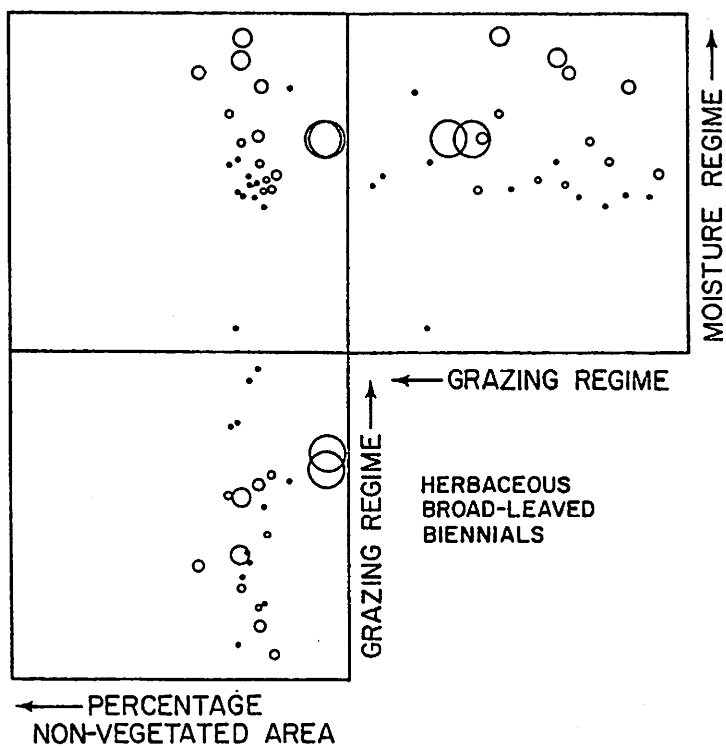

MOISTURE REGIME
GRAZING REGIME
GRAZING REGIME
WOODY
LESS THAN 5
METERS IN HEIGHT
PERCENTAGE
NON-VEGETATED AREA

Figure 26.



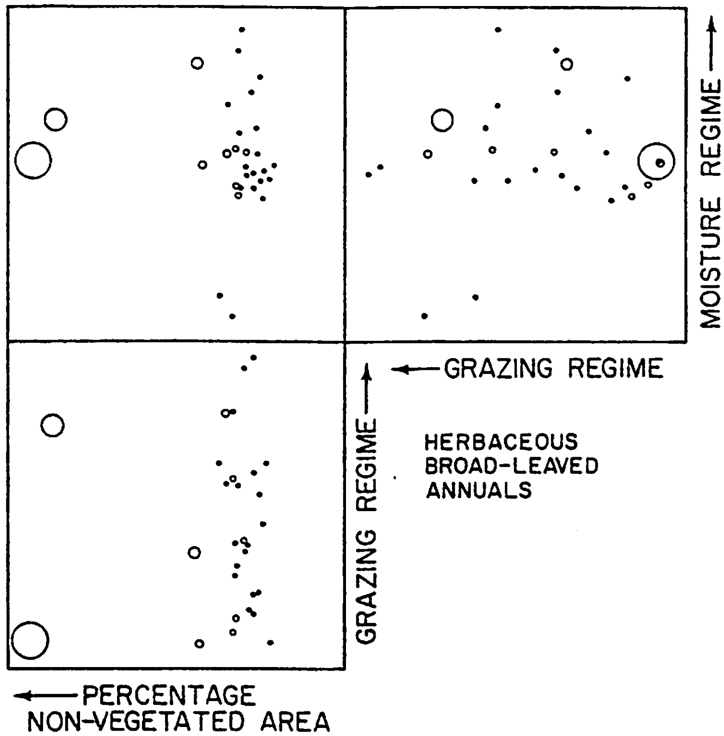
C.



D.

Figure 26 (cont.).

E.



F.

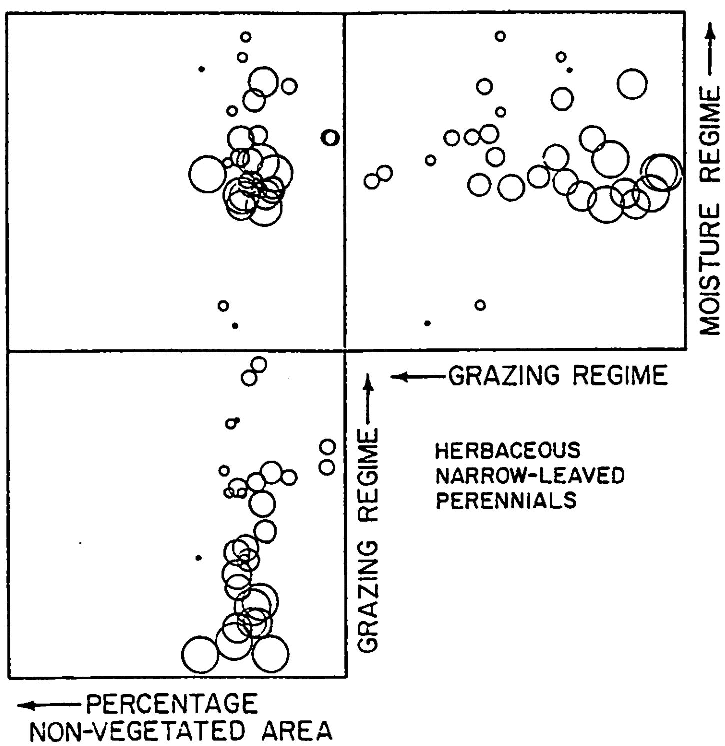
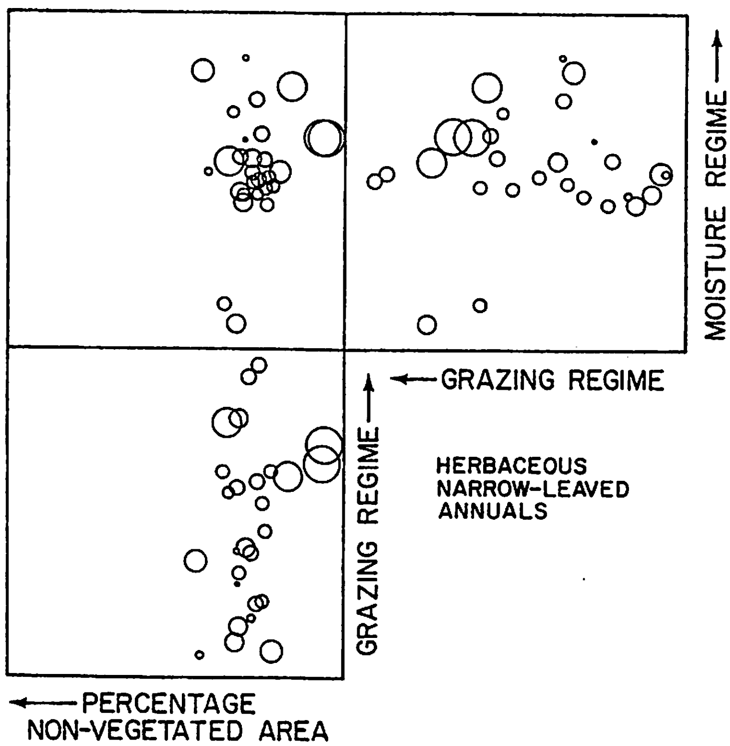
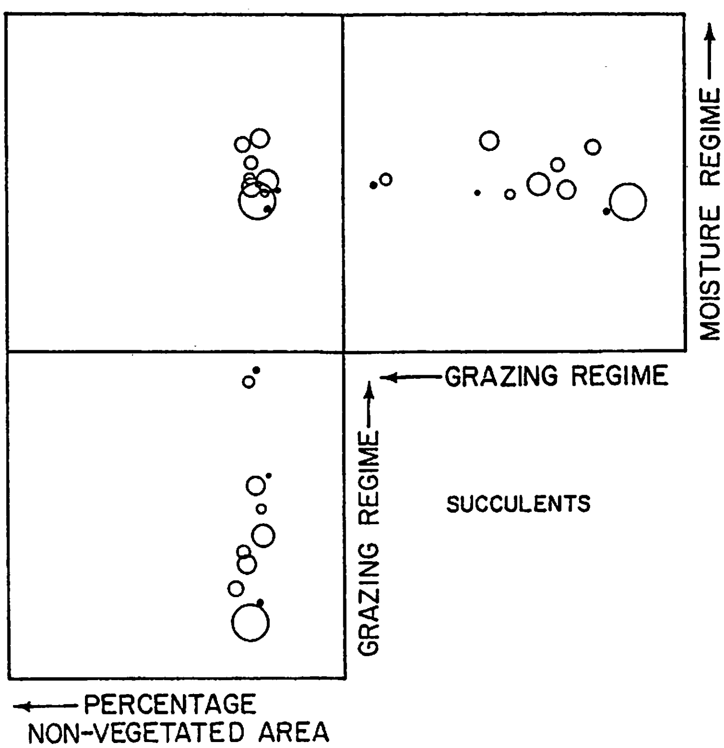


Figure 26 (cont.).

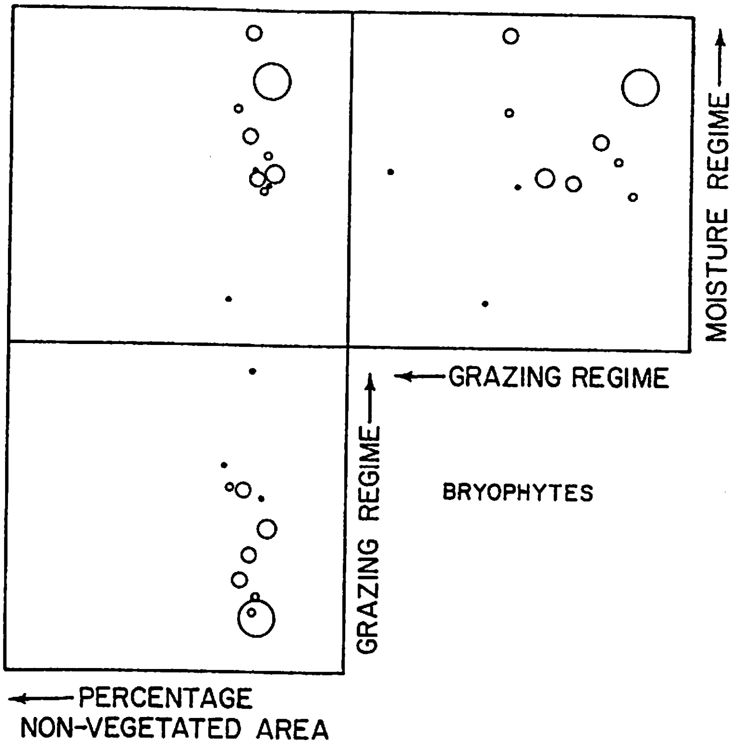


G.

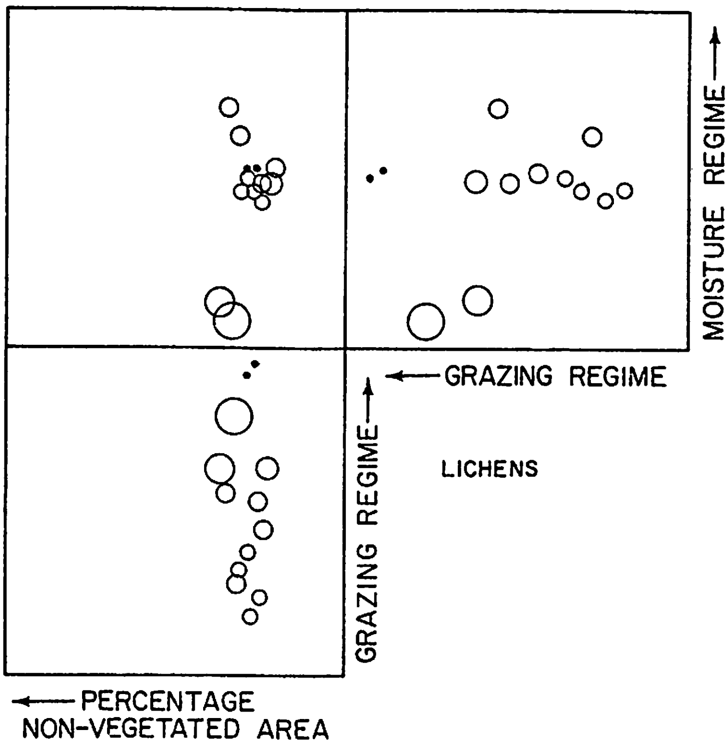


H.

Figure 26 (cont.).



I.



J.

Figure 26 (cont.).

where it is found in greatest abundance, and where it intergrades with the DRY, *Hypericum perforatum-Paronychia jamesii*, PASTURE. These two mapping units seem to have a similar tolerance of grazing. Typically, there is a smaller percentage of nonvegetated area in the DRY, *Heterotheca villosa-Buchloë dactyloides*, PASTURE because of the sod-forming tendency of the latter species, which is lacking in the DRY, *Hypericum perforatum-Paronychia jamesii*, PASTURE. Soil data from stands which represent these two types indicate that there is a larger portion of clay in the soil on which the former mapping unit is found, but not as large a portion as in the soil on which grow the other two *Buchloë dactyloides* pasture mapping units.

The MOIST, *Agropyron trachycaulum-Poa compressa*, MEADOW is found throughout the middle portion of the study area where the valley-sides are slightly steeper and more mesic than in the eastern part and where grazing is not severe. Like the two *Buchloë dactyloides*-dominated pasture mapping units, this mapping unit is found on soil which is underlain by Arapahoe Formation. All these three mapping units intergrade.

SUMMARY, CONCLUSIONS, AND FUTURE RECOMMENDATIONS

The vegetation map (1:12,000) of the Rocky Flats site, supplemented by the descriptions of the mapping units, represents a permanent record of the site vegetation. Any major changes in vegetation cover will be apparent when the current vegetation status is compared with the map. Future construction and management policies can be directed by the information on the distribution of vegetation types and the direction of vegetational change induced, for example, by grazing. The vegetation mapping units were based on plant species composition, but were also characterized by the environmental factors they integrate, primarily by moisture, influence of man, and grazing; i.e., they reflect the effect of these factors on vegetation cover. The vegetation map, which integrates the environment, can be used to monitor changes in both vegetation and environment more effectively than if single environmental factors or vegetation were monitored separately.

Three environmental factors can be considered important controls which influence the vegetation distribution at Rocky Flats. Two of them, percent bare ground and moisture regime, are the basis on which the colors for the 1:12,000 color map of the Rocky Flats vegetation were chosen. The third factor is grazing intensity. All three factors could fairly readily be modified as a means of managing the vegetation. Each of them correlated significantly with an axis of the Bray and Curtis ordination based on growth forms: percent bare ground (r_s = -.55, X axis), moisture regime (r_s = .48, Y axis) and grazing (r_s = .36, Z axis).

As Vestal (1914) predicted, the vegetation does not appear to be any more stable in the Rocky Flats area than it was at the time of his study; on the contrary, it appears to be more disturbed today. Two factors mentioned by Vestal (1914) contribute to this: the location of Rocky Flats in a transition area between plains and foothills, and further cumulative disturbance, primarily by grazing. The replacement of mixed prairie by short-grass plains vegetation in the presence of grazing pressure, and return of mid grasses when the grazing ceases (Weaver and Clements, 1938) has been observed at Rocky Flats. It appears that the disturbance of vegetation at Rocky Flats, primarily by overgrazing, has increased the number of vegetation types present there. At the same time, the species diversity of each type has been reduced, compared to the great species diversity characteristic for the native mixed prairie grasslands. A number of non-native species play an important role in the Rocky Flats vegetation today; some of these species appear in the names of the mapping units. The importance of nonnative species shows how much the original vegetation has been disturbed. If the proportion of vegetated area, and species diversity, which are very low in some heavily disturbed areas at Rocky Flats, could be increased, and the proportion of bare soil thus lowered, the hazard of redistribution of particulate pollutants from bare soil could be lessened. This may be a difficult task in view of the strong wind erosion of the disturbed bare surfaces and the overall dryness of the area. The mobility of plutonium in vegetation and its subsequent movement up the food chain to man should be also considered.

When grazing is discontinued, the vegetation has much potential for recovery, as has been exhibited over the past 20 years in the 10-km^2 area in the plant buffer zone, inside of the outer wire fence. In the past, management at Rocky Flats has used spraying and excavation. Such activities cause great damage and recovery from these drastic practices can be expected to be slow. Increasing the moisture availability in the soil through irrigation and reseeding the barren areas with seed of native grasses would accelerate the natural revegetation process. The mapping units DRY, *Koeleria macrantha-Agropyron trachycaulum*, PRAIRIE; DRY, *Buchloë dactyloides-Arnica fulgens*, PASTURE; and MOIST, *Agropyron trachycaulum-Poa compressa*, MEADOW would probably then constitute a majority of the Rocky Flats vegetation. The marsh, streambank, scrub, low-scrub, and savannah communities would probably have a similar extent as at present.

In the future vegetation-land use oriented research, several permanent, fenced enclosures should be set up in representative areas of each of the sixteen mapping units. Moisture regimes and the composition of reseeding mixture should be varied in different enclosures in each mapping unit and changes in vegetation, particularly in terms of cover, should be monitored. Sections of the plots could be clipped for productivity determinations at regular intervals. The value of individual species (both native and introduced) for artificial revegetation could also be determined from these experiments.

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