AN ABSTRACT OF THE THESIS OF

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Title: PLANT COMMUNITIES OF THE STEENS MOUNTAIN SUBALPINE GRASSLAND AND THEIR RELATIONSHIP TO CERTAIN ENVIRONMENTAL ELEMENTS

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Robert E. Frenkel

Plant communities in a 3.5 km^2 area along the summit ridge of Steens Mountain, Harney County in southeastern Oregon are identified. The character of winter snow deposition and spring melt in this subalpine zone is a major factor in producing the vegetation pattern. Past domestic grazing, topography, wind pattern, climate, soil depth and soil moisture availability are related to the present vegetation mosaic.

Computer-assisted vegetation ordination of 278 transect-located sample units using SIMORD and tabular plant association analysis of 346 areally-located relevés using PHYTO were applied complementarily. Aided by the interpretation of true-color aerial photography (1:5000), this analysis revealed and mapped 12 plant communities and one additional combination community named after dominant species. After comparison of four selected similarity

indexes commonly used in vegetation ordination analysis, Sorensen's modified similarity index was chosen as best for interpretation of stand groupings in the study data. The general vernal snow cover recession pattern was verified with LANDSAT-1 digital data representations.

Plant communities associated with snow deflation, or crest, areas are Erigeron compositus-Astragalus whitneyi, Erigeron compositus-Astragalus whitneyi-Poa cusickii, and Arenaria nuttallii-Castilleja steenensis; with moderate snow cover, or midslope transition, areas are Lupinus lepidus-Eriogonum ovalifolium, Helenium hoopesii-Poa spp., Festuca scabrella, and Festuca idahoensis (bunchgrass "islands"); with snow accumulation, or downslope, areas are Spraguea umbellata-Trisetum spicatum, Lewisia pygmaea-Draba sphaeroides, Arenaria aculeata-Sedum lanceolatum-Cerastium berringianum, Agropyron caninum-Deschampsia cespitosa, and Deschampsia cespitosa.

Plant Communities of the Steens Mountain Subalpine Grassland and their Relationship to Certain Environmental Elements

by

John William Mairs

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When Steen had been reenforced by the artillery companies, he marched on the 4th of August [1860] toward a range of snow mountains east of Harney Lake, extending for some distance southward, near which he believed the Indians would be found, taking with him a hundred dragoons and sixty-five artillerymen.... Attached to Steen's division was a small company of scouts from the Warm Spring reservation, who on the fourth day discovered signs of the enemy on the north slope of a high butte, which now bears the name of Steen [sic] Mountain, and on the morning of the 8th a small party of Indians was surprised and fled to the very top of this Butte to the region of perpetual snow, hotly pursued by the troops. Arrived at the summit, the descent on the south side down which the Indians plunged, looked impassable; but, with more zeal than caution, Steen pursued, taking his whole command, dragoons and artillery, down a descent of six thousand feet, through a narrow and dangerous canyon, with the loss of but one mule. The country about the mountain was then thoroughly reconoitred for three days, during which the scouts brought in three Indian men and a few women and children as prisoners.

Bancroft (1888)

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TERMINOLOGY

The following terms are defined according to their use in this research.

environmental element. A component of the environmental complex such as snow cover, soil, wind, or insolation. Element is favored over the use of "factor" or "variable" which may imply a comprehensive study of the interaction of a given element with vegetation in the study area.

plant association. The basic unit, recognized by its character species, of the Braun-Blanquet tabular vegetation classification system.

plant community. An aggregation of plants sharing a common habitat. Plant communities, in this research, are subdivisions of the vegetation cover based on plant associations.

vegetation segment. Major division of the vegetation based on interpretation of indirect ordination of stands. Segments are identified by evident stand groupings in two-dimensional plots and named after dominant species in these groups of stands. Plant ecologists sometimes refer to the segments directly as plant communities.

<u>vegetation unit</u>. Major preliminary division of the vegetation based on initial arrangement of relevés (sample units) in the Braun-Blanquet plant association table.

PLANT COMMUNITIES OF THE STEENS MOUNTAIN SUBALPINE GRASSLAND AND THEIR RELATIONSHIP TO CERTAIN ENVIRONMENTAL ELEMENTS

I. INTRODUCTION

Research Objective

The subalpine grassland of Steens Mountain, Harney County, in southeastern Oregon has generally been regarded in the past as a single vegetation unit. However, field observation of the grassland suggests a mosaic of plant communities. The analysis of the summit ridge vegetation presented here aims to describe and understand these plant communities in the subalpine zone of Steens Mountain relative to selected environmental elements. Basic to the research design, community analysis, and interpretation was the consideration that snow pattern is a major factor in producing the subalpine mosaic.

Reconnaissance of the Steens vegetation in 1972 suggested advantages in applying two differing analytical approaches. The Braun-Blanquet phytosociological method of identifying plant communities through a systematic analysis of floristic association is one approach (Mueller-Dombois and Ellenberg, 1974); indirect ordination of vegetation based on the methods of Bray and Curtis (1957) is the other. Indirect ordination of stands as well as direct ordination of key species is used in a classificatory manner to identify broad variations in the vegetation cover along a topographic-snow accumulation gradient beginning at the crest of the mountain and extending downslope about 500 meters. Subsequent tabular floristic association analysis is used to refine the vegetation classification derived from the ordination and identifies specific plant communities.

Selected soil characteristics, winter snow depth measurements, topographic features, and local climate are examined in order to support community differentiation. In addition, detection of general vernal snow cover recession in the study area using LANDSAT-1 digital data contributes to an explanation of the snow-vegetation relationship. The interpretation of the plant communities as they relate to these selected environmental elements meets the research goal of characterizing the subalpine environment and fills an information-gap concerning vegetation on one part of Steens Mountain.

Description of Steens Mountain and the Study Area

The isolated massive fault-block of Steens Mountain lies across latitude 42°40'N in southeastern Oregon just north of the Oregon-Nevada border (Fig. 1). The nearest population center of any consequence is the adjacent towns of Burns and Hines, combined population 4,600 (U.S. Bureau

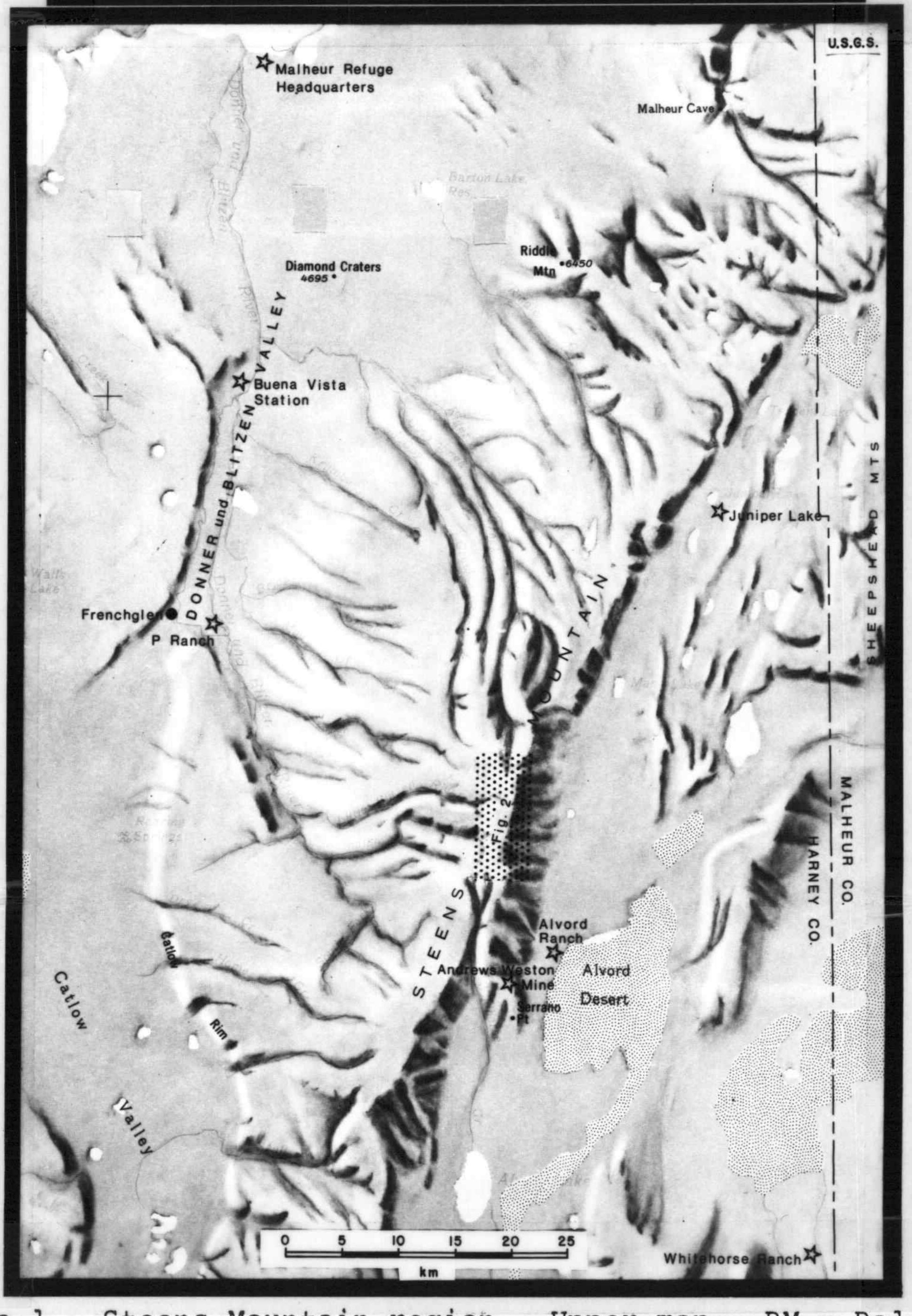

Figure 1. Steens Mountain region. Upper map: BM = Bald Mt.; WEM = East Warner Mts.; L = Lakeview; MM = Mahogany Mts.; O = Ontario; W = Winnemucca.

of the Census, 1973) 130 kilometers to the north. The mountain's isolation in terms of human habitation is further emphasized by the fact that it is over 325 kilometers by road to Steens Mountain from Bend, Oregon to the northwest; Ontario, Oregon on the Snake River to the northeast; Winnemucca, Nevada to the south; and Lakeview, Oregon to the southwest.

Geology

Physiography. The Steens Mountain fault-block trending SSW to NNE for over 50 miles is in the extreme northwest Basin and Range Province (Fenneman, 1931). The base elevation of the region is approximately 1250 meters. The east-facing escarpment at its highest point rises over 1500 meters above the edge of the Alvord Desert only five kilometers distant. The gentle west slope stretches nearly 30 kilometers to the Donner und Blitzen Valley and Catlow Rim (Fig. 1). The mountain's geology and physiography have been described in early reconnaissance work by Russell (1884, 1903), Davis (1903), and Waring (1909). Later work by Smith (1927) and Fuller and Waters (1929) examines the "horst and graben" features of the Steens Mountain area. Although to the casual observer the mountain appears to be a simple homoclinal uplifted block, Smith suggests a horst-graben structure for the region which includes anomalously dipping strata on Steens and compressional warping and faulting associated with its uplift. Fuller and Waters (1929) explain the mountain's structure entirely in terms of normal curving, zigzag, and step faults but strongly refute Smith's compressional tectonic theory. Piper, et al. (1939) and Williams and Compton (1953) support the tensional stress explanation of Fuller and Waters. Fryberger (1959) and Donath (1962) both suggest north-south compressional fault systems related to Steens Mountain and surrounding structure. The debate continues with Avent (1969) who relates the petrogenics and tectonics of Columbia River Basin basalts to basalts on Steens Mountain and the Pueblo Mountains just to the south. Avent has questioned the exclusively tensional or normal faulting explanation based on the study of stratigraphic units at the time of deformation, particularly normal faulting coincident with the extrusion of basalts which are now the highest part of Steens Mountain. He suggests that these volcanics were associated with compressional faulting in the region similar to concurrent tectonics in the Columbia River Basin and that normal faulting occurred later in the uplift period which has been dated at nine to ten million years (Lund and Bentley, 1976).

Stratigraphy. Stratigraphic work of Fuller (1931) identifies the Alvord Creek and Pike Creek Formations of tuffaceous sediments and rhyolitic and dacitic material at the eastern base of the escarpment overlain by the Steens

Mountain Volcanic Series of basalt and andesite flows. The basalts on the highest portions of Steens Mountain are referred to as Steens Mountain basalts, or Steens Basalt, a series of thin flows over 1000 meters thick (Fuller, 1931: 101). Fossil flora of the Alvord Creek Formation has been dated by Chaney, in Fuller (1931), as late Miocene in age and subsequently by Axelrod (1944 and 1957) as being early Pliocene. However, later work has correlated the Steens Basalt with Columbia River Basalt which is of late Miocene age (Avent, 1969). Further problems of stratigraphic sequence especially those related to the Alvord Creek and Pike Creek Formations have been taken up by a number of authors (Wilkerson, 1958; Johnson, 1960; Evernden and James, 1964; Baldwin, 1976; Walker and Repenning, 1965), but no consensus on the entire volcanic succession of Steens Mountain has been reached (Beaulieu, 1972; and Lund and Bentley, 1976).

Glaciology. The most striking contrast between Steens Mountain and most other fault-block ranges in the northern Great Basin is the presence of dramatic glacial erosional features. Four major U-shaped canyons cut into the mountain on the north, south and west: Kiger Gorge, Wildhorse Canyon, Little Blitzen Canyon and Big Indian Gorge. The steep eastern escarpment features several stream canyons with small cirques at their heads (Fig. 2). The glacial geomorphology and glacial advances on Steens Mountain are

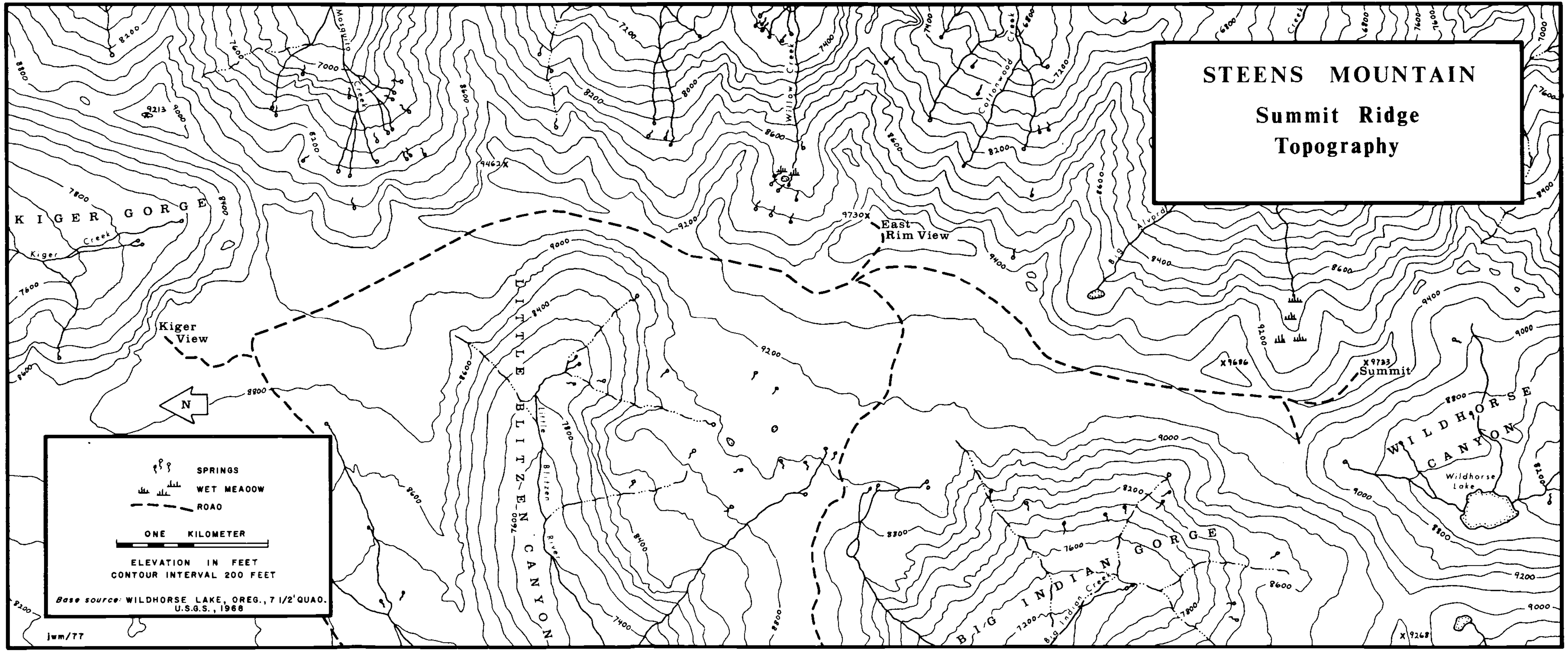

Figure 2. Steens Mountain summit ridge topography.

described by Bentley (1970) and Lund and Bentley (1976).

The Steens Mountain Basalt on the highest part of the mountain and underlying the study area is a series of relatively parallel, uniform strata dipping less than five degrees to the west (Williams and Compton, 1953). These strata are exposed in the upper reaches of the deep glacially eroded canyons and eastern escarpment and the general slope of the high subalpine surface between the crest and canyon headwalls is nearly parallel to the dip (Fig. 2). In at least one area, outcropping strata appear to intersect the slope at a very acute angle. The whole of this uppermost topographic surface appears pedestalled due to deep gorges on the north, west, and south and the sharp relief to the east. The extent of this surface corresponds almost precisely with the study area of the present research.

Vegetation

General Regional Description. Steens Mountain is surrounded by the semiarid Shrub-Steppe vegetation Zone of Franklin and Dyrness (1973). High sagebrush plains (1100-1500 meters) dominated by *Artemisia tridentata* and *Festuca idahoensis* var. *idahoensis* and *Agropyron spicatum* communities having shallow, sandy soils are typical of this warm, dry summer and cold, wet winter region. *Juniper occidentalis* and *Cercocarpus ledifolius* var. *ledifolius* are common in scattered woodlands at higher elevations adjacent to the plains. Lower elevation portions of the broad west slope of Steens Mountain are included within a *Juniperus occidentalis* Zone by Franklin and Dyrness (1973: 44, 45). The physiognomic Shrub-Steppe Zone occurs again at mid to high elevations. The highest part of the mountain is placed within an alpine region. A similar treatment of the mountain's vegetation is given by Frenkel (in Highsmith, 1973). The basin to the east of the mountain is within the Desert Shrub Zone where plant communities on saline soils on the edge of playas grade into upland sagebrush communities. Typical plant species within this zone are *Grayia spinosa*, *Atriplex confertifolia*, *Elymus triticoides* and *Distichilis stricta* (Franklin and Dyrness, 1973).

Critchfield and Allenbaugh (1969) summarize the distribution of Pinaceae in the northwestern Great Basin and discuss the disjunct and insular nature of the family in terms of topographic barriers, Pleistocene climate, and species range extensions. Steens Mountain is located in a region described as transitional between outliers of Pinaceae species bordering the northern Great Basin and the members of Pinaceae which are typical of mountain ranges within the basin (Critchfield and Allenbaugh, 1969: 12). On the west slope of the mountain, in the middle of the juniper zone at approximately 1850 meters elevation, are two small groves of Abies concolor var. lowiana.[1] Both occur on north-facing slopes, the smaller in Little Fir Creek watershed and the larger, not more than 20 hectares, in Big Fir Creek drainage. This is the only reported species of the Pinaceae family from Steens Mountain. A population of 22 Pinus ponderosa has been reported by Packard (in Cronquist, et al., 1972) just north of Mahogany Mountains to the northeast of Steens Mountain (Fig. 1). It is believed that this species occurs also in the Owyhee Mountains just east of the Mahogany Mountains. Pinus ponderosa occurs southwest of Steens Mountain (Fig. 1) on Hart Mountain, the Warner Mountains, the East Warner Mountains, and Bald Mountain (Critchfield and Allenbaugh, 1969). Outliers of Abies concolor var. lowiana occur in these mountains also. Thus, from the northwest corner of the Great Basin proceeding in a south and easterly direction the Steens Mountain population of A. concolor is an outlier in the range of the species and one of the few representatives of Pinaceae at mid-elevation until Pinus monophylla is encountered on ranges well within Nevada.

Study Area Vegetation Summary. The study area for the present research is in the designated subalpine grassland zone. This zone is typified by grass vegetation growing on

[1]The fir is classified here following Cronquist, et al. (1972). Critchfield and Allenbaugh (1969) give Abies grandis as the species name for these trees explaining that they are morphologically similar to A. grandis found in the Blue Mountains to the north.

the relatively gentle slope of the mountain immediately west of the crest. Tree species are absent and only a few shrub species with scattered distributions are present. Low-growing forbs such as *Agoseris glauca* var. *dasycephala*, *Trifolium longipes* ssp. *multipedunculatum*, and *Lupinus lepidus* var. *lobbii* are abundant. The dominant bunchgrasses are *Festuca idahoensis* var. *idahoensis* and *Poa sandbergii*. Areas bare of vegetation or with very sparse vegetation cover occur throughout this grassland. For the most part these bare surfaces result from seasonal snow accumulation, wind and meltwater erosion, and exposed basalt.

Soils

General Description. Standard detailed soil surveys for Steens Mountain and the surrounding region have not been completed. The Oregon Water Resources Board (1969) has mapped and described soil units based on a reconnaissance soil survey conducted as part of the National Cooperative Soil Survey in the Malheur Lake drainage basin which includes Steens Mountain watershed. On the gentle west slope of the mountain from the Donner und Blitzen Valley to the summit ridge of Steens, typical soils are described as shallow to very shallow, light to moderately dark colored, stony, and with basalt, rhyolite, or welded tuff parent material. The lighter colored soils are on uplands adjacent to the valley and are shallow, very stony, fine loamy to clayey, and basic in reaction. At increasing elevation soils are darker, shallow to very shallow, and loamy to clayey. Some of these higher elevation soils may have slightly acid surface layers reflecting an increase in effective moisture with elevation. A few areas of wind-borne or alluvial deposits are deeper, silty, and commonly support dense communities of bunchgrasses and/or big sage-brush.

Subalpine Soil Classification. Many of the soils within the subalpine grassland are poorly developed over basalt parent material. On the whole, they may be described as shallow to very shallow, very stony to rocky, loamy, with virtually no horizon development. The less stony and deeper soils, which support the more vigorous grass communities, are provisionally placed within the soil classification system (U.S.D.A., Soil Survey Staff, 1975) at the subgroup level, as Lithic Cryoborolls (Oregon Water Resources Board, 1969: 78, 79). Lithic Cryoborolls occur at high elevations in mountains of the western United States. Mean annual soil temperatures are low, 0.0° to 8.0°C, and summers are cool and short. They are mainly formed in late Pleistocene and Holocene deposits and usually support grass and/or open forest vegetation. The Lithic subgroup descripter indicates a shallow lithic contact and allows the mollic epipedon[2] (a required characteristic for Mollisols) to extend to rock with no horizons intervening (U.S.D.A., Soil Survey Staff, 1975: 287). In general, these criteria are met by better soils typical of the study area.

No specific soil moisture regime is applied to Cryoborolls in the classification system. However, the Steens Mountain subalpine is subject to snow cover up to eight months of the year (October through May) with total annual precipitation estimated between 70 and 80 centimeters. Precipitation as both rain and snow reaches a peak in the study area during late spring (Fig. 3). Occasional summer showers provide some soil moisture but evaporation is rapid. Although standard climatic data are not available for the study area, the soil moisture regime for the grassland may be described as closest to a Ustic regime where the mean annual soil temperature is less than 22°C and the mean summer and winter soil temperatures differ by 5°C or more at 50 centimeters depth. The soil is dry in some or all parts for more than 90 cumulative days in most years, but is not dry in all parts more than half of the time that the soil temperature exceeds 5°C at 50 centimeters depth (Aridic and Torric regimes). Nor are Ustic regime soils

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[2] A friable, darkened surface layer of a mineral soil with a thickness of at least 18 centimeters, relatively high in organic matter (greater than 1%) and high in base saturation.

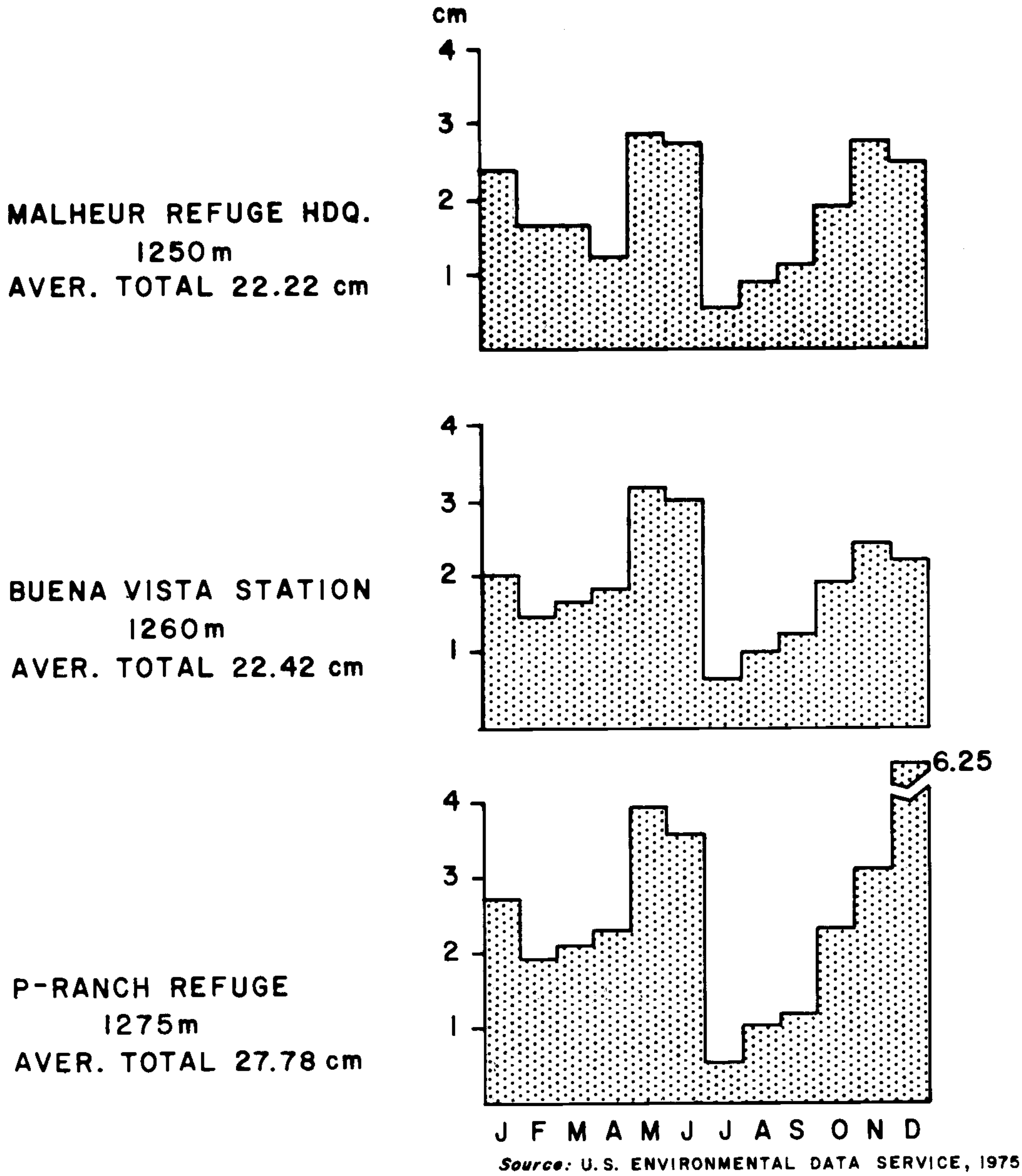

Figure 3. Average monthly precipitation at three stations near Steens Mountain. For locations see Figure 1. Averages based on long term monthly precipitation totals of from 10-29 years used in place of normals.

dry for as long as sixty consecutive days within the three month period following the summer solstice in more than seven years out of ten, if they are moist in all parts for 60 consecutive or more days in the three month period following the winter solstice (Xeric regime). However, a Ustic moisture regime is not applicable to Cryoborolls primarily because of the low mean annual and seasonal temperatures of these soils (U.S.D.A., Soil Survey Staff, 1975: 56). In addition, it is doubtful that summer rains on Steens Mountain in seven years out of ten are sufficient to moisten the "moisture control section" of the soil which is defined as being between the depth to which the dry soil will be moistened by 2.5 centimeters of water within 24 hours (upper boundary) and the depth to which the dry soil will be moistened by 7.5 centimeters of water within 48 hours. If moistening of all of this section does not occur at least once in 60 consecutive days within the period following the summer solstice, then the regime resembles a xeric moisture regime. But, again, as with the Ustic regime, a true Xeric moisture regime would not be applicable to any soils in the suborder Borolls (U.S.D.A., Soil Survey Staff, 1975).

Assigning the better soils of the study area to the Lithic Cryoborolls is tentative but extremely helpful in understanding their development and productivity. The high altitude environment and associated climatic regime explain relatively cold mean soil temperatures and lack of moisture during summer. Soil surfaces are subject to freezing and thawing particularly in early spring when snow cover is partially removed and daily minimum temperatures are well below freezing. Evidence of surface particle sorting from freeze-thaw action can be found in bare expanses throughout the summit area. Snow meltwater in spring and high winds during summer contribute to soil erosion which exhibits its most notable form in long rills, up to 150 centimeters deep, and exposed basalt surfaces along the crest. Erosion in dense grass areas produces a pedastalling effect leaving the vegetation in islands surrounded by erosional channels or flat, sparsely vegetated areas of gravelly soils (Fig. 4).

Cryoborolls in the western United States commonly support grass or open coniferous forests. Perennial bunchgrasses are the dominant plants in the subalpine on Steens Mountain and if high altitude climate or the isolation of the mountain or other factor is not adequate to account for the absence of coniferous trees then the shallowness of much of the soil significantly contributes to the explanation.

Climate

Regional Climate. Steens Mountain lies in a regionally semiarid climate zone with annual mean temperature and

Figure 4. Grass "islands" surrounded by sparsely vegetated surfaces in background beyond snow. Photograph taken in late June, 1972.

average rainfall similar to other locations in the northern basin and range physiographic province. The climatic station at Burns, Oregon, a basin location at 1260 meters, records a mean annual temperature of 7.8°C. The coldest month is January, mean temperature -3.8°C, and the warmest, July, with 20.2"C. These statistics compare with Winnemucca, Nevada (elevation 1310 meters), 8.8°C annual mean temperature, -2.1°C January mean and 21.7°C July mean temperatures and with Lakeview, Oregon (elevation 1455 meters, 7.9°C annual mean temperature, -2.3°C January mean and 19.2°C July mean temperatures. The average annual precipitation at Burns, Lakeview and Winnemucca (Fig. 1) is 29.0 centimeters, 39.4 centimeters and 20.8 centimeters respectively. These stations have a "double maximum" precipitation pattern with the peaks occurring in winter (November-December-January) and spring (May-June). Summer and early fall are driest with usually less than one centimeter per month recorded (U.S. Environmental Data Service, 1975).

Although temperature data are sparse for stations near Steens Mountain, the average annual mean temperature at the P-Ranch Refuge station (elevation 1275 meters) is given as 8.9°C (Oregon Water Resources Board, 1967). At this station, which is located in the upper Blitzen Valley near Frenchglen, winter monthly mean temperatures are typically between -1.1°C and 2.2°C and summer monthly mean temperatures between 15.0°C and 19.0°C. These mean temperatures indicate that the climate at the western base of Steens Mountain is more moderate than most of the surrounding region.

Long-term average monthly precipitation data which are available for P-Ranch, Buena Vista Station (elevation 1260 meters), and Malheur Refuge Headquarters (elevation 1250 meters) (Fig. 3) show a distinct May-June primary maximum. This spring primary maximum which is typical of the region has been documented and explained by Quinn (1977). Winter precipitation at these stations is also significant but spread over a three or four month period with monthly amounts ranging from two to six centimeters. Much of this precipitation is in the form of snow whereas nearly all precipitation in the spring is from rainfall. Average annual totals at these stations west and north of Steens Mountain (Fig. 1) are from 22 centimeters to 28 centimeters.

Few long-term precipitation data are available for the area immediately east and south of the mountain, but it is inferred that these areas have similar averages and seasonal patterns of precipitation. In Figure 5, 1974 monthly totals at the Andrews Weston Mine Station, elevation 1460 meters, 10 kilometers south of Steens Mountain summit and at Whitehorse Ranch station, elevation 1280 meters, 43 kilometers southeast of the summit may be compared with the

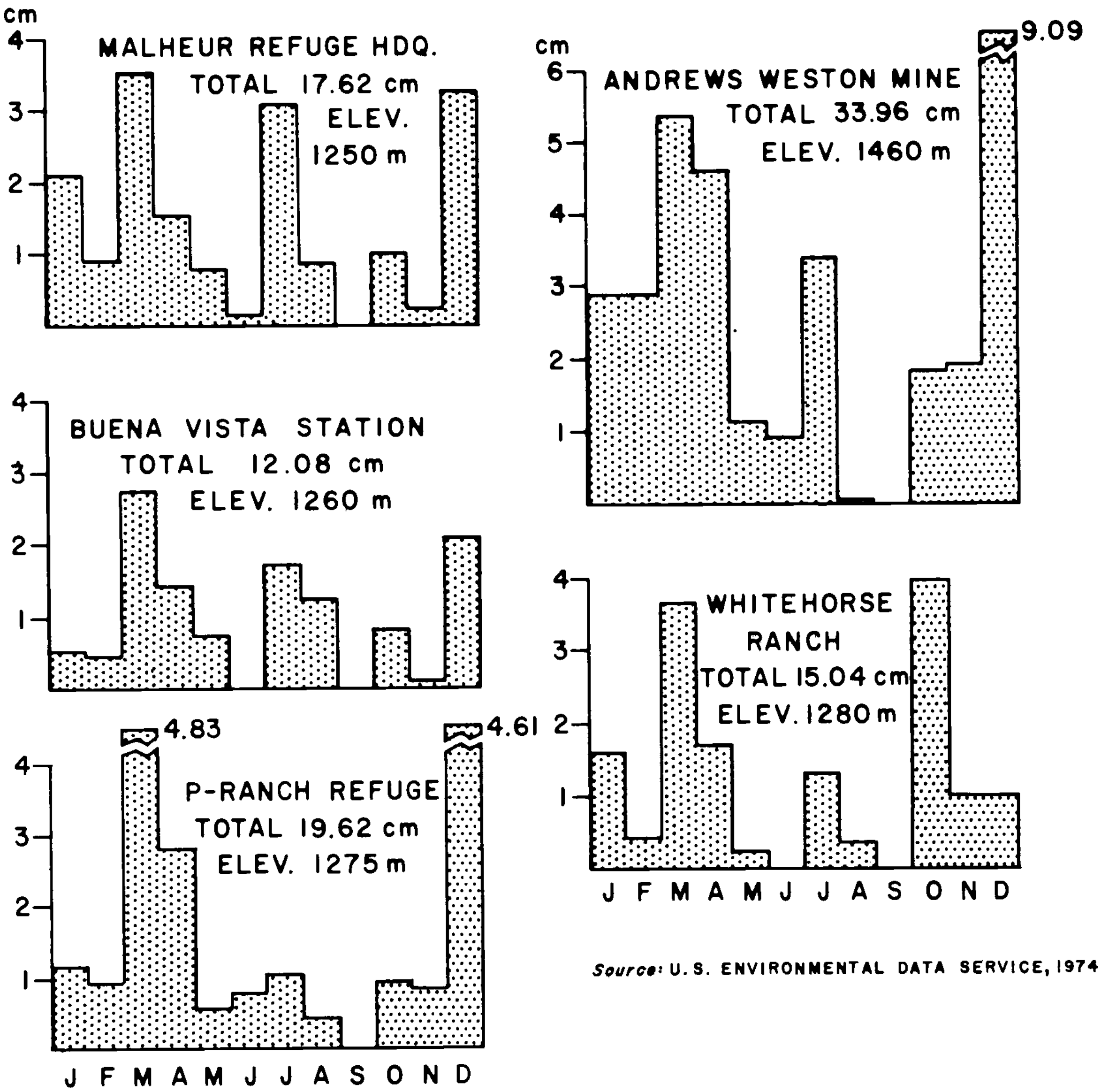

Figure 5. Monthly precipitation totals for 1974 at five stations near Steens Mountain. Compare with averages, Figure 3. Long-term averages not available for Andrews Weston Mine and Whitehorse Ranch.

1974 monthly totals at the stations west and north of the study area (Fig. 1). Although long-term average monthly totals for Whitehorse Ranch and Andrews Weston Mine are not available for comparison, the 1974 seasonal pattern of precipitation is similar for all stations. Spring rains occurred early, in March and April. Midwinter, late spring, and early fall precipitation were well below normal. July, 1974, had exceptionally high rainfall. This is noteworthy since most of the vegetation data analyzed in this study were taken in July and August, 1974, and therefore the interpolated above-normal precipitation in the study area at this time may have affected plant species cover data.

Total 1974 precipitation for the three stations that have long term records are 55 to 80 percent of normal amounts. If it is assumed that precipitation was below normal for the entire region, then the amounts for Whitehorse Ranch and Andrews Weston Mine stations can be considered below normal also. No long-term precipitation averages have been computed by the U.S. Environmental Data Service for these stations but their recorded annual totals and averages for the past six years, 1970 through 1975, are in Table 1. The six-year average for these two stations when compared with the 1974 totals and with 1974 precipitation totals at adjacent stations indicate the year on the

Table 1. Andrews Weston Mine and Whitehorse Ranch total precipitation in centimeters, 1970-1975. (U.S. Environmental Data Service, 1970-1975).

	Andrews Weston Mine	Whitehorse Ranch
1970	49.78	26.12
1971	46.65	24.79
1972	42.51	18.82
1973	39.59	22.49
1974	33.96	15.04
1975	43.30	20.04
Six Year Average	42.63 (17.40 inches)	21.22 (8.66 inches)

whole was drier than normal for the region. This condition is extended to the study area as well.

It would appear to the observant traveller on Steens Mountain that the massive mountain block rising 1800 meters above the surrounding basins produces a rain shadow effect that contributes to the dry landscape of the Alvord Desert, the playa in the basin east of the mountain (mean elevation 1235 meters). The vegetation and associated marshes in the Blitzen Valley and Malheur Lake basin give the impression of a relatively wet (less dry) climate on the west side of the mountain. However, available data suggest that the local precipitation regime is such that the Alvord Desert basin receives as much rain and perhaps more than the Blitzen Valley and Malheur Lake basin. Both basins have a cool, dry climate with most precipitation occurring in spring and winter. Whitehorse Ranch, 22 kilometers southeast of the Alvord Desert and at the northwest base of the

Trout Creek Mountains, has an average precipitation record for 1970-1975 (Table 1), the only years a complete record is available, only slightly less than averages for stations on the west side of Steens Mountain (Fig. 3). Juniper Lake station (elevation 1250 meters, Fig. 1) just on the east side of the low northern escarpment of Steens Mountain, has a complete precipitation record from 1960 to 1976. Table 2 compares the Juniper Lake annual totals with Buena Vista

Table 2. Juniper Lake and Buena Vista Station Total precipitation in centimeters, 1960-1967. (U.S. Weather Bureau, 1960-1967).

	Juniper Lake	Buena Vista Station
1960	32.66	21.68
1961	25.19	15.02
1962	24.63	19.53
1963	32.93	25.09
1964	40.08	27.00
1965	27.69	21.66
1966	17.71	22.42
1967	21.41	16.24
Eight Year Average	27.79 (11.34 inches)	21.08 (8.60 inches)

station totals for the same years of record. Except for one year, Juniper Lake had consistently higher totals for the period. In addition to the figures in Table 2, discontinuous precipitation data from a station at Alvord Ranch (elevation 1280 meters, Fig. 1) when compared with data recorded for the same periods at Buena Vista Station (U.S. Weather Bureau, 1961, 1962, 1964) also suggest that the

Alvord basin has no less precipitation than the west side of Steens Mountain. However, available temperature data for these two stations indicate slightly higher summer temperatures that could be a factor explaining a drier environment in the Alvord basin.

The extensive snowpack and large watershed area on the west slope of the mountain is responsible for the large amount of surface water that maintains the marshy habitats year-round in the lower Blitzen drainage and around Malheur Lake. The eastern escarpment of Steens Mountain provides little catchment area for the Alvord Desert basin. Surface water from rain and snowmelt in spring fills only a small portion of the basin in typical years and this is quickly evaporated in June and July. Thus, the apparent desert landscape of the Alvord basin is more a result of a relatively small catchment area and playa condition in a broad, ancient lakebed and somewhat higher summer temperatures than due to a mountain barrier to rainfall.

Indeed, the mountain, if affecting local precipitation patterns at all, may produce a slight rain shadow to the northwest. When cyclonic disturbances pass through the area, surface winds draw moisture-laden air generally from the south and up over the SSW-NNE trending escarpment from that direction. Although precipitation data are insufficient and the relationship between cyclonic wind patterns and local topography has not been studied in detail, the relatively high average precipitation, 42.63 centimeters, at the Andrews Weston Mine station (Table 1), which is only 200 meters higher in elevation and three kilometers west of the Alvord playa, suggests that there is a strong orographic effect related to cyclonic storms which are the main source of precipitation in the area. Allowing that orographic processes occur on the west slope also, the steep east slope may still receive as much, if not more, precipitation than the west slope.

Study Area Climate. Because of a lack of data and certainty regarding precipitation-topography relationships the average annual precipitation in the study area is difficult to estimate. Amounts most likely vary widely over the mountain's expanse. Higher elevations receive relatively greater amounts through funnelling as well as by orographic effects which may produce even greater precipitation in upper canyons. Seasonal precipitation distribution is similar to the stations in the surrounding basins except that at the elevation of the study area most precipitation is in the form of snow. Snow depths in the subalpine grassland typically reach a maximum in the early spring and range from 45 to 300 centimeters depending on local wind conditions and topography. Mean daily temperature maximums begin to exceed 0°C in March[3] and snow precipitation after this time is subject to melting within a few days. Assuming an average water equivalent of 33 percent for the Steens Mountain snow pack, this average derived from U.S. Soil Conservation Service data for the two stations nearest the study area (U.S.D.A., Soil Conservation Service, 1973), it is possible to roughly estimate winter precipitation. Using a ratio method described by Conrad and Pollack (1950) an average snow accumulation of 150 cm for the grassland was extrapolated from winter snow depth data collected during the winter season 1972-1973 and from snow depths recorded between 1936 and 1976 at lower elevation stations by the U.S. Soil Conservation Service (U.S.D.A., Soil Conservation Service, 1973). The water equivalent for this extrapolated average accumulation would be 50 cm. This estimate does not account for evaporation, ablation, and possible meltwater runoff and must therefore be considered conservative. However, adding this to a liberal estimate of from 20 to 30 cm spring and summer rainfall would give a 70 to 80 cm average annual precipitation for the summit ridge of the mountain. Although derived in a different manner, this is similar to

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[3]Interpolated from normal temperature lapse rate (6.4°C/ 1000 m) and differences in 1974 summer month mean daily temperatures between P-Ranch and the summit ridge. It is estimated that maximum temperatures at the higher altitude are normally 10 to 13°C lower than at the mountain's western base at 1275 meters.

the estimate of Frenkel (1975).

Winter temperatures are quite low. No data are available but it is expected that January daily minimums fall into the -30° to -40°C range. Mean July and August temperatures are estimated at between 10°C and 12°C. Mean daily maximums and minimums are approximately 19°C and 3°C respectively during these months. Light frosts occur frequently during the growing season and snow or hail from a summer storm is not unusual.

In summary, the climate of the subalpine study area is marked by a cold winter with significant snow cover accumulating for several months and a dry, cool summer with wide diurnal temperature ranges. Normally, snow accumulates and reaches a maximum in early spring after which time a two to three month snow melt begins. Maximum precipitation coincides with this melt period, most of it in the form of infrequent but relatively heavy rains. July and August are the driest months with a small amount of rain from convectional storms or unseasonable cyclonic disturbances.

Plant life over the subalpine grassland is almost wholly perennial. Where shrubs occur their stunted form reflects severe winter and spring climate and dry summers. Plants with large taproots are common. New growth of dominant bunchgrasses emerges in July and seed heads are usually mature by mid-August. Steens Mountain, due to its elevation and isolation in the semi-arid steppe of the northern Great Basin, appears as an oasis of cooler climate during this season. September signals the end of the growing season with colder temperatures and the possibility of winter-type storms. The first significant storm is usually in late October.

Human Impact

Past. Steens Mountain and the surrounding region have been historically rangeland for domestic cattle, sheep, and horses. The mountain itself is an attractive summer range and this grazing resource has been the major economic use since the late nineteenth century. Before this time American Indians hunted deer, antelope, mountain sheep, and other game on the mountain and their arrowheads and other artifacts are found there.

The Homestead Act, passed by the United States Congress of 1862 and which affected much of the land settlement in the western United States, resulted in the filing of claims by stockmen on land in the bottoms and entrances to the deep canyons of Steens Mountain primarily where water was available. Although much of the land in the area remained public, by the 1870's the west side of the mountain and access to it was virtually controlled by a large California-based cattle company. A similar situation existed on the east slope and the margins of the Alvord

Desert (French, 1964). In the 1860's the State of California had enacted a "fence law" which made cattle owners liable for damage on land not their own whether or not the land was fenced. Considering the drought in California in the mid-1860's as well as the potentially less restrictive range in eastern Oregon some California cattle interests moved their grazing operations to Oregon in the early 1870's where no fence law existed and where range conditions appeared better (Brimlow, 1951).

During the next few decades vegetation on the mountain was affected by foraging cattle and, by the beginning of the twentieth century, by bands of domestic sheep which had entered the Steens Mountain range. The *de facto* land control of the large cattle companies declined slowly with an increase in the population of settlers in the region and subsequent demand for public rangeland and access to better water sources during this period. Around 1900, sheep reached a high market value relative to cattle (Waring, 1909) and came to dominate the mountain's summer range. I.C. Russell (1903: 19) noted the destruction of bunchgrass by sheep on Steens Mountain and Griffiths (1902: 28) gives the following account of range conditions on the mountain in 1901:

> The most closely pastured region visited was Steins [sic] Mountain. On the whole trip of three days we found no good feed, except in very sharp ravines, until we reached the vicinity of Teger [Kiger] Gorge. On a portion of the trip from here to Mann Lake there was a

> good stand of grass, the side of the gorge and the area immediately to the east being exceptionally fine. There was a good many cattle in the locality, but no sheep had been pastured there this season.....
>
> The injury to the open grassy areas from overstocking [sheep] results mainly from too close cropping which exposes the bunches of roots to the direct rays of the sun, and deprives them of the beneficial action of the accumulation of debris from previous years, both in protection from excessive heat and in holding moisture. On this trip we crossed three areas of this grass varying in extent from 3 to 60 acres, upon which the beautiful pure growths of sheep fescue [given as Festuca ovina but probably includes Festuca idahoensis var. idahoensis] were completely ruined. The bunches of great size were completely killed. Fig. 6a [a reproduction of the original plate] shows one of these localities. The objects in the foreground are mainly closely cropped bunches of this beautiful grass which under natural conditions stands at a height of from 1 1/2 to 2 feet, and, although in bunches 4 to 10 inches apart, the abundant and graceful culms cover the entire surface. Under ruinous pasturing the bunches appear to die usually from the center. One may often find in these mountains a narrow green ring fringing a dead center [this could be due to natural aging, too]. It is a very striking characteristic, and is found in many places. In the figure referred to above the grass is completely killed.

Although extensive sheep grazing on the mountain has continued until only a few years ago, it apparently reached a peak in the early part of this century. Shinn (1977) has compiled census data on the numbers of cattle and sheep in eastern Oregon from 1880 to 1969, Figure 6b. Peak census years for sheep were 1900 and 1930 when approximately 2.4 to 2.5 million head grazed in eastern Oregon. In 1938

Figure 6a. "A depleted range in Steins Mountains [sic], Oregon," from Griffiths (1902). Exact location not given, but it is probably in or near the north end of study area.

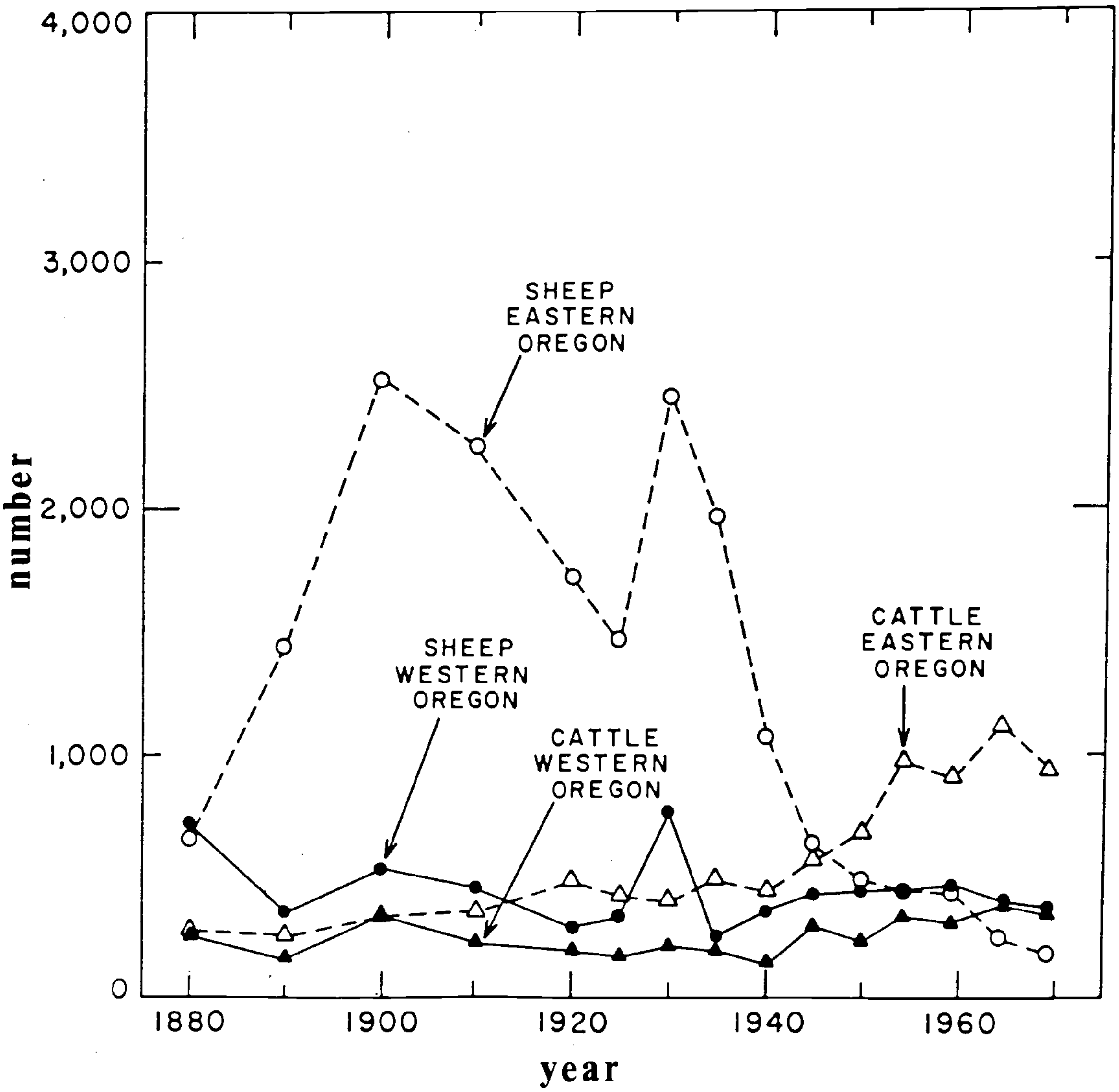

Figure 6b. Number of cattle (except milk cows) and sheep in Oregon, 1880-1969. From Shinn (1977).

and 1939, during a regional decline in sheep grazing, Hochmuth, et al. (1942) reported approximately 200,000 sheep in Harney and Lake Counties (Oregon Grazing District 2) and 94 operators.

Griffiths (1902: 30) relates some extraordinary statistics he gathered on his excursion over Steens Mountain. From a supplier familiar with sheep herding on the mountain he ascertained that there were 73 bands of sheep each averaging 2,500 animals on top of Steens Mountain at the time. He estimated that this would be approximately 450 animals per square mile during a four month summer grazing season. Cattle were being run also over the same area during this time. Although the accuracy of these figures may be questioned, they nevertheless indicate that severe grazing pressure was placed upon this high elevation environment over a period of years, perhaps decades. Hansen (1956) concludes that overgrazing was an important factor in the formation of remnant grass "islands" in the subalpine zone (see p. 108).

The Stockraising Homestead Act of 1916 allowed larger parcels, 640 acres, of rangeland to be homesteaded by stockmen. This resulted in more private ownership on Steens Mountain and consequently some restriction on wandering bands of sheep (U.S. Bureau of Land Management, 1971). The Taylor Grazing Act of 1934 ended an era of gross exploitation of the mountain's public lands for forage.

Present. Since 1934 the allotment system for domestic grazing on public lands administered by the Bureau of Land Management refined the use of the mountain's rangeland resource. In 1969 the Bureau ended all grazing allotments above 2400 meters while considering a new management plan based on a complete study of vegetation and soils in this high altitude environment. In 1971 there were approximately 17,000 cattle and horses and 6,000 sheep licensed to use federal lands on other parts of the mountain at some time during the year (U.S. Bureau of Land Management, 1971: 18).

Over the past fifteen to twenty years recreation use of the mountain has been increasing rapidly. Efforts made in the late 1950's to draw attention to the scenic beauty and recreation potential of the mountain resulted in the formation of the Steens Mountain Recreation Committee which was influential in the construction of a summit road completed in 1962 and which improved access to the highest part of the mountain. Traffic sampling by the U.S. Bureau of Land Management (1971) in 1970 compiled the following visitor data for the summit access road:

Average daily vehicle traffic, May-October	57
Total season traffic	8,550
Total visitors	29,500

Although designated camping areas and facilities are present, either by choice or necessity, many visitors camp at dispersed sites at mid-elevations on the mountain especially on summer weekends when designated campgrounds are full. This situation, as well as off-road vehicle activity, damages vegetation and creates sanitation problems.

Future. Steens Mountain is a good example of an area long isolated from the mainstream of recreation travel but which in recent years has been visited by an increasing number of campers, hikers, horsemen, sightseers, artifact hunters, and fishermen. Recent high gasoline prices and increased energy conservation awareness notwithstanding, increased leisure time and the trend toward amenity-rich mobility epitomized by the self-contained recreation vehicle has caused many isolated areas littled used by outdoor recreationists in the past to become extremely popular. Continuing management of public lands must take into account the fragile nature of the environments being affected by the impact of increased human recreational activity.

Toward this end the BLM, Burns District, together with a broad group of local business people and ranchers, has proposed a plan and made recommendations with the aim of increasing protection of the mountain's resources through appropriate management practices (U.S. Bureau of Land

Management, 1971). Although grazing will remain a large part of the resource use on the mountain, more attention is being given to recreation development in the form of roads, trails, campgrounds, overlooks, and interpretive programs. The subalpine grassland has been designated a "people influence" zone for planning purposes based on the fact that the summit road passes through the extent of the grassland.

II. BACKGROUND AND REVIEW OF LITERATURE

Steens Mountain Environment

Vegetation Zonation

Vegetation on Steens Mountain has been described in terms of zones or belts by Hansen (1956) and Faegri (1966) and may be discussed within the zonation framework for the intermountain region as presented by Billings (1951) and Cronquist, *et al*. (1972).

Hansen's Vegetation Belts. Hansen (1956) in his pioneer ecological work on the mountain describes its vegetation in terms of elevational zones or "belts". Although these vegetation "belts" are not strictly observable, they are useful for general understanding of the vegetation and as departure points into more detailed description (Fig. 7a). The four zones are named after the most characteristic species and cover elevation ranges as follows:

Elevation in Meters	Vegetation
2425 - 2950	Sub-alpine Bunchgrass Belt
1975 - 2425	Aspen Belt
1675 - 1975	Juniper Belt
1275 - 1675	Tall Sage Belt

The Tall Sage (*Artemisia tridentata* var. *tridentata*) Belt is an extension up the lower slopes of the mountain of the nearly ubiquitous shrub-steppe vegetation that

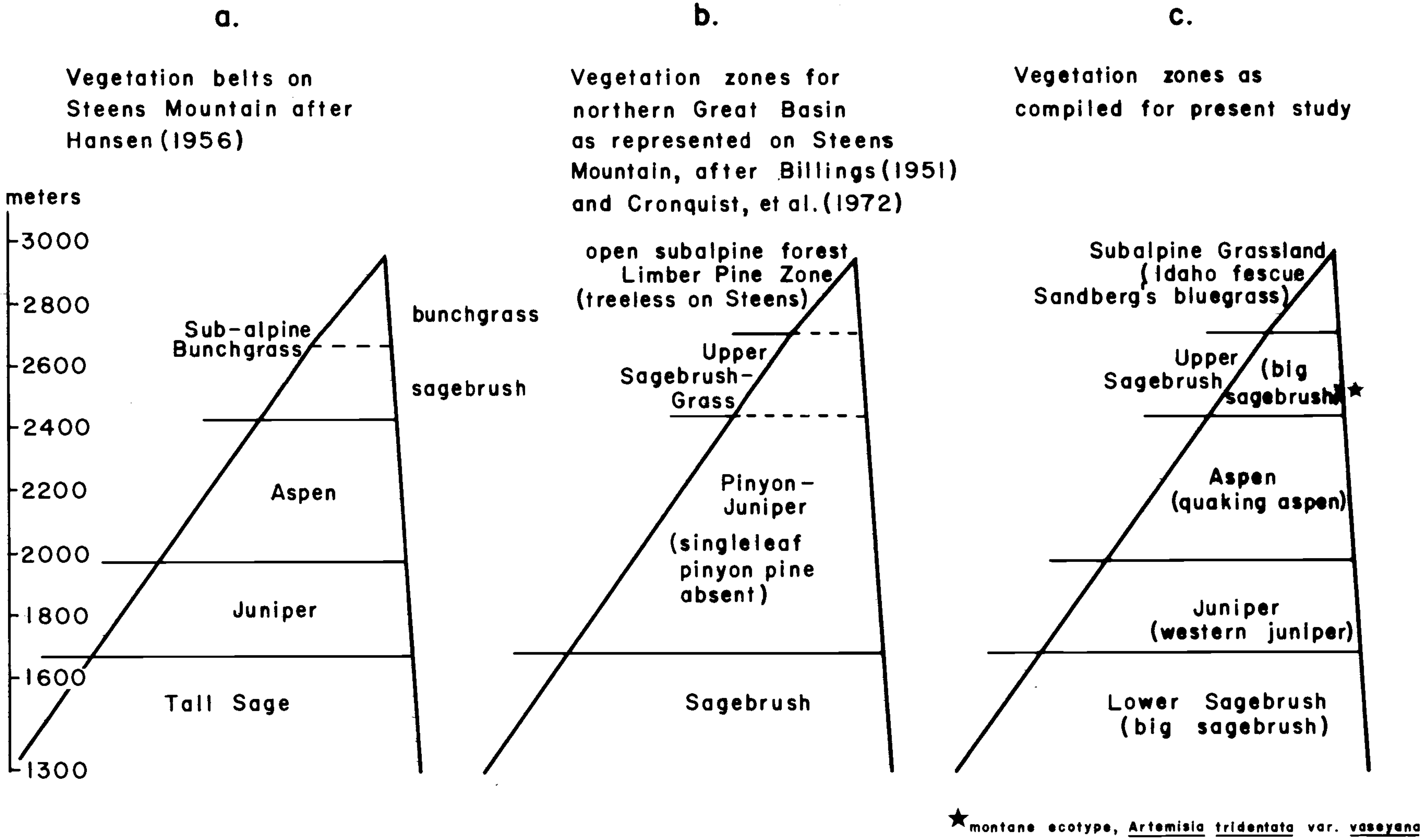

Figure 7. Steens Mountain vegetation zonation diagrams.

occurs regionally. The Juniper (*Juniperus occidentalis*) Belt consists of prominent but discontinuous juniper woodland. Some portions of this woodland, although individual trees are not exceptionally large, are very dense and take on the appearance of a forest. Toward the upper elevation limit assigned by Hansen, 1975 meters, *Juniperus occidentalis* occasionally becomes intermixed with *Cercocarpus ledifolius* var. *ledifolius* and *Populus tremoloides* depending on the local habitat. The *Populus tremuloides* occurs commonly in groves between 2000 and 2400 meters and in more sheltered and moist sites such as along tributary creeks at the upper limits of its distribution. In the canyons the groves reach their greatest extent and individuals their largest size. *Cercocarpus ledifolius* var. *ledifolius* is scattered throughout the upper Juniper and lower Aspen Belts in rocky habitats.

Above the limit of *Populus tremuloides*, in Hansen's Sub-alpine Bunchgrass Belt, the vegetation is dominated by, after Hansen, *Artemisia arbuscula* var. *arbuscula*. Based on the present author's observations, *A. arbuscula* var. *arbuscula* is present but *A. tridentata* var. *vaseyana* is the dominant. This vegetation type extends up to about 2700 meters above which altitude, sagebrush gives way to the bunchgrasses *Festuca idahoensis* var. *idahoensis* and *Poa sandbergii*. It is noted that the sagebrush physiognomic vegetation type is a recurring element over the entire mountain. It is often the understory in the *Juniperus occidentalis* woodland and *Populus tremuloides* groves. One of the few areas where it is conspicuously absent is above 2700 meters in the subalpine grassland.

Hansen's vegetation belts apply primarily to the west slope of Steens Mountain but may be applied generally to the eastern escarpment with modification due to a differing climatic regime, steeper slopes, and the absence of favorable sites for extensive vegetation growth. Abundant *Cercocarpus ledifolius* var. *ledifolius* occurs mixed with *Juniperus occidentalis* on the east slope at mid-elevations, especially east of Kiger Gorge.

Great Basin Vegetation Zones. The vegetation of the entire intermountain region (Utah, all but extreme southern Nevada, southern Idaho, southeastern Oregon, parts of eastern California, and extreme northwestern Arizona) has been divided into both basin and montane type zones by Cronquist, *et al*. (1972, after Billings, 1951). Three zones as described by these authors can be recognized on Steens Mountain: Sagebrush Zone, Pinyon-Juniper Zone, and Upper Sagebrush-Grass Zone (Fig. 7b). These zones correspond generally to Hansen's vegetation belts except that the *Populus tremuloides* groves are considered restricted to the moister parts of the upper limits of the Pinyon-Juniper Zone and as common inclusions in canyon bottoms and wet places within the Upper Sagebrush-Grass Zone (Cronquist, *et al.*, 1972: 130 and 135). A fourth zone, Limber Pine-Bristlecone Pine open subalpine forest, as such, is not present on the mountain but a treeless, subalpine meadow is apparent in its place on the summit ridge.

The Pinyon-Juniper Zone type on mountain ranges in central Nevada and Utah is characterized by low to mid-elevation woodlands (1525-2450 meters) consisting of *Pinus monophylla* and *Juniperus osteosperma*. On Steens Mountain, neither of these species is present; both are replaced by *Juniperus occidentalis*. The composition of the zone in central Nevada is such that *J. osteosperma* occupies lower elevations and *Pinus monophylla* upper elevations with some mixing of the two tree species at middle elevations within the zone (Cronquist, *et al.*, 1972). The *Juniperus occidentalis* woodland on Steens Mountain extends from 1675 meters to 1975 meters and occupies the lower half of a coniferous tree zone that would be expected to extend much higher if *Pinus monophylla* or an ecologically similar pine ranged into the Steens Mountain region. *Populus tremuloides* is the dominant tree at the elevation equivalent to the upper half of the Pinyon-Juniper Zone (approximately 2000-2400 meters) and is the only tree ranging into higher elevations on Steens.

The prominence of *Populus tremuloides* on the mountain in the upper half of the Pinyon-Juniper Zone suggests that it has become more abundant than is typical on ranges of the Great Basin in the absence of an aborescent competitor. Aspen groves here, although scattered in distribution, occur along a gradient of xeric to mesic habitats. The groves are not confined to canyon bottoms and moist parts, or wet places, as in many of the ranges of the northern intermountain region. Extensive patches are found on open ridges, especially at 2000 to 2200 meters, as well as in areas adjacent to springs, lakes, and streams. The environmental implications relative to latitude, or edaphic, or other factors, that may explain the relative narrowness of the Pinyon-Juniper Zone on Steens Mountain have not been explored. The possible replacement of *Pinus monophylla* by *Populus tremuloides* has also not been explored and is suggested as a potential research project.

Discussion of Vegetation Zones. After considering the preceding approaches to vegetation zonation on Steens Mountain, i.e., Hansen's "belts" and Billings' and Cronquist's zones for the Great Basin, a slightly modified zonation scheme has been compiled for the mountain (Fig. 7c):

Approximate Elevation in Meters	Vegetation Zone
above 2700	Subalpine Grassland
2400 - 2700	Upper Sagebrush
2000 - 2400	Aspen
1700 - 2000	Juniper
below 1700	Lower Sagebrush

Billings (1951) and Cronquist, *et al*. (1972) in their description of the plant geography of the intermountain region do not recognize an aspen zone but the conspicuousness and stability of Populus tremuloides on Steens Mountain requires the zone designation in this case. Faegri (1966) explains the presence of Populus tremuloides through climatic limitations and extensions due to continentality and elevation. The species has sufficient precipitation given the altitude of the mountain. Sufficient moisture availability would otherwise be a problem at this interior location. Summer temperatures are warm enough for seed development whereas on mountains nearer the ocean temperatures would be cooler in summer due to maritime influences thus limiting reproduction. Faegri believes, since winter temperatures are colder in the continental interior, Populus tremuloides would be limited in its altitudinal distribution occurring higher in the mountains nearer the coast. According to Faegri the interaction of these macro-environmental influences restrict the aspen zone on Steens Mountain to its present position.

Faegri considers Populus tremuloides on Steens Mountain to be ecologically similar to Betula tortuosa in the mountains of Scandinavia which occurs as the treeline species. A deciduous subalpine tree is curious since nearly all mountains at mid latitudes have a treeline made up of coniferous species. Faegri cites the maritime climatic influence in Scandanavia as an explanation for the phenomenon there, but notes the absence of Populus *tremuloides* as a treeline species in more maritime mountain ranges in western North America, where it does not follow the pattern of *Betula tortuosa* in Europe, suggesting that further explanation is needed.

Larix lyallii, a deciduous conifer, occurs at timberline in the northwest United States and British Columbia. Richards (1977) has documented certain moisture and photosynthetic adaptations of *Larix lyallii* which apparently allow its survival under droughty subalpine conditions in spring and summer. Similar adaptive characteristics could be investigated for the purpose of explaining the presence of a deciduous nonconiferous treeline on Steens Mountain. Also, an explanation should consider such factors as comparative soil characteristics, man-caused effects from fire and grazing and local climate variation as well as continental versus maritime climatic influences. Comparison of Steens Mountain aspen distributions and high elevation tree distributions on adjacent mountain ranges would be another direction in which to proceed in explaining the subalpine character of the mountain top.

Billings (1951) and Cronquist (1972) note that at elevations above 2300 to about 3000 meters the Sagebrush-Grass Zone occurs followed by the Limber Pine-Bristlecone Pine Zone. The latter is best developed between 2900 and 3200 meters and is described as the "open subalpine forest" of higher mountains in the Great Basin (Cronquist, *et al*., 1972: 135).

The zone is represented by *Pinus flexilis* at high elevations in the ranges of northern Nevada and southern Idaho and is replaced by *Pinus albicaulis* in the Pine Forest Range 110 kilometers south of Steens Mountain, in which the highest elevation is 2884 meters. The Santa Rosa Range, with a highest elevation of 2960 meters, 145 kilometers to the southeast of the Steens, is topped by an open forest of *Pinus flexilis* (Cronquist, *et al.*, 1972). Steens Mountain, at a similar elevation and slightly higher in latitude, has no subalpine conifers. But when the subalpine zone of the intermountain region without representative coniferous trees is extended to Steens Mountain it would apparently occupy elevations above approximately 2600 meters (Fig. 7). This takes into account the higher latitude of Steens in the northern extreme of the Great Basin and a coarse extrapolation of the lower limits of the open subalpine forest on adjacent, comparative ranges. Thus, a treeless subalpine vegetation type, in the form of a grassland, is expected to exist above 2600 meters on Steens Mountain.

An Upper Sagebrush-Grass Zone, typically occurring below the subalpine on ranges in the northern Great Basin between 2300 and 3000 meters,[4] is also well represented on Steens mountain, but as expected at a slightly lower elevation. This zone on Steens is characterized by patches of sagebrush between groves of Populus tremuloides and can be considered transitional to the subalpine grassland at approximately 2600-2700 meters. Topographically the Upper Sagebrush Zone covers the upper canyon walls and higher inter-canyon slopes. The vegetation is characterized by extensive areas of moderately dense Artemisia tridentata var. vaseyana and A. arbuscula var. arbuscula interspersed with Festuca idahoensis var. idahoensis and Poa sandbergii. At the lower limits, Populus tremuloides groves occur in moist pockets and Cercocarpus ledifolius var. ledifolius occupies rocky sites. At the upper limits, the sagebrush-grass vegetation grades into pure bunchgrass. Also, more low-growing forbs begin to appear at the upper limit of this zone and bare surface areas resulting from deflation and snow melt erosion become conspicuous. The lower, sagebrush phase, 2424 to 2700 meters, of Hansen's Subalpine Bunchgrass Belt corresponds to this zone.

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[4]The elevation range, 2300-3000 meters, is that given by Cronquist, et al. (1972). They include within the Upper Sagebrush-Grass Zone for Steens Mountain, "north slopes... partly forested with the western juniper" and stands of Abies concolor var. lowiana. For this study the upper limit of Juniperus occidentalis is considered 2000 meters and A. concolor var. lowiana, occurring at 1850 meters, is well within the Pinyon-Juniper Zone as expressed on the mountain.

As discussed under the section entitled "Billings' and Cronquist's Vegetation Zones", the juniper zone on Steens Mountain is related to the Pinyon-Juniper Zone typical of the Great Basin but occurs without *Pinus monophylla*. The lower zone of sagebrush, where *Artemisia tridentata* is dominant, is similar to shrub-steppe vegetation throughout the intermountain region.

Subalpine Environment

Definition. Löve (1970) has proposed that the definitions relating to high altitude mountain environments be made universal. Traditionally in North America the subalpine landscape has included the coniferous forest and meadows just below treeline, or the upper limit of tree growth (Weaver and Clements, 1938: 492). This definition of subalpine includes the transition zone from closed forest to treeless alpine vegetation consisting of open meadows and usually clumped and stunted coniferous trees. Löve's definition, following the European concept, designates the zone whose upper limit is the extent of closed forest as *montane* and the zone between closed forest and treeless alpine vegetation as *subalpine*. In support of this concept, Löve presents an etymological argument for designating the forest-alpine ecotone as subalpine. The prefix "sub" would connote the adverbial meaning of "not quite" or "somewhat" as opposed to denoting the physical occurrence of the zone "below" the treeless alpine (Lőve, 1970: 64).

Daubenmire (1946) presents a zonation scheme for the northern intermountain region of the western United States based on biotic distribution and the climax concept. The use of terms such as subalpine or Hudsonian (after Merriam, 1894) is dropped in favor of dominant climax plant species names for zones, e.g., sedge grass zone for vegetation above the limits of forests in this region.

Both Daubenmire (1954) and Wardle (1974), while recognizing the existence and complexity of the transition zone between montane forest and alpine vegetation, place a line dividing forest and alpine types within the forest-alpine tundra ecotone thereby eliminating a subalpine zone. Wardle points out that a forest-alpine (tundra) ecotone does not always exist. A subalpine designation therefore is unnecessary and where a transition or krummholz vegetation is present the alpine timberline should be placed where tree growth becomes less than two meters (Wardle, 1974: 372). Daubenmire (1954) favors a boundary for alpine timberline at a point midway between the closed forest and the upper limit of tree growth (Daubenmire, 1954: 119).

Both Daubenmire (1954) and Wardle (1974) are concerned with the physiological explanation for the altitudinal progression to treeless alpine vegetation. The manifestation of severe environmental conditions which induce the dwarfing and flagging of trees, the close growing habit of herbaceous and woody-stemmed plants, and other adaptive plant characteristics, in these authors' opinions, marks the single boundary between two distinct habitats; thus, creating a third zonal entity based on transitional vegetation seems unnecessary. Douglas (1972: 147, 148) accepts the krummkolz zone as being alpine in character but retains the designation "subalpine" for the zone between closed forest and the limit of upright trees. For the present study, a subalpine zone, i.e., a zone in which the environment and vegetation approach alpine characteristics, is considered to exist on the summit ridge of Steens Mountain between Kiger Gorge and Wildhorse Canyon.

Environmental Factors. The severe conditions which influence plants marking the vegetation landscape of mid-latitude high mountain environments include long, cold winters, short cool summers, high velocity winds, high levels of insolation, poor soil development, and extreme variation in moisture availability. The literature concerning vegetation under these conditions is confined chiefly to subalpine forests and alpine environments. Noting this, Kuramoto and Bliss (1970) in their study of subalpine meadows in the Olympic Mountains, Washington, cite ecological studies by Ellison (1954), Brooke (1965, and Klikoff (1965a) all of which concern subalpine low shrub and herbaceous communities. In addition, Klikoff

(1965b) describes subalpine (timberline-alpine) herbaceous communities found in the Gaylor Lake Basin in the central Sierra Nevada, California. Subsequent ecological studies which deal with treeless subalpine plant communities in the Pacific Northwest are Douglas (1972), describing subalpine communities of the western North Cascades, Canaday and Fonda (1974), detailing the influence of snowbanks on subalpine communities in Olympic National Park, Washington, and Henderson (1973), examining subalpine meadows on Mt. Rainier, Washington.

Principally because the Steens Mountain study area is on an exposed summit ridge, its landscape appears alpine in character. The close growing habit of many of the plant species, the absence of trees and erect shrubs, and the flat, gravelly surfaces nearly bare of vegetation suggest an ecological situation similar to alpine environments. Billings (1974), Billings and Mooney (1968), and Bliss (1962) discuss alpine and arctic plant physiology, and associated environmental factors which govern the type of vegetation on the Steens summit ridge.

Snow Persistence and Vegetation. The effect of differential snow cover and snow melt on alpine and subalpine vegetation has been reported and discussed by Harshberger (1929), Dahl (1956), Billings and Bliss (1959), Holway and Ward (1963), Gjaerevoll (1950, 1965), Bringer (1965), Douglas (1972), and Canaday and Fonda (1974).

Winter snow in a given mountain environment accumulates to a variable depth related primarily to local topography, microrelief, and prevailing wind direction and velocity. Subsequent snow recession is related to depth and exposure. Deeper snow lingers well into the growing season receding at a more or less regular rate. These persistent snow patches provide the classic environment for snowbank or snowbed vegetation (Gjaerevoll, 1965). Vegetation pattern varying in species composition, structure, and density is related to snow cover melt which produces a typical concentric, developmental zonation. Generally, plants which require a longer growing season, are relatively intolerant of snow cover, but if present, must also be able to withstand early spring exposure with concomitant frost, and subsequent summer drought. These plants are found near the periphery of snowbanks. Plants found near the center of a snowbank are typically intolerant of extensive frost exposure and summer drought. In addition to receiving protection from dessicating winds, plants beneath snowbanks of 50 centimeters or more experience moderation in winter temperature extremes (Dahl, 1956: 271; Perla and Martinelli, 1976). Vegetation which is protected by the snowbank also has a progressively shorter growing season as the snow recedes. Date of release and advanced phenological stage of plants are positively correlated in snowbanks (Billings and Bills, 1959; Canaday and Fonda, 1974).

Moisture is an important variable in the snowbank environment. Typically, once the snow has receded soil moisture is rapidly depleted through plant transpiration and through evaporation due to the high levels of insolation and heating of the ground surface. Plants when released from snow cover, particularly where soil is coarse, quickly experience drought conditions and mature rapidly. Associated with sloping snowbanks, soil moisture is the most critical difference between the productivity of vegetation growing near the upper and lower snowbank positions (Billings and Bliss, 1959; Holway and Ward, 1963).

Although only two or three small persistent snowbank environments, where snow lingers into September, exist within the study area, all communities identified in the present work are influenced by snow cover or the lack of it. The differential release of vegetation from snow cover over broad areas is generally correlated with identifiable community types. Sharp vegetation gradients such as exist in true snowbank environments are not common; however, subtle phenologic, physiognomic, and plant cover density differences related to duration of annual snow cover have been observed among communities during the course of the research.

Soil Development and Drought. Well developed soil is essentially non-existent within the Steens Mountain subalpine grassland. Shallow, coarse, and gravelly surfaced soils with little or no pedogenic development are common. Wind and water erosion and cryopedogenic processes are evident and result in unstable surfaces. Summer soil drought is apparent. Similar conditions have been reported in alpine and other subalpine environments in western North America (Thilenius, 1975; Root and Habeck, 1972; Kuramoto and Bliss, 1970; Mueggler and Harris, 1969; Brink, 1964; and Johnson and Billings, 1962).

Results of frost action and other cryopedogenic forces may be observed in the stone stripes and polygonal micropatterned soil surfaces of the study area. Bamberg and Major (1968) and Johnson and Billings (1962) have documented the effects of frost heaving, sorting, and mixing on vegetation pattern in mountain ranges of Montana and Wyoming. Brink (1964) attributes barren soil surfaces found in alpine and subalpine areas in British Columbia to the recession of snow fields and ice since the Pleistocene. Surficial soil movement due to frost action and dry summer soil conditions help maintain these barren surfaces.

Kuramoto and Bliss (1970) believe that slope angle and exposure to erosion, as well as a short growing season and fire frequency, limit soil development and vegetation cover in certain communities in Olympic National Park, Washington. Ellision (1954: 162, 163) found on the Wasatch Plateau, Utah, "erosion-pavement" areas dotted with individual bunchgrass pedestals. Erosion, enhanced by grazing, leaves behind residual gravel surfaces which "sink" below a formerly well-vegetated plane. Brink (1964) in his British Columbia study describes a landscape of large vegetated areas adjacent to and overhanging flat, non-vegetated surfaces. He recognizes the erosion influence but seems to favor an explanation centered on the failure of the vegetation to rejuvenate since Pleistocene times due to the factors stated in the paragraph above. While similar appearing features are found in the Steens Mountain grassland their formative processes have not been investigated.

Coarse textured, well-drained soil in the present study area contributes to early summer drought for the vegetation, particularly since most snow melts before July 1. Also much of the area lacks a dense vegetation cover and is exposed west-southwest. Once the snow is gone for the season there is an almost immediate transition to xeric conditions. Brink (1964) suggests that seedling establishment is difficult under summer drought conditions at high elevations and therefore barren surfaces are maintained. McMinn (1952) relates portions of the vegetation pattern in the northern Rockies to soil temperature-moisture variation due to slope aspect, topography, and plant cover condition. Different plant associations are correlated with different extents of drought (McMinn, 1952: 14). Summer drought conditions due to soil coarseness, inadequate precipitation, and exposure in grasslands of the Sawtooth

Range, western Montana, have been cited as factors in maintaining a grassland climax in the montane forest zone (Root and Habeck, 1972).

Vegetation Analysis

The Continuum and Unit Concepts

There has been a lingering discussion within the literature of vegetation research concerning the appropriateness of viewing vegetation, for the purposes of analysis, as a gradient in space changing continuously across the landscape or as a series of discrete, classifiable, homogeneous areal units (Goodall, 1954; Daubenmire, 1960, Anderson, 1965, Whittaker, 1967). The present research applies both Braun-Blanquet classification techniques (Braun-Blanquet, 1932; Moore, *et al*., 1970; Westhoff and var der Maarel, 1973), a unit approach to analysis, and ordination techniques, usually associated with the continuum or gradient approach (Bray and Curtis, 1957; Curtis, 1959; Orloci, 1966; McIntosh, 1967; Anderson, 1971; Whittaker, 1973).

Recent literature has emphasized the compatibility of the continuum and unit approaches to vegetation analysis. Westhoff and van der Maarel (1973: 630) state:

> ... the difference between the concept of the gradient approach and Braun-Branquet's is clearly one of degree - of emphasis of continuity vs. discontinuity where both are

> present, of species individuality vs. species groupings where both are realistic, and of gradient analysis vs. classification where both are possible. We judge the difference between less extreme students of gradient analysis, and the Braun-Blanquet approach, to be one of emphasis and perspective, not one of fact or understanding.

Van der Maarel in another review of the Braun-Blanquet approach further reconciles the unit approach with the continuum concept by pointing out that "... a typological [unit] concept does not imply a general recognition of discontinuity.... That which is evident and characteristic of a type is always its nucleus, not its periphery; types are not pigeon holes but foci in a field of variation" (van der Maarel, 1975).

Mueller-Dombois and Ellenberg (1974) in their comprehensive text on vegetation ecology present ordination (continuum) and classification (unit) analytical techniques as separate but intimately linked processes. Because of the differing degree of final segmentation of the vegetation cover and the distribution of sampling, the continuum approach emphasizes recurring plant assemblages. Ordination is considered an initial step in vegetation analysis revealing the relative degree of continuity or discontinuity among sample stands. Classification then proceeds within a framework that avoids the possible creation of classes that may not exist in nature (Mueller-Dombois and Ellenberg, 1974: 41, 275). It is the intent of the present research to use the two approaches in a complementary fashion in order to achieve a high degree of accuracy in the final description of the vegetation pattern in the study area.

III. DATA COLLECTION METHODS AND FIELD PROCEDURES

Vegetation Sampling

Visual observation of the vegetation in the study area suggested that species composition and vegetation density varied more strikingly between the crestline and the canyon heads to the west than between Kiger Gorge on the north and Wildhorse Canyon on the south (Fig. 8). Because of the general topographic uniformity of the west facing slope in the study area, a series of six east-west transects, A, B, C, D, E, F, was adopted as the initial sampling strategy for the placement of 20 x 50 centimeter quadrat frames. Transect lines were begun at the east edge of the study area on the Steens Mountain crest and extended along a 270° true aximuth (Fig. 8). The approximate distance between the transects was 1000 meters, except between transect C and D where the distance was extended to approximately 1800 meters to avoid a narrow section of the ridge. The transects were preselected and their starting points located in the field along the crest with the aid of maps and aerial photography.

Using a steel measuring tape and a 20 x 50 centimeter quadrat frame, sample plots were located every ten meters along each transect. Plots falling in areas without vegetation or in severely disturbed sites, e.g., the roadbed

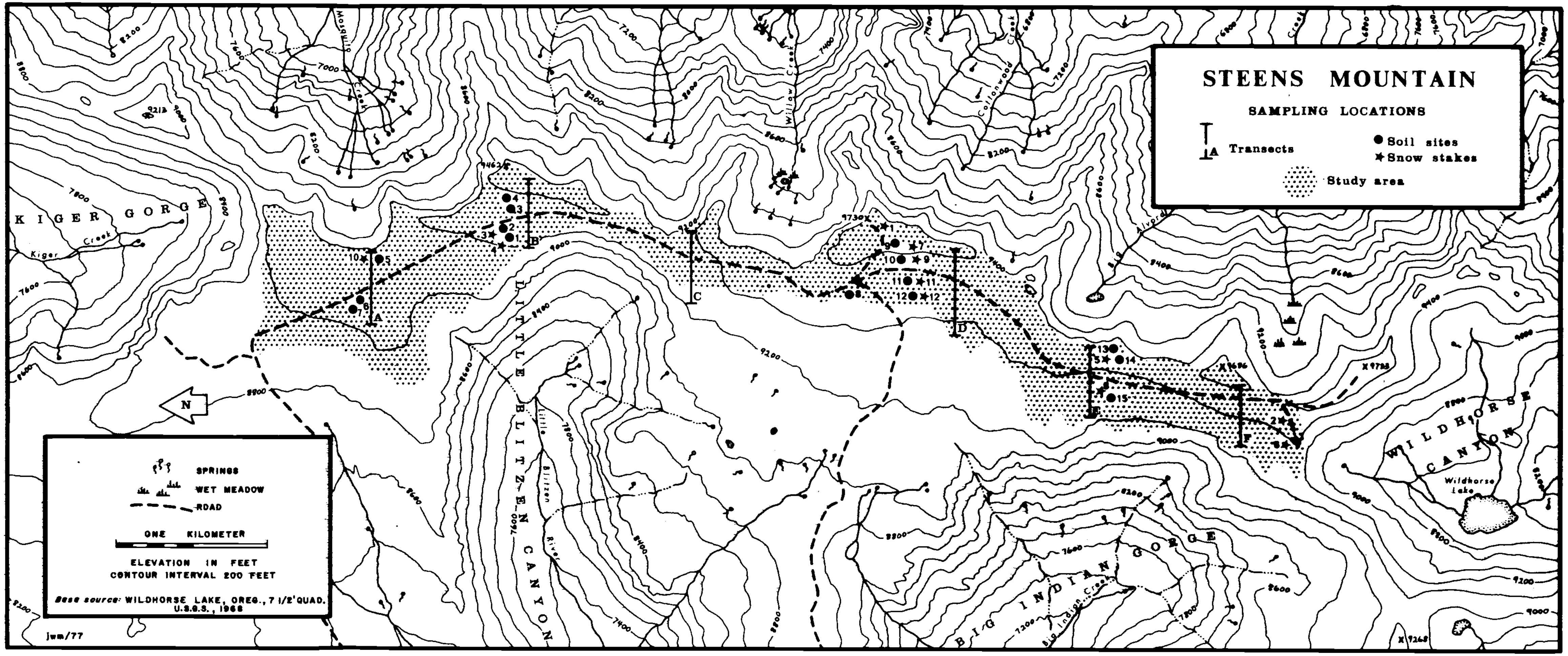

Figure 8. Study area map showing sample locations.

and its margin, were counted for measurement purposes but were not used to collect floristic data. A total of 278 sample plots were used to record floristic data in the six transects (Table 3).

Table 3. Sample plot distribution along transects.

Transect	Number of Sample Plots
A	46
B	44
C	46
D	57
E	48
F	37
Total	278

For each sample plot the variables measured were: 1) percent slope, 2) slope aspect, 3) percent cover estimate for each species present, and 4) number of individuals of each species present. Percent slope and slope aspect were measured with a Brunton compass which was also used to check the proper direction of the transect. Relative importance of a species in a given sample plot was visually estimated as percent cover to the nearest five percent. Cover was considered the area projected perpendicular to the ground by the perimeter of foliage and stems of individual plants of that species. Species number was determined by counts within the sample plot and, occasionally, counting the number of individuals of bunchgrass species presented difficulty because of their radial growing habit. In these cases contiguous grass clumps in circular or near-circular symmetry constitute one individual.

In addition to this systematic sampling along transects, the entire grassland was sampled by a stratified random method using meter square quadrats. On 1:5,000 true color aerial transparencies (Western Aerial Contractors, Eugene, Oregon, September 10, 1972) areas of apparently homogeneous vegetation were delimited. To aid delimitation, adjacent frame pairs were viewed in stereo. The downslope, west, boundary for the grassland was defined by canyon rims, margins of exposed basalt, and steeper slopes; the north and south boundaries by the head walls of Kiger Gorge and Wildhorse Canyon, respectively; and the east boundary by the mountain's escarpment.

Within the defined bounds, 59 areas were typed on the photography. These usually included discontiguous areas with similar vegetation signatures. The area of each type unit was measured with a polar compensating planimeter. The number of plots to be sampled in the type unit was determined on the basis of one meter square for every 10,000 square meters. Type sample sites were located on the photo transparencies in a random manner by placing a 2.5 x 2.5 millimeter grid under each transparency. Random numbers were chosen for the X,Y grid coordinate values of each sample site point. These points were marked on the transparency. Once a type unit reached its quota of sample plots additional coordinate locations falling within it were ignored. This procedure was continued until all typed units contained the required number of sample points.

The extent of the grassland was 3,482,000 square meters (3.5 sq. km). Rounded area measurements for each of the 59 typed units resulted in a final total of 346 sample points or a 0.01 percent sample of the area being investigated. During field sampling, sample points were located with the aid of the marked transparencies. While holding the film up to skylight each sample point location was found relative to easily identified landscape features, e.g., large rocks, erosion channels, which appeared on the photographic image as well as on the ground. The one meter square quadrat frame was placed as close as possible to a location determined in this manner.

Variables recorded for each plot in this phase of the vegetation sampling were: 1) percent slope, 2) slope aspect, 3) soil surface rockiness (visually estimated), 4) percent of ground surface not covered by vegetation (visually estimated), and 5) total percent cover estimate for each species present.

Soil Sampling

Sites for soil sampling were located in five areas considered ecologically significant. These fives areas are described as follows:

1) Downslope areas of snow persistence, i.e., toward the west boundary of the grassland. Three sites.

2) Midslope areas of snow persistence. Three sites.

3) Mid to upper slope areas of apparent snow persistence and meltwater erosion between dense grass "islands". Two sites.

4) Mid to upper slope grass "islands". Four sites.

5) Crest area. Three sites.

Soil moisture conditions during the growing season, mid-June to mid-September, were monitored by sampling each of the fifteen sites in the areas described, four times in 1972 and four times in 1974. From 200 to 500 grams of soil were taken at each 15 centimeter depth interval down to fractured basalt bedrock. Each sample was sealed in a plastic bag and enclosed in a container. Within a few days after each sampling, the soil sample was weighed to the nearest tenth of a gram, over-dried for 72 hours at 105°C, and weighed a second time to determine moisture content expressed as a percent of dry weight:

GROSS FIELD WEIGHT - GROSS DRY WEIGHT = SOIL MOISTURE WEIGHT

GROSS DRY WEIGHT - CONTAINER WEIGHT = NET DRY WEIGHT

$$\frac{\text{SOIL MOISTURE WEIGHT}}{\text{NET DRY WEIGHT}} \times 100 = \text{PERCENT SOIL MOISTURE}$$

Percent soil moisture was plotted for each collection date during the summer of 1972 and 1974 to give an approximate seasonal soil moisture curve.

Soils varying in texture also vary in their capacity to have moisture available to root systems of higher plants. Soils proportionally high in silt and clay have a greater percentage of moisture present at a given level of tension, or the degree of force with which moisture is retained in the soil through molecular cohesion and adhesion, than do coarser soils. As soil moisture is depleted through plant evapo-transpiration and soil surface evaporation, tension becomes greater. Plant root systems must exert more suction to extract available moisture. The lower limit of soil moisture availability to agricultural plants where subsequent permanent wilting occurs is considered to be 15 bars[5] of tension (Brady, 1974: 191). Because of the greater total colloidal matter, greater total pore space, and greater adsorptive surface in finer soils they will have a higher percentage moisture content than coarser soils at 15 bars of tension; although, in both fine and

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[5]A bar is the standard unit for the expression of soil suction, A bar of pressure is equal to 10^6 dyne per cm^2 or 0.987 atmospheres or 14.5 pounds per square inch.

coarse soils the moisture still retained by the soil will be unavailable to plants. It was considered appropriate that the moisture retention characteristics of selected samples from the study area be determined in the laboratory in order to make an assessment of the relationship of the soil moisture availability to vegetation.

Soil samples representing the five ecological sites described on page 63 were tested for soil moisture retention. Moisture was extracted from the samples at different levels of atmospheric pressure in a ceramic pressure-plate apparatus (U.S.D.A., Salinity Laboratory, 1954). Duplicate 25 gram subsamples for each site were subjected to pressures of 1/3 bar, 1 bar, 7 bars, and 15 bars. The moisture content remaining in the samples after reaching equilibrium (i.e., water no longer passed through the porous plate under the pressure level applied) was calculated as a percent of dry weight using the same procedure as for the field samples. Appropriate moisture retention curves were constructed showing percent soil moisture against atmospheric pressure in bars.

Soil texture analysis was performed on combined samples for each of the fifteen soil sampling sites. The combined samples consisted of all the soil collected over the sampling periods for a given depth interval. The coarse material greater than two millimeters in diameter was separated from each of the samples by sieving with a number ten screen and a soil shaker. The proportion by weight of the entire sample which was coarse material was recorded (Appendix A).

A subsample of 50 grams was carefully extracted from the fine separates (less than two millimeter portion) and the proportion of sand, silt, and clay determined by a hydrometer method. The procedure used by the author is described in Appendix B. Percentages by weight of each fraction, sand, silt, and clay, were recorded for each combined sample. Composite texture percentages were derived by averaging the percentages of the depth interval samples for a given site. This provided a representative soil texture description for each of the fifteen sites. For example, soil site number 14 composite texture was calculated to the nearest percent as follows:

	PERCENT		
DEPTH INTERVAL	CLAY	SAND	SILT
Surface - 15 cm	60	35	5
15 cm - 30 cm	64	31	5
30 cm - 45 cm	59	37	4
COMPOSITE (AVERAGE) PERCENTAGES	61	34	5

Soil data for the study including texture analysis and moisture retention for the fifteen sample sites may be found in Appendix A.

Snow Depth and Cover

Snow depth was measured at twelve locations in the study area during the 1972-73 season on November 27, January 28, and March 28. Snow measuring stakes were positioned vertically and stabilized with guy wires. The 5 x 5 centimeter snow stakes each measured approximately 90 centimeters from ground surface to the top of the stake. The stakes, a few in precarious locations, were reached on the dates mentioned and appropriate measurements taken by members of the Highland Snowdrifters, a snowmobile club headquartered in Hines, Oregon. The depth of the snow was determined by subtracting the height of the stake above the snow surface from its pre-measured height above the ground surface. Care was taken to avoid measuring that portion of the stake exposed by wind deflation (Fig. 9). The stakes were located at the crest of the mountain, at upslope sites just below the crest, on grass islands, in inter-island areas, and in downslope areas of suspected snow accumulation.

LANDSAT-1 digital data were acquired through the Environmental Remote Sensing Applications Laboratory at Oregon State University for four dates in late spring and early summer 1973 and 1974. The data were analyzed with the assistance of the CDC 3300 and CYBER 73 computers, Milne Computer Center, Oregon State University, for the purpose

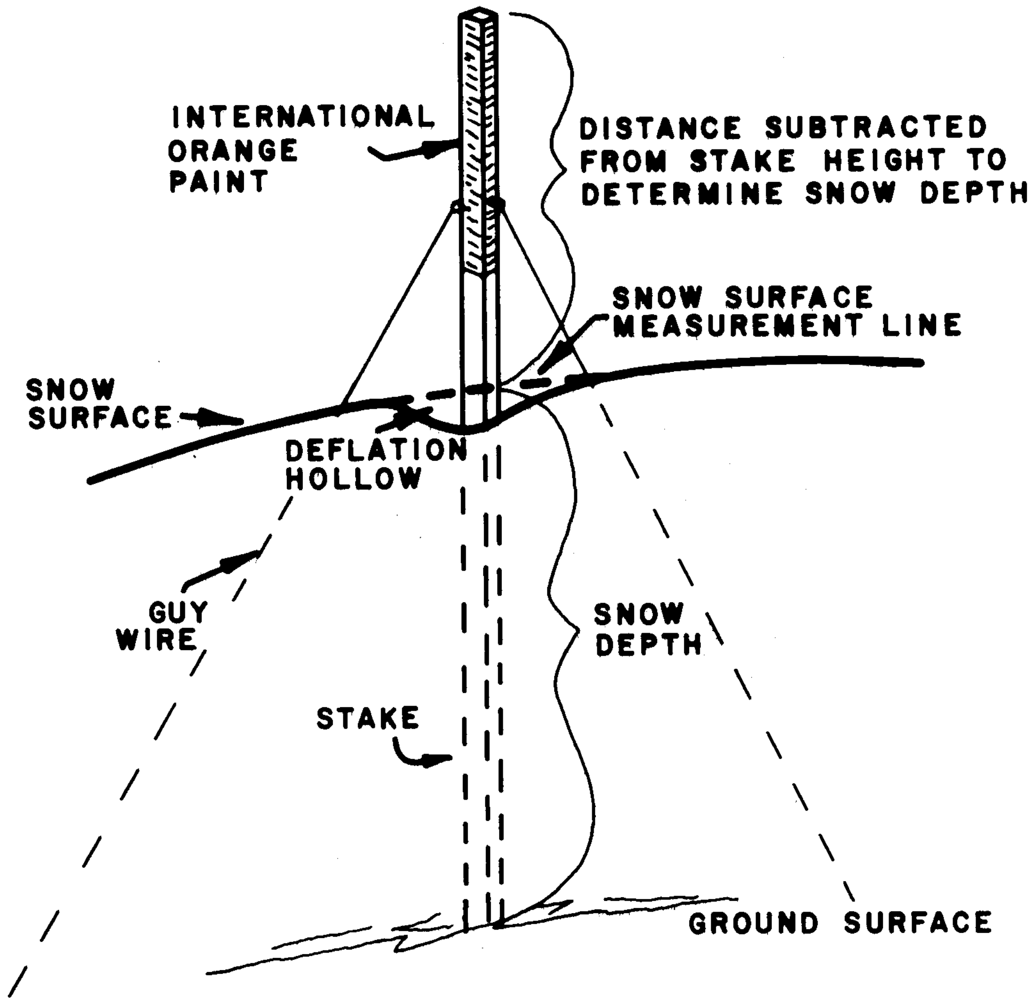

Figure 9. Snow depth measurement stake.

of determining the extent of snow cover during a typical spring melt-off and its relationship to vegetation patterns apparent later in the year.

Summer Temperature Measurements

Temperature data were collected using a 31-day clock-wound recording thermograph (The Partlow Corp., Model RFHTT-217F) placed near the center of the study area. Because of the openness of the landscape and the number of visitors to the summit area the instrument was partially hidden among rocks and the sensor placed near the ground in the shade of these rocks. Therefore, recorded temperatures may possibly be at variance with temperatures that would have been recorded at a standard field weather station. Nevertheless, these data are of interest when analyzed and compared with diurnal maximums and minimums recorded by nearby stations at Andrews, P Ranch, and Malheur National Wildlife Refuge Headquarters. Appendix C gives the minimum and maximum daily temperatures recorded in the study area from 12 July 1974 to 14 October 1974. Monthly minimum and maximum temperature averages for the Steens Mountain grassland are compared with adjacent station data for the same period in Table 12, Chapter V.

IV. ANALYSIS OF VEGETATION

A two-fold approach was adopted in analyzing the vegetation in the study area. First, the observation of change in the species composition of the vegetation from the crest to the downslope edge of the grassland suggested a vegetation continuuum along a topographic gradient. The data collected from sample plots or stands along the six east-west transects were subjected to ordination analysis based on stand similarity. The object in ordinating the stands was to detect groupings which reflect changes in the vegetation along the topographic gradient. Second, the data from the more extensive stratified random sampling of the area were used to produce a Braun-Blanquet association table. Pairs of differential species, i.e., species pairs which tend to occur mutually in the collection, were identified. Quadrat sample units, or relevés, were grouped according to the occurrence of these differential species. The final species-relevé table displays "blocks" which represent the grouping of similar relevés with species ordered on the basis of frequency.

The SIMORD Ordination Program

Few vegetation studies using an ordination program for analyzing data examine closely the selected algorithm. An attempt is made here to discuss important features of the

SIMORD processing routine in order to understand what this particular program is doing with submitted data. The plot coordinate subroutine and similarity index function vary among the many ordination programs available and undoubtedly affect interpretation. It is expected that the following expository discussion of SIMORD and a few of the more widely used similarity indexes will aid future users of SIMORD as well as lead to a better understanding of the results gained in this study.

The SIMORD computer program developed by Dick-Peddie and Moir (1970) was used to calculate a similarity index value for all possible pairs of stands and to determine the X,Y coordinates for plotting the stands in a two-dimensional ordination. The similarity index used in SIMORD is somewhat different from indexes usually associated with the Wisconsin school of vegetation analysis as presented by Goodall (1973). Dick-Peddie and Moir's similarity index function is:

$$SDM_{ij} = \frac{1}{n'} \sum_{k=1}^{n} \left(\frac{2 \min(a_{ik}, a_{jk})}{a_{ik} + a_{jk}} \right)$$

where SDM_{ij} is the similarity value between 0 (no similarity) and 1 (maximum similarity) for two stands, i and j, being compared; where n is the number of species in the entire sample collection and n' is the number of species occurring either in one or both stands i, j; and, where a is the quantitative measure (e.g., cover, density, or biomass) for the k^{th} species in stands i or j as noted.

SIMORD and the Sorensen Index

The index employed by many vegetation analyses of the Wisconsin school can be traced to work by Dahl and Hadac (1941, cited in Goodall, 1973: 134), Sorensen (1948), Motyka, Dobrzanski and Zawadski (1950, cited in Mueller-Dombois and Ellenberg, 1974: 219), Bray and Curtis (1957). In this research the index will be referred to as the modified Sorensen similarity index and is written:

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

where SMS is the similarity value or "coefficient" for two stands being compared, a is the sum of the quantitative measures for species in one stand, and b the sum for species in the other. The symbol w is the sum of the lesser quantitative measures of species common to both stands.

Dick-Peddie and Moir's similarity index, SDM_{ij} is similar to SMS in that both initially use the quantitative measures of species in common only; but differs in the method of summation. The minimum value for the k^{th} species tested by SDM_{ij} in a two-stand comparison is doubled and divided by the sum of the two values for that species. If the species occurs in neither or only in one stand, the calculated result is zero and if it occurs in both stands the result is a value between zero and 1. Each species in the sample collection is tested by SDM_{ij} and the values sequentially summed, the value increasing only when a species occurs in common. The final sum for the compared stands is then divided by n', or the number of species occurring in either one or both stands, thus giving a similarity value averaged over n'.

Index SMS sums the minimum values of all species occurring in common and the sums of the quantitative measures of species in the two stands being compared. The first sum is then divided by the second to arrive at SMS. Due to the difference in the summation procedure between SDM_{ij} and SMS, similarity values for a given data set may be appreciably different. An example of these differences is shown with stand data in Table 4 taken from transect A of the Steens Mountain subalpine grassland samples. Both SDM_{ij} and SMS were used to calculate similarity matrices for this data set with the results shown on page 75.

Generally, the SIMORD function gives lower similarity values than the Sorensen similarity index for a given data set. This appears to be the result of the summation and averaging technique of SDM_{ij} which in effect deemphasizes the common occurrence of species in compared stands. In other words, the stands evaluated using SMS or the modified Sorensen index, would group more closely, in a two-dimensional ordination than those stands with many species

Table 4. First data subset from transect A Steens Mountain subalpine grassland used to show difference in calculation of similarity indexes SDM_{ij} and SMS.

Species	Percent Cover Stand # 34	47	48	60	77
Agoseris glauca var. *dasycephala*	0	1	1	0	0
Arenaria aculeata	1	0	0	0	0
Astragalus whitneyi	10	0	0	0	0
Erigeron bloomeri var. *bloomeri*	1	0	0	0	0
Erigeron compositus var. *glabratus*	1	0	0	0	0
Eriogonum ovalifolium var. *nivale*	1	15	10	1	10
Helenium hoopesi	0	10	10	0	0
Lupinus lepidus var. *lobbii*	0	20	20	0	0
Poa cusickii var. *cusickii*	1	0	0	0	0
Poa sandbergii	20	0	0	1	20
Sitanion hystrix var. *hystrix*	0	10	10	20	10
Spraguea umbellata var. *caudicifera*	0	1	1	0	0
Trifolium longipes ssp. *multipedunculatum*	0	0	0	1	20
TOTAL PERCENT COVER	35	57	52	23	60

in common. SDM_{ij}, the Dick-Peddie and Moir index, would tend to separate these stands. This separation may not be desirable when using the ordination as means of classifying.

SDM_{ij} matrix:

Stand #	47	48	60	77
34	.010	.015	.122	.131
47		.967	.099	.225
48			.106	.250
60				.260

SMS matrix:

Stand #	47	48	60	77
34	.022	.023	.069	.442
47		.954	.275	.342
48			.293	.357
60				.313

SIMORD Stand Plot Method

The SIMORD program fills a matrix with percent similarity values (SIM_{ij} or other similarity value x 100) for all stands in a given sample collection. As a user option, reference stands for the two dimensional plot are selected by the program using either an "independent" or a "dependent" mode (Dick-Peddie and Moir, 1970: 20, 21). The independent mode was used in this analysis. The stand having the lowest column sum in the similarity matrix, in effect, the least average similarity to all other stands, is selected as the reference stand, E1, at one end of the X axis (Fig. 10). The reference stand assigned to the opposite end of the X axis, E2, is determined after the stands

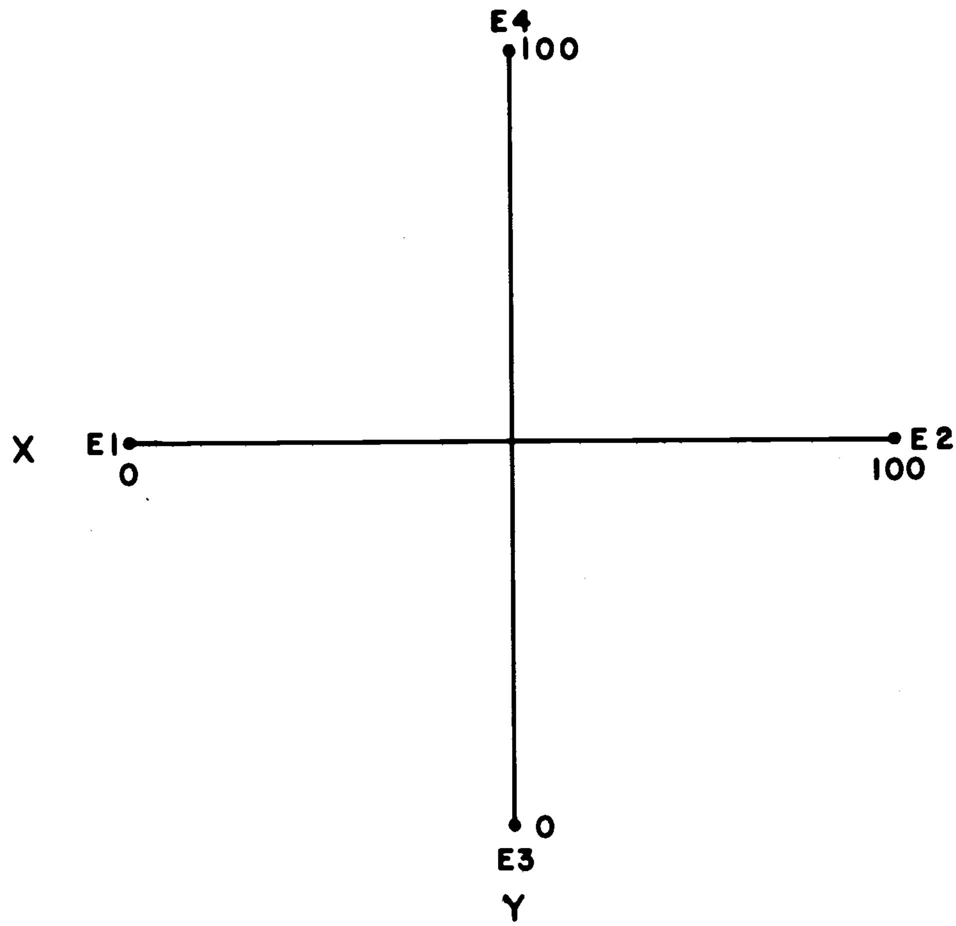

Figure 10. Ideal ordination axes and reference stands.

of the data set are divided into two groups: the first, those stands that have no similarity to E1, i.e., similarity equals zero (this occurs when E1 and the compared stand have no species in common[6]); the second, those stands, when paired with E1, that have a similarity value of greater than zero. Then, from among the first group, the stand which has the lowest average similarity to the stands in the second group is selected as E2.

In dependent mode the reference stands for the Y axis are chosen outside the cluster of stands near the center of the X axis. An optimization routine (best axis method) is used whereby the chosen Y axis reference stands have high similarity to respective reference stands of the X axis, and also have a high mean similarity to the stands near the center of the X axis (Dick-Peddie and Moir, 1970: 120).

The distance between E1 and E2 is scaled at 100 units and all stands are located on the X axis relative to the two reference points. For example, the similarity of S(I), a non-reference stand, to E1 and E2 is calculated as 66 and 48 percent respectively. Percent dissimilarities of 34, (100-66), and 52, (100-48), are used to determine the distances from E1, or zero on the X axis:

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[6]If all stands in the collection have at least one species in common, then similarity is greater than zero in all comparisons. The program then sets a threshold value to 2, 4, 6....until one or more stands falls into a "no similarity" group.

$$\frac{(X^2 - Y^2)}{200} + 50 = DX$$

where X is the percent dissimilarity between stands E1 and S(I) and Y is the percent dissimilarity between E2 and S(I). DX is the distance of S(I) from E1 on the X axis, 200 is a constant which scales the values to the 100 unit length of the X axis, and 50 is the mid-scale reference.

Once E1 is determined, the value DX is found for all other stands. The dissimilarity transformation causes high values of similarity between stands to become low values of spatial separation thus allowing similar stands to group along the X axis.

SIMORD expands the plot to two dimensions by identifying the stands clustering within ten units on either side of the X axis midpoint. From this group of stands the one having the least average similarity to both E1 and E2 is selected as E3, the reference stand at zero on the Y axis. To determine E4, the stands within the central cluster on the X axis are divided into two groups using a criterion similar to the selection of E2. From the group with stands having no similarity to E3, i.e., no species in common or zero similarity, the stand having the least average similarity to both E1 and E2 is selected as E4. The Y coordinate distance, DY, is calculated in the same manner as for the X coordinate, DX. This allows two-dimensional plotting of all stands where stands with similar species composition and dominance tend to form groups.

The user of SIMORD has the option to allow the program to select the reference stands as described above or to specify on a control card any one, two, three, or all of the reference stands, E1, E2, E3, E4. This is sometimes necessary when one or a number of stands in the sample collection are anomalous and do not reflect gradient variation but would be selected by the program as reference stands because of their floristic dissimilarity to the other stands.

Selection of a Similarity Index

Need for Index Comparison

Mueller-Dombois and Ellenberg (1974) have emphasized the importance of being aware of the diagnostic capacity of a given index and have compared several similarity indexes (after Spatz, 1970, cited in Mueller-Dombois and Ellenberg, 1974), including the modified Sorensen index. The SIMORD function is not included in their comparison. The authors demonstrate that a relatively recent variation of Jaccard's (1901, cited in Mueller-Dombois and Ellenberg, 1974) index by Spatz (1970) gives the best results for the indexes compared and for the hypothetical data set used. Spatz index is written (notation after Mueller-Dombois and Ellenberg, 1974):

$$SS = \frac{(Mw : Mg)}{a + b + c} \times \frac{Mc}{Ma + Mb + Mc}$$

where Mw is the smaller of the two measurement values for species common to stand pair being compared and Mg is the larger value; a is the number of species unique to stand a, b is the number of species unique to stand b, and c is the number of species in common between the two stands; Mc is the sum of the measurement values for species in common, and Ma and Mb are the sums for the values unique to a and b respectively.

The more nearly equal the quantitative measurements for common species in a tested pair the larger will be the SS value. Also, the index value will decrease (lower similarity) as the number of species not occurring in common increases. This is generally what occurs when using other similarity indexes to derive a similarity value, the differences among indexes being one of emphasis concerning common species and quantitative values for those species. When the Spatz index was compared by Mueller-Dombois and Ellenberg with Jaccard's and Sorensen's indexes and their modifications, it stressed unique species and quantitative differences between common species to a much greater degree than did the other indexes. With the hypothetical data set used by Mueller-Dombois and Ellenberg (1974) it was concluded by these authors that the sensitivity of the Spatz index produced favorable comparative results.

Goodall (1973: 145) notes that there is little informed comparison of the merits of one similarity index over another and suggests that "choice among them is still largely a matter of taste". He makes no recommendation of a specific index but prefers a "simpler index". Since similarity indexes do vary in emphasis and a comparison using hypothetical data may not result in the same index choice as if actual data were used in a comparative analysis, an index selection procedure was carried out for this study.

Comparison of Indexes

Typical plots were selected from sample data collected in the study, Table 5, and four similarity values calculated for selected pairs using different indexes, Table 7. In addition, similarity values using these indexes were calculated for a portion of the hypothetical data from Mueller-Dombois and Ellenberg (Table 6) and included in the analysis for interest.

The indexes compared are: 1) the simple Jaccard presence-absence index (Jaccard, 1901, cited in Mueller-Dombois and Ellenberg, 1974):

$$SJ = \frac{c}{a + b + c}$$

where c is the number of species common to two stands being compared, a is the number of species unique to one stand,

Table 5. Second data subset selected from Transect A of study data. Values are cover to nearest five percent, used for tests on different indexes of similarity.

Species	Sample Plots (Stands) 28	29	34	47	48	60	76	77
Achillea millefolium spp. *lanulosa* var. *alpicola*							1	
Agoseris glauca var. *dasycephala*				1	1		1	
Arenaria aculeata.			1				20	
Astragalus whitneyi.	10	10	10					
Erigeron bloomeri var. *bloomeri*.			1					
Erigeron compositus var. *glabratus* . . .	20	20						
Eriogonum ovalifolium var. *nivale*. . . .			1	15	10	1		10
Helenium hoopesii.				10	10			
Lupinus lepidus var. *lobbii*.				20	20			
Poa cusickii var. *cusickii*			1					
Potentilla gracilis var. *glabrata*. . . .							1	
Poa sandbergii			20			1	10	20
Sitanion hystrix var. *hystrix*.	10			10	10	20	10	10
Spraguea umbellata var. *caudicifera*. . .				1	1	1		
Trifolium longipes ssp. *multipedunculatum*.							1	20

Table 6. Selected hypothetical data from Mueller-Dombois and Ellenberg (1974: 228) after Spatz (1970). Values are percent biomass.

Species[a]	Sample Plots							
	A_1	B_1	A_2	B_2	A_3	B_3	A_4	B_4
1	44	.2	44	44	44	44	44	
2	20	.2	20	20	20	20	20	
3	10	.2	10	10	10	10	10	
4	8	.2	8	8	8	8	8	
5	7	.2	7	7	7	7	7	
6	4	1	4	4	5		5	1
7	2	1	2	2		5	2	1
8	2	2	2	2	2		2	2
9	1	2	1	2		2	1	2
10	1	4	1	1	2		1	5
11	.2	7	.2			2		7
12	.2	8	.2		1			8
13	.2	10	.2			1		10
14	.2	20	.2		1			20
15	.2	44	.2			1		44

[a]Species are hypothetical.

Table 7. Percent similarity values for ten paired plots of data subset using numbered plots from Steens Mountain (Table 5) and lettered plots from Mueller-Dombois and Ellenberg, 1974 (Table 6).

	Indexes					
	SJ	SG	SMS	SDM	SS	
Plot Pairs	Jaccard, Presence-absence	Jaccard, measure-ment values	Sorensen, measure-ment values	Dick-Peddie and Moir	Spatz	Comments on Similarity
28,29	66.7	85.7	85.7	66.7	57.1	com. sp., equal value; one sp. unique
28,77	16.7	20.0	20.0	16.7	3.3	one com. sp., equal values
34,47	8.3	17.4	2.0	1.0	.1	one com. sp., diff. values
47,48	100.0	100.0	95.0	96.7	94.4	all sp. com., equal values except one
60,77	100.0	100.0	31.0	26.0	17.5	all sp. com., diff. values
76,77	42.9	68.9	40.8	25.2	15.3	some com. sp., diff. values; most sp. unique
A_1,B_1	100.0	100.0	8.0	23.0	17.8	all sp. com., diff. values
A_2,B_2	66.7	99.5	99.0	64.0	62.7	most sp. com., equal values
A_3,B_3	33.3	89.0	89.0	33.0	29.4	some com. sp., equal values, most sp. unique
A_4,B_4	33.3	11.0	6.0	20.0	1.7	some com. sp., diff. values, most sp. unique

and b is the number unique to the other; 2) the Jaccard index as modified to incorporate measurement values for species (Gleason, 1920):

$$SG = \frac{Mc}{Ma + Mb + Mc}$$

where Mc is the sum of the values for species common to two stands being compared, Ma is the sum of the values for species unique to one of the stands, and Mb is the sum of the values for species unique to the other; 3) the similarity index most commonly associated with the Wisconsin school of vegetation analysis (Dahl and Hadac, 1941 cited in Goodall, 1973; Sorensen, 1948; Motyka, *et al.*, 1950 cited in Mueller-Dombois and Ellenberg, 1974; Bray and Curtis, 1957; Goodall, 1973) referred to here as the modified Sorensen index, SMS, and given on p. 72; 4) the SIMORD similarity function of Dick-Peddie and Moir (1970) SDM given on p. 71; and, 5) Spatz (1970) SS, index given on p. 80. Since the values derived from these indexes range from zero to one they are usually expressed as percent similarity, i.e., each is multiplied by 100.

Differences among Indexes

It is noted in Table 7 that the Spatz and the Dick-Peddie and Moir indexes given relatively low percent similarity values between stands when compared to the Jaccard presence-absence and the Jaccard index using measured values. The Spatz index is particularly sensitive to variation in the number of common species and the quantitative differences between the measurements for common species. The two versions of the Jaccard index register 100 percent similarity when all species in the stands being compared occur in common even though the measurements (percent cover or biomass, density, or some other species variable) vary.

The modified Sorensen index, with generally higher similarity between stands, follows the same pattern of emphasis as the Spatz and the Dick-Peddie and Moir indexes with two exceptions. Stand pairs A_1B_1 and A_4B_4, Table 7, have very low percent similarity using the Sorensen index. Pair A_1B_1 has no unique species but the common species have inversely varying measurement values (Table 6). This variation pattern results in an extremely low similarity value. Although pair A_4B_4 has in common only one third of the species occurring in both stands, these also have unequal measurements. However, A_3B_3 also has one third of the species in common but the measurement values are equal and the similarity value quite high. Thus, it appears that the modified Sorensen index is particularly sensitive to variation in common species measurements regardless of their proportion and gives relatively high similarity percentages when either a large proportion of species occur in common with nearly equal values or when the proportion of common species is small but measurements for these species are also equal or nearly so in the compared stands. The Spatz and the Dick-Peddie and Moir index values do not range as widely over the entire subset of stand pairs and consequently it is expected that these indexes would not cluster stands in a two-dimensional ordination as well as the Sorensen index.

Also, it is expected, judging from the percent similarity values displayed in Table 7, that both versions of the Jaccard index would group well those pairs with a high proportion of common species. However, the presence-absence version would not measure differences in species dominance, and the second Jaccard index, although accounting for the measurement values, appears to be less sensitive to measurement variation than the remaining indexes.

Comparison of Ordination Plots

In order to evaluate further the indexes tested, all but one, the Jaccard index as modified by Gleason (1920), were inserted as the similarity function in the SIMORD ordination program. Figures 11 through 14 are plots of Transect A data and Figures 15 through 18 are plots of Transect B data using the Jaccard presence-absence, modified Sorensen, Dick-Peddie and Moir, and Spatz indexes respectively in each series.

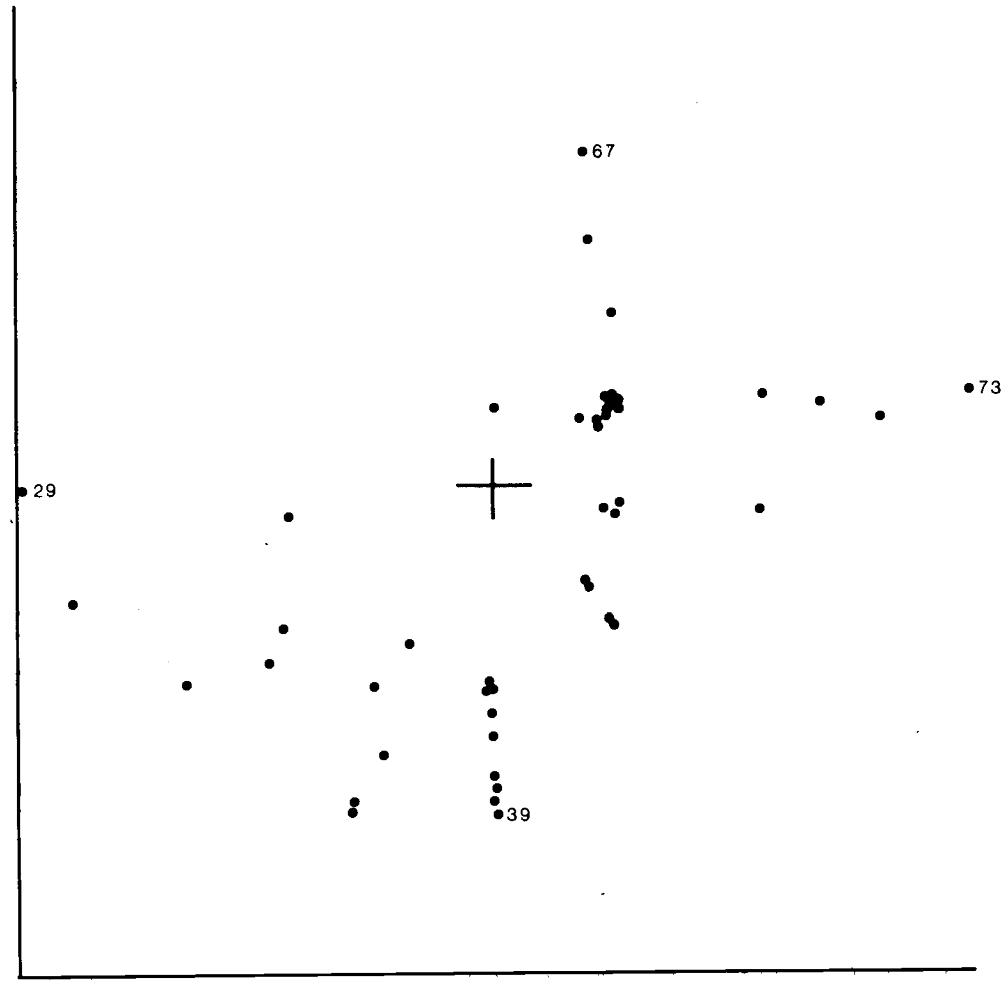

Figure 11. Transect A plot using Jaccard (1901) presence-absence similarity index. Reference stands are labeled.

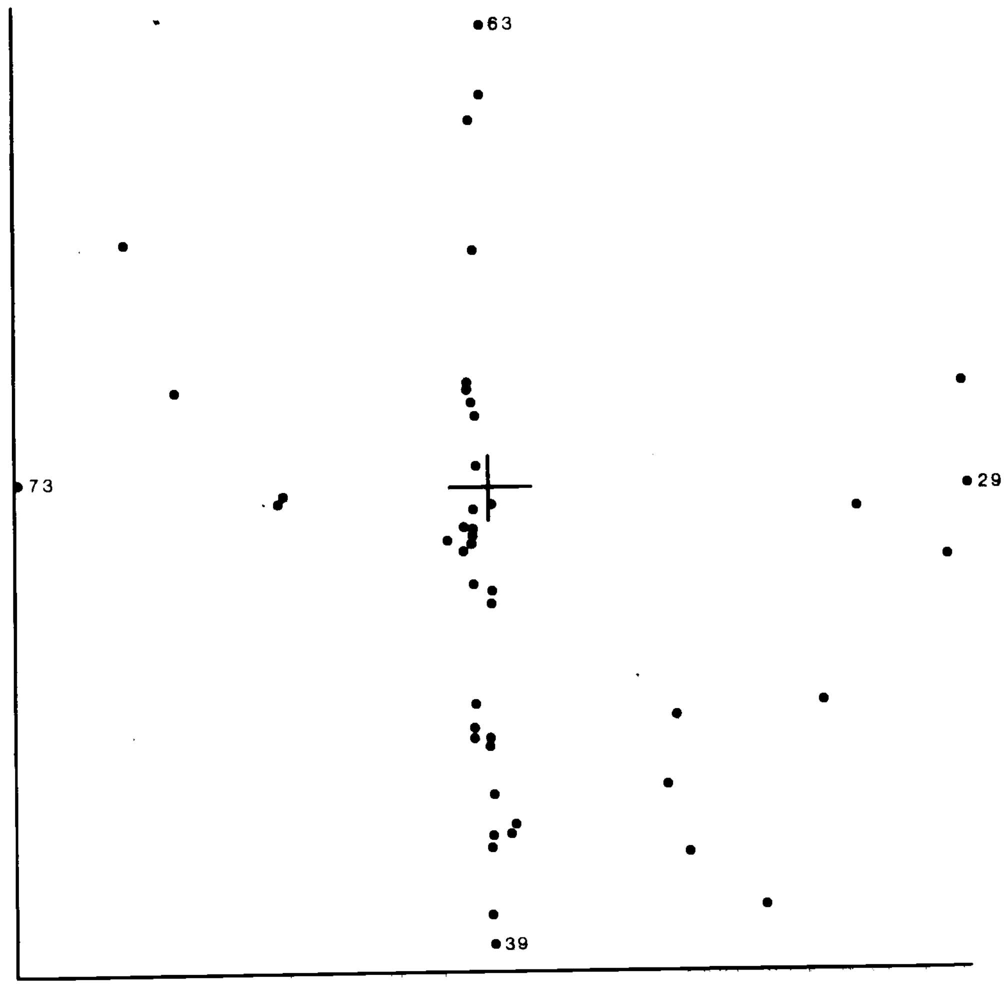

Figure 12. Transect A plot using Sorensen (1948) similarity index modified for quantitative values. Reference stands are labeled.

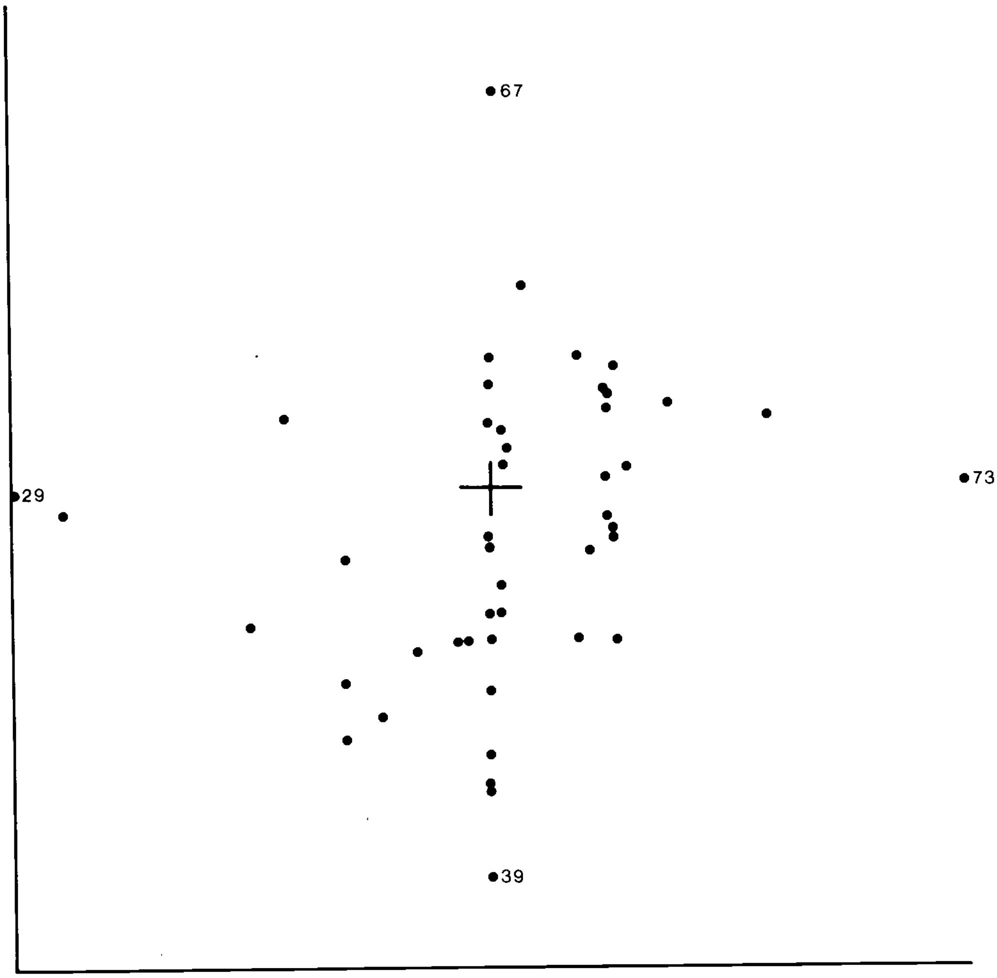

Figure 13. Transect A plot using Dick-Peddie and Moir (1970) similarity index. Reference stands are labeled.

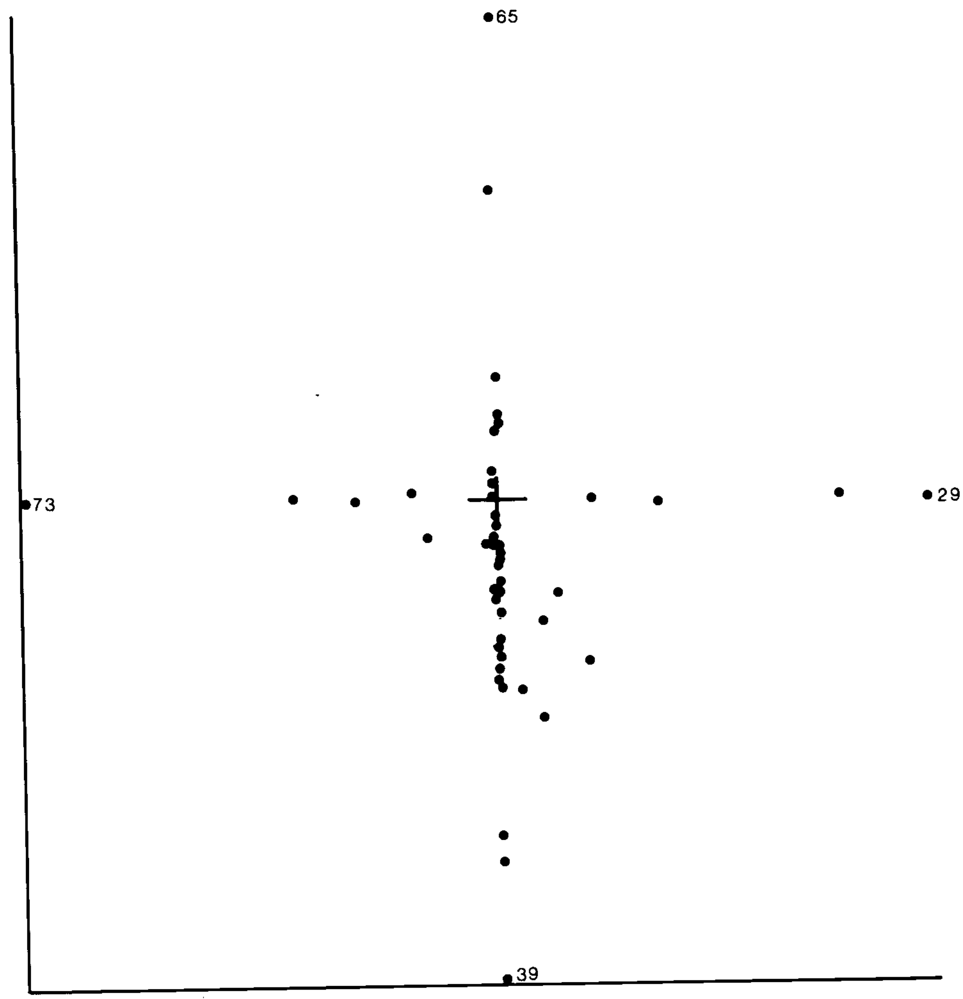

Figure 14. Transect A plot using Spatz (1970) similarity index. Reference stands are labeled.

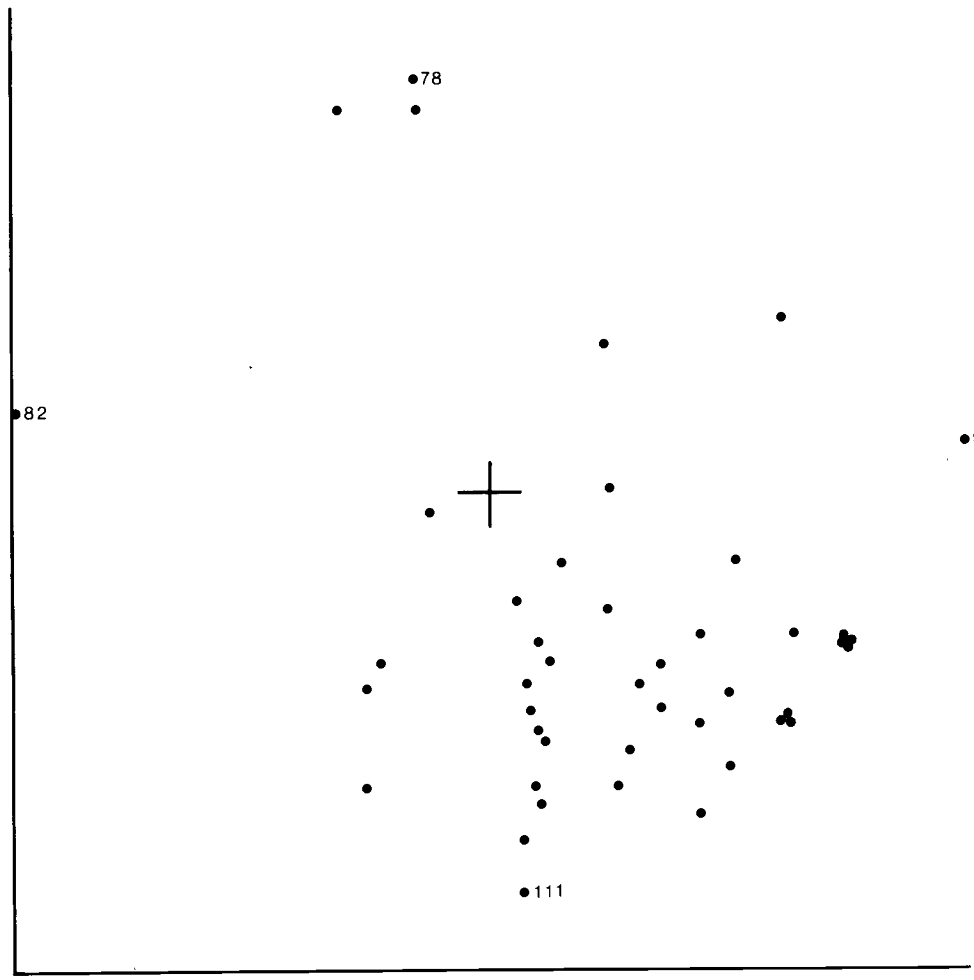

Figure 15. Transect B plot using Jaccard (1901) presence-absence similarity index. Reference stands are labeled.

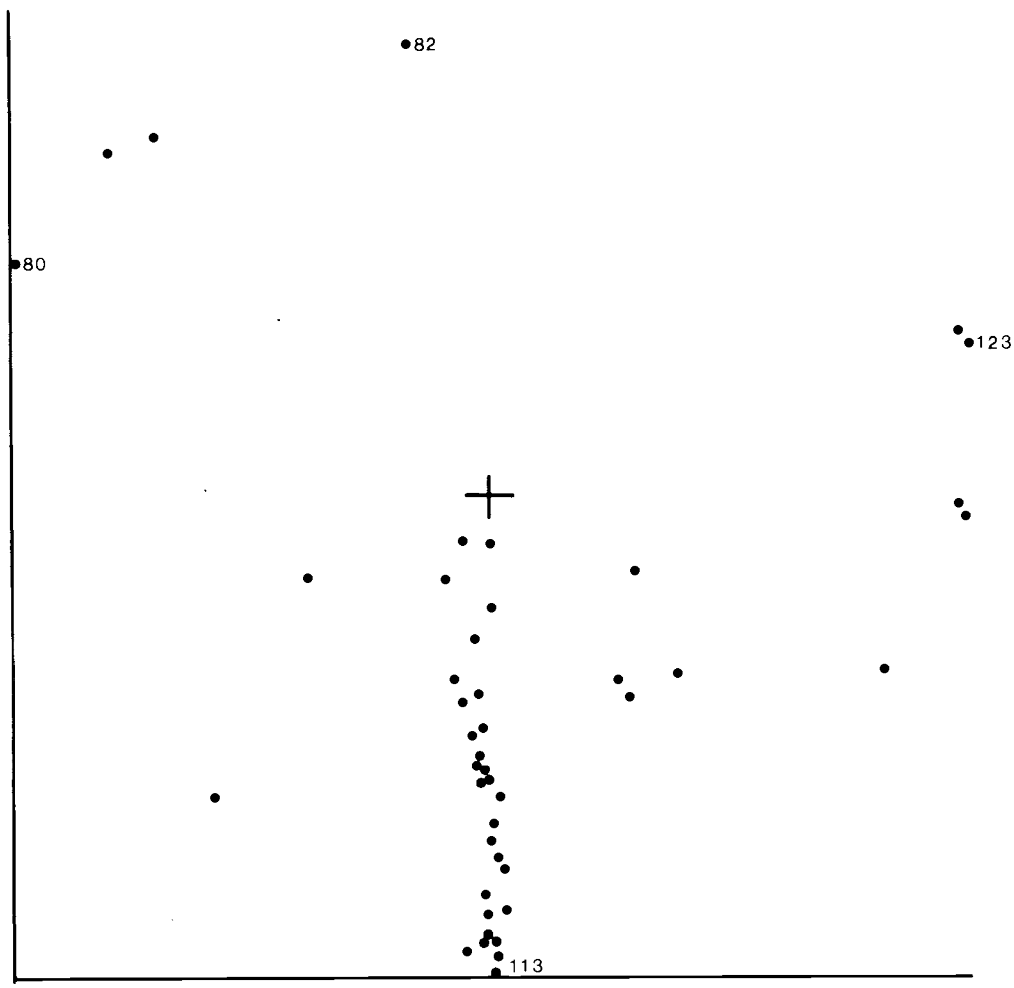

Figure 16. Transect B plot using Sorensen (1948) similarity index modified for quantitative species values. Reference stands are labeled.

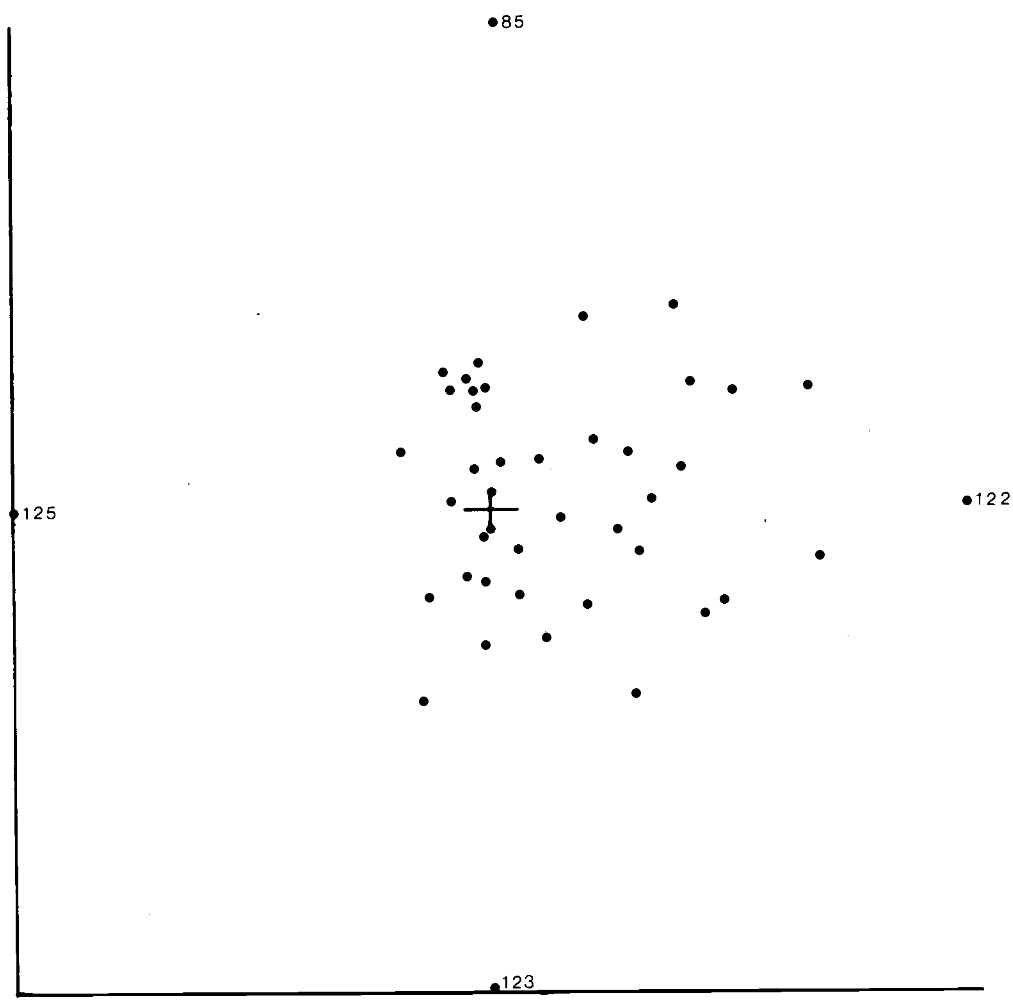

Figure 17. Transect B plot using Dick-Peddie and Moir (1970) similarity index. Reference stands are labeled.

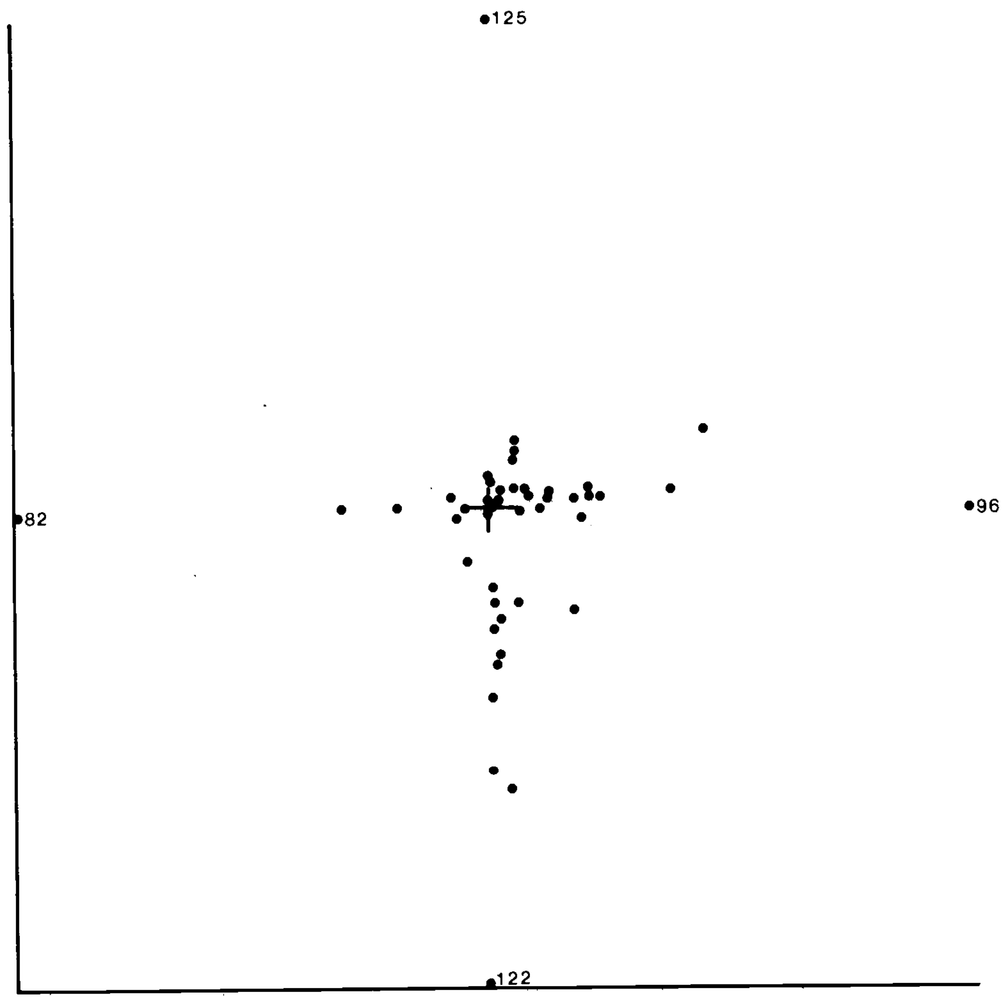

Figure 18. Transect B plot using Spatz (1970) similarity index. Reference stands are labeled.

The program selected the reference stands, E1, E2, E3, E4, in all cases. In the Transect A series the reference stands selected by the program are virtually the same for each index. Also these reference stands are at or near the respective ends of the field transect; thus, the X axis reflects the topographic gradient along which the plots were sampled.

Of the four indexes, the Jaccard presence-absence index, Fig. 11, gives the best grouping, i.e., discrimination among clusters of Transect A stands. The Dick-Peddie and Moir index, Fig. 13, gives a similar pattern but the grouping is much more open. The Spatz index, Fig. 14, gives a very tight linear arrangement of the stands along the X and particularly along the Y axis. The Sorensen index, Fig. 12, gives only a suggestion of linear pattern along the Y axis and groups of stands are apparent.

In the Transect B comparison series the selection of reference stands varied from ordination to ordination. Only the Spatz and Jaccard indexes have the same E1 and E2 stands and E3 and E4 for these two are different. Nevertheless the general grouping attributes of the four indexes observed for Transect A series are nearly the same for Transect B, Figures 15 through 18. The Jaccard index does not cluster as well as it did with the Transect A data but still pulls out some clusters and disperses stands away from an undesirable linear pattern (for the purposes of this study) along axes. The Dick-Peddie and Moir index leaves a relatively open pattern with little visual distinction among possible groups. Spatz' index again produces a tight clustering along axes and near the center of the plot. The Sorensen index in the case of Transect B data tends to string out most of the stands along the bottom half of the Y axis but at least there is good dispersion away from the center of the plot where stands tend to cluster when there is little similarity differentiation except for end stands.

Considering the grouping attributes of the indexes in both the Transect A and Transect B series, it is possible to identify a preferred similarity index for the discrete classification of the study data. Ordination plots produced using the Spatz and the Dick-Peddie and Moir indexes would be more difficult to interpret since groups or clusters of stands are less distinct. The Jaccard presence-absence index apparently gives better grouping but does not take into account measurement variation among species; hence, no weighting factor for species dominance when available can be included and information pertinent to the vegetation analysis is lost. Thus, of the four indexes compared, the Sorensen index has the most desirable attributes: groups of stands are more distinguishable than with the Spatz and Dick-Peddie and Moir indexes and species dominance is taken into account when the similarity between two stands is calculated.

Ordination of the Grassland Transect Data

Choosing Reference Stands

Based on conclusions of the preceding section the SIMORD program was modified to calculate stand pair similarity using the modified Sorensen index, SMS. The final plot for each of the six transects sampled in the field was run with the two reference stands E1, E2 being chosen by the user. E3 and E4 were selected by the program. To determine which stands would be designated E1 and E2 two factors were considered: 1) the reference stands had to reflect the topographic gradient, i.e., they had to be at or near the respective ends of the field transect; and, 2) the reference stands had to come close to meeting the SIMORD program criteria for selecting reference stands (p. 75) and represent the major vegetation variation within the transect. These criteria assured that anamalous stands were not selected as reference stands; however, in only one or two instances did the choice of the reference stands, E1, E2, diverge significantly from the program selected E1 and E2 stands. No special criteria were set up for choosing reference stands E3 and E4 since no secondary gradient was assumed and the program selection criteria (independent mode) fit the needs of the analysis.

Identification of Stand Groupings

The intention of the ordination is to identify sample plot or stand clusters which relate to vegetation variation along the topographic gradient. Data for each of the transect plots occurring in a recognizable cluster on the two-dimensional plots, Figures 19 through 24, were examined to identify dominant species common within, but relatively unique to, a given cluster. Cluster boundaries were determined from visual inspection of the polar ordination plot. These clusters, reflecting vegetation segments, were labeled with the code names of identifier species.[7] In all ordination plot figures for the transects the upper, or crest, end of the transect is represented to the left on the plot; the lower end to the right. The topography of the study area, nearly uniform in angle and aspect, contributes to changes in vegetation composition along this physical gradient.

Upper Slope and Crest. The first cluster that stands out on the plot series is that identified by the species *Astragalus whitneyi* and *Erigeron compositus*. In all cases an *Astragulus whitneyi-Erigeron compositus* segment occurs at the crest. These areas have an exposed, windswept environment and little soil development. The ground surface

[7]Full scientific names and authors for all species are found in Appendix D. Key to code names for species in Figures 19 to 24 is given in Table 8.

Table 8. Code name key for species in Figures 19 through 24.

AGGL	*Agoseris glauca* var. *dasycephala*
ARAC	*Arenaria aculeata*
ASWH	*Astragalus whitneyi*
ERCO	*Erigeron compositus* var. *glabratus*
FEID	*Festuca idahoensis* var. *idahoensis*
FESC	*Festuca scabrella*
LULE	*Lupinus lepidus* var. *lobbii*
POSA	*Poa sandbergii*
SIHY	*Sitanion hystrix*
TRLO	*Trifolium longipes* ssp. *multipedunculatum*
TRSP	*Trisetum spicatum*

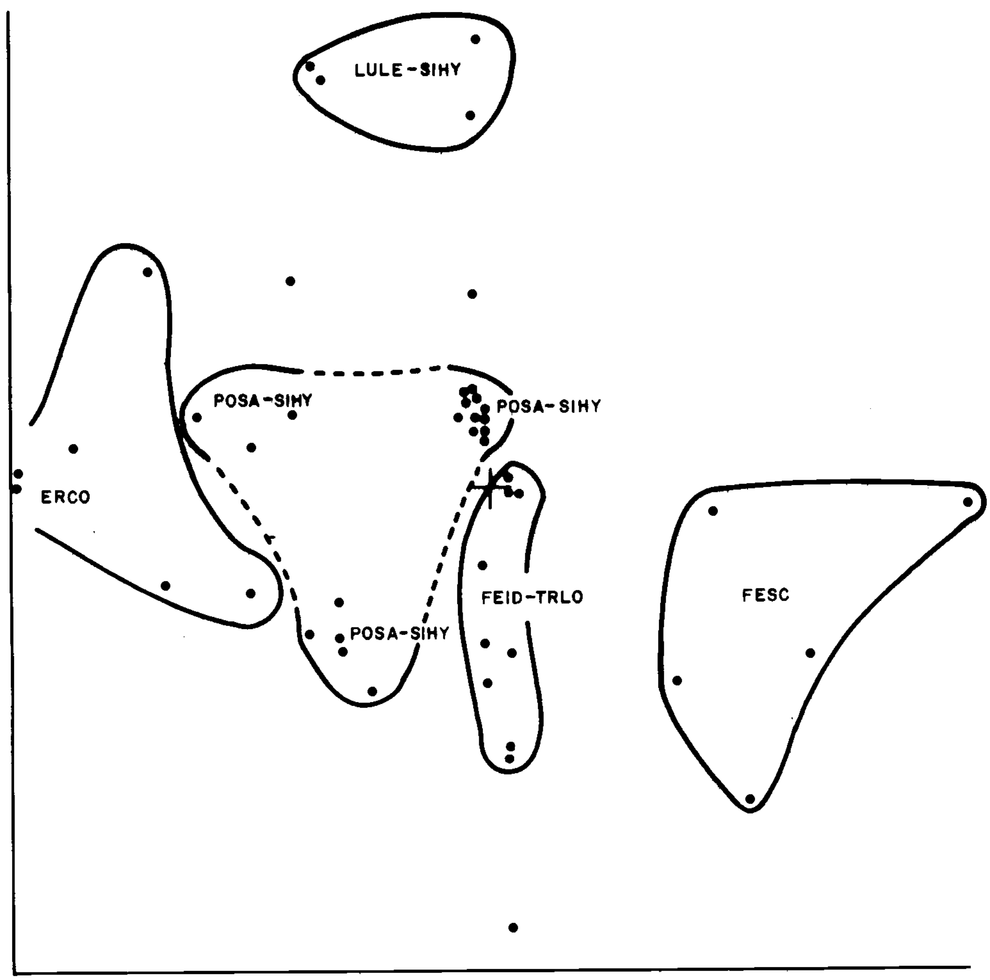

Figure 19. Transect A stand ordination. Groupings labeled with dominant species, see Table 8.

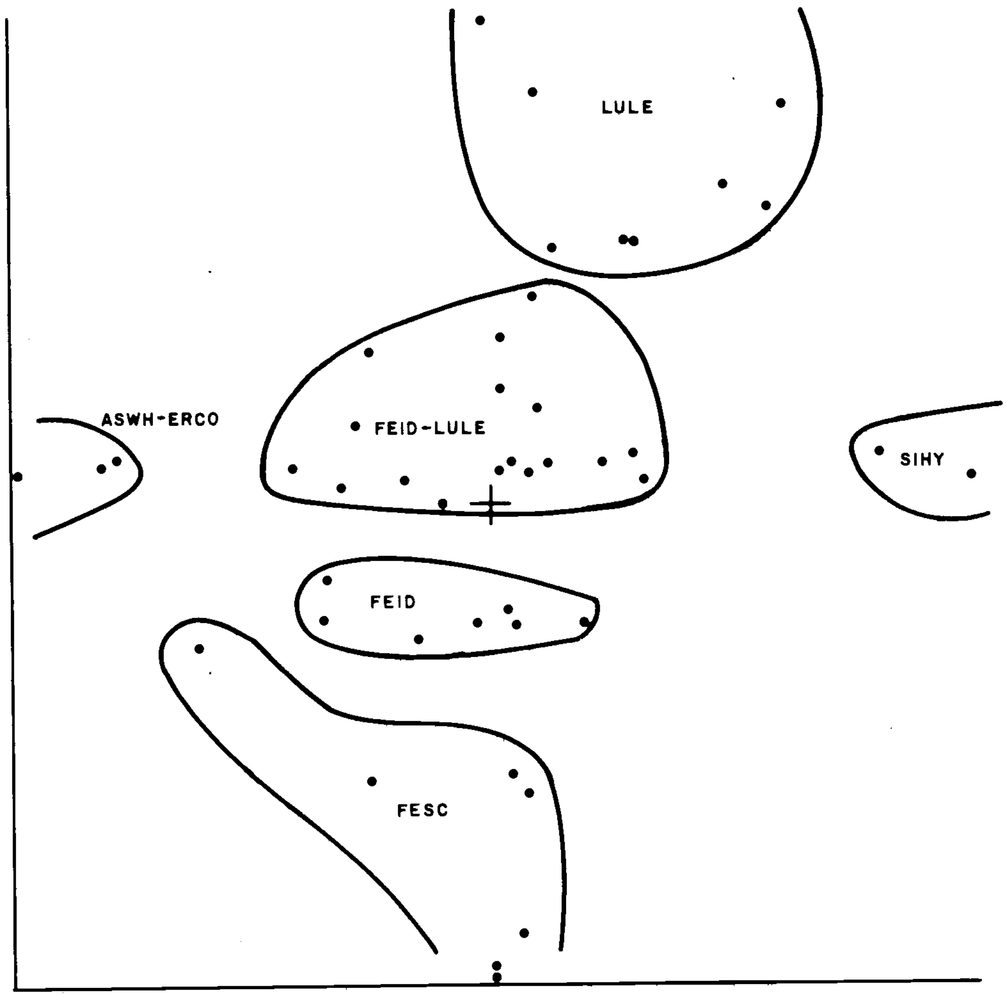

Figure 20. Transect B stand ordination. Groupings labeled with dominant species, see Table 8.

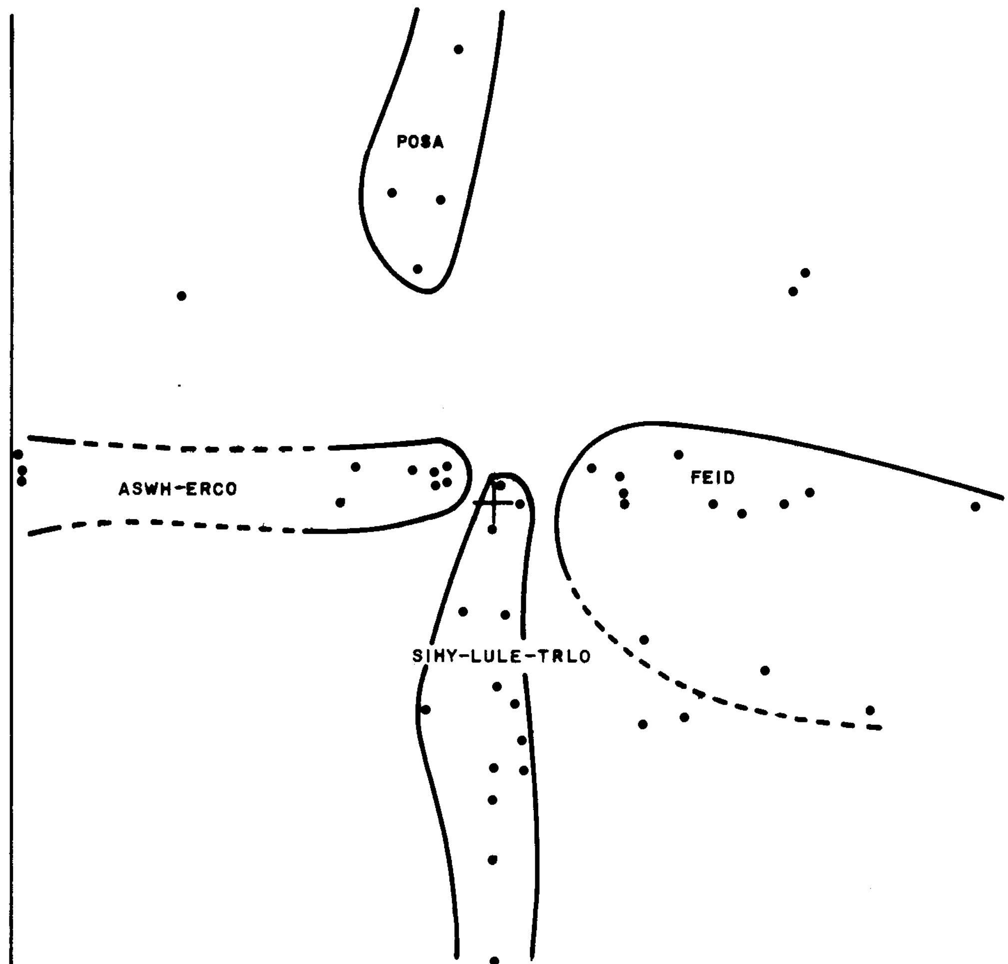

Figure 21. Transect C stand ordination. Groupings labeled with dominant species, see Table 8.

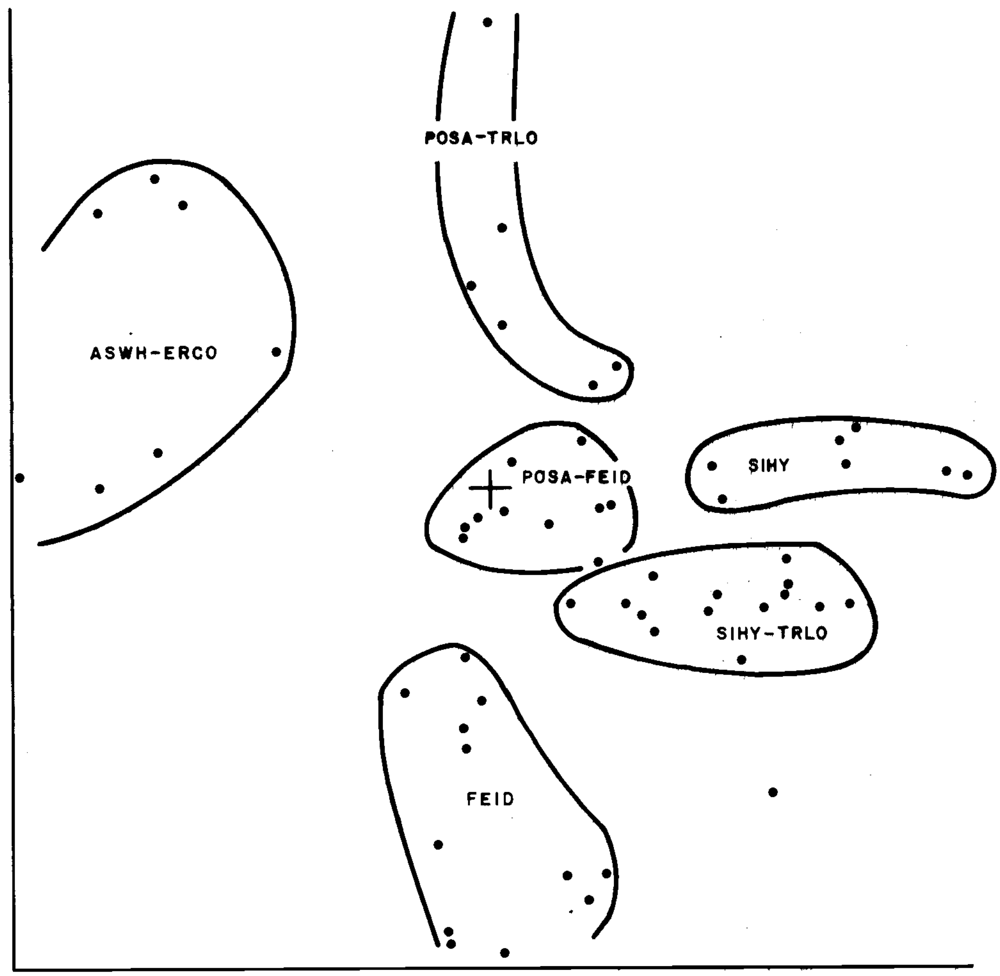

Figure 22. Transect D stand ordination. Groupings labeled with dominant species, see Table 8.

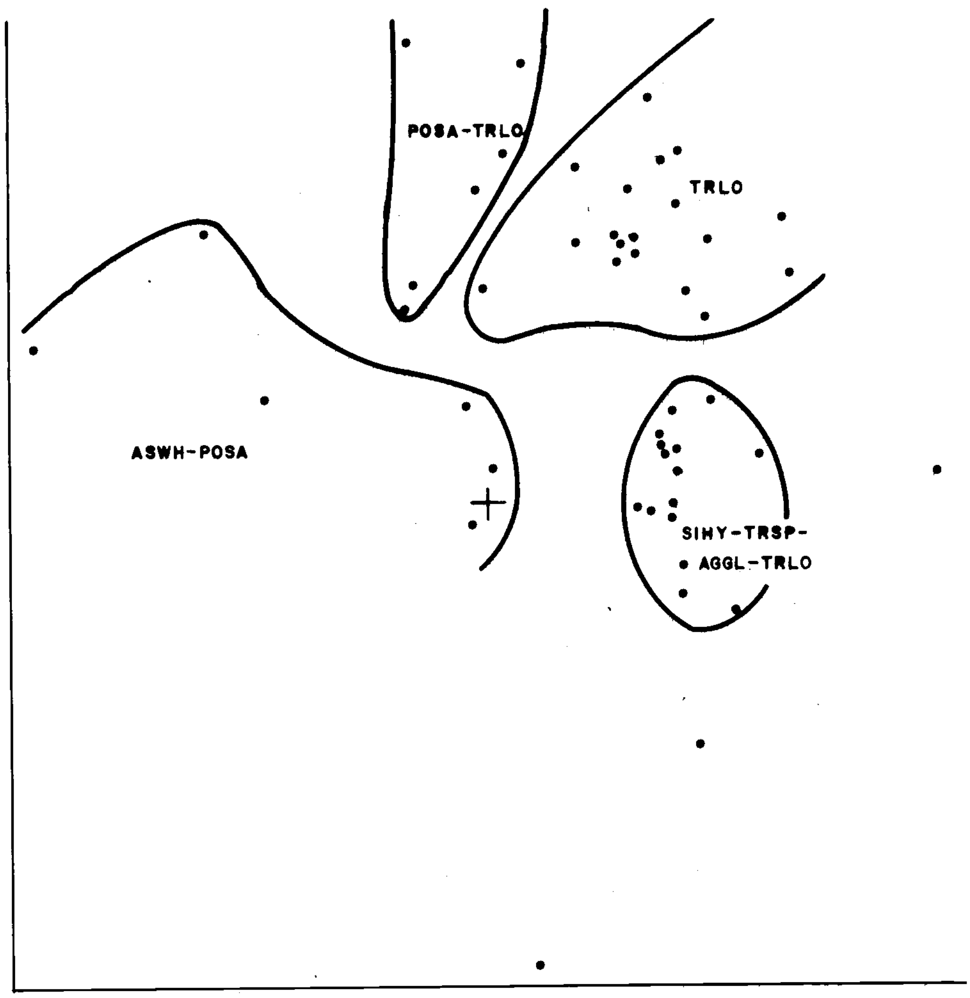

Figure 23. Transect E stand ordination. Groupings labeled with dominant species, see Table 8.

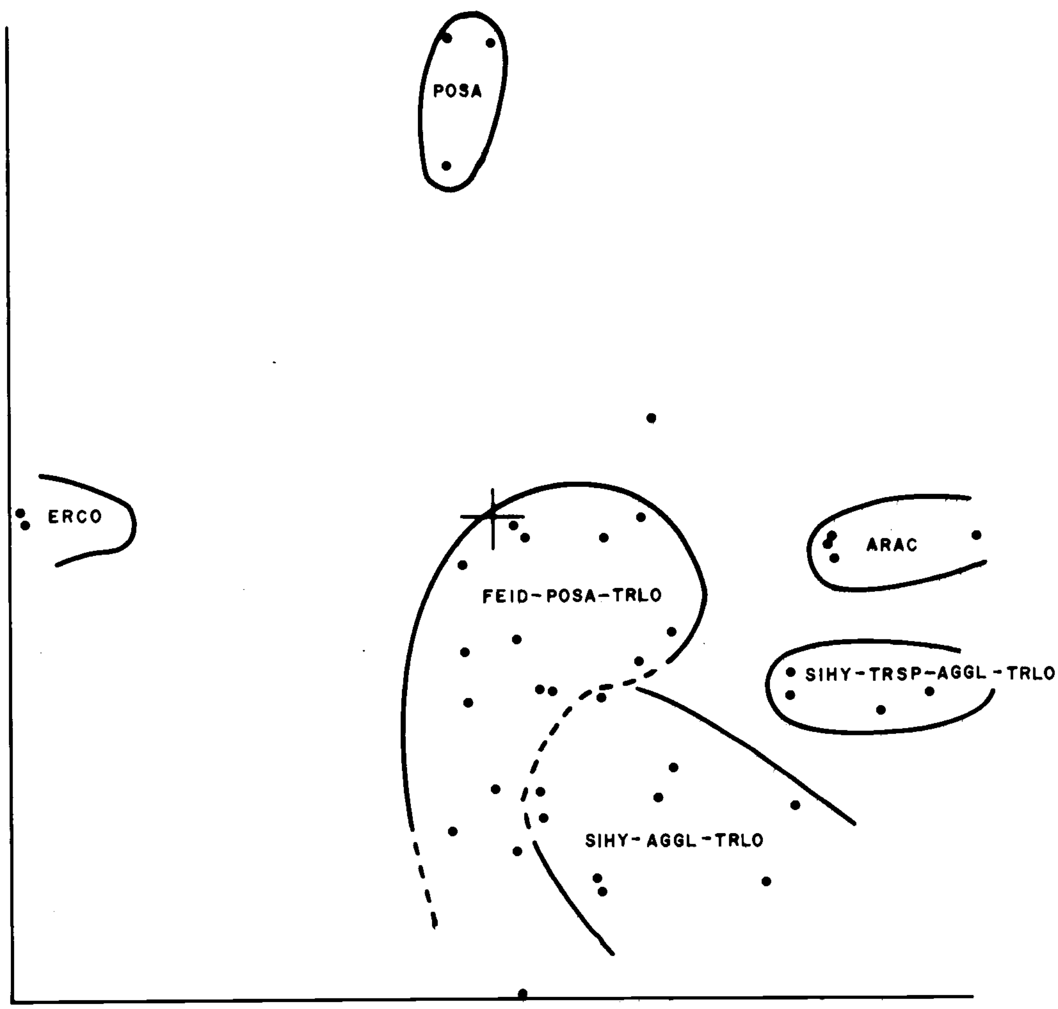

Figure 24. Transect F stand ordination. Groupings labeled with dominant species, see Table 8.

has little winter snow accumulation and is exposed early in the spring, dries quickly, and is subject to wind deflation and abrasion and extreme fluctuations in diurnal temperatures.

Mid-slope. Those groups of stands near the center of the ordination plot along the Y axis represent, in nearly all cases, vegetation segments found at midslope in the study area. They are identified as: 1) bunchgrass areas with dense cover of Festuca idahoensis[8] and Poa sandbergii, sometimes with Festuca scabrella, and 2) area of Lupinus lepidus and Trifolium longipes mixed with some bunchgrass. Dense bunchgrass is apparent as isolated and slightly raised islands. Winter snow begins to accumulate at this point on the slope giving some protection to plants from cold, dessicating winter winds. In the extensive area surrounding them is found a sparse vegetation of Lupinus lepidus and Trifolium longipes among other forbs with scattered bunchgrass. These are wind and snow meltwater erosion areas lacking the soil development of the dense grass islands. Snow accumulates in the inter-island areas to a greater depth than on grass islands in winter and

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[8] Festuca idahoensis Elmer var. idahoensis. This important species is referred to in the Steens Mountain literature as F. ovina L. (e.g., Griffiths, 1902; Hansen, 1956; Faegri, 1966). F. ovina is present and moderately abundant in certain downslope areas but the common bunchgrass in midslope areas in the Steens Mountain subalpine is identified as F. idahoensis var. idahoensis by strictly following the key in Hitchcock, et al., 1969.

melts off rapidly in May and June contributing to the lack of soil development. Wind in summer also adds to the erosion of these areas.

Grass Islands. The islands of dense bunchgrass are a marked feature on the landscape. Hansen (1956: 25,70) attributes the extensive inter-island eroded surfaces to heavy grazing by hooved animals, principally domestic sheep. Sheep, the stocking of which was estimated by Hansen to be 45 sheep per acre over the Steens Mountain range during the summer months in the 1950's, not only closely grazed the bunchgrass over the years but trampled the ground surface as well, thereby greatly contributing to subsequent erosion. Although Hansen's estimate of stocking is one-tenth of Griffiths' liberal estimate of fifty years before, Hansen notes the present (1956) overstocked condition of the range and suggests that grazing be halted as a step in recovering a depleted range.

In this subalpine environment environmental elements such as effective growing season related to snow cover, potential for erosion from meltwater and wind, and soil moisture available during the growing season are critically interrelated to the development and stability of the bunchgrass vegetation. Past grazing has apparently upset the environment-vegetation relationship and allowed extensive bunchgrass areas to be reduced to remnant islands. It has not been determined yet whether or not the restriction of grazing in the grassland in recent years has had the expected favorable effect of rejuvenating the bunchgrass islands.

Lower Slope. Vegetation segments are typified by the species Sitanion hystrix, Trisetum spicatum, Agoseris glauca, Arenaria aculeata, with Trifolium longipes and Lupinus lepidus sometimes mixed. Bunchgrass species of mid and upper slopes are not entirely absent but are infrequently present. The grasses, Sitanion hystrix and Trisetum spicatum, occur on flat gravelly surfaces subject to heavy snow accumulation at the lower end of the study area. Although snow lingers into the growing season here, it melts rapidly by late June causing erosional rills and leaving a coarse textured soil surface after finer texture material is removed. The relatively gravelly textured soil dries rapidly when freed of snow providing a droughty habitat occupied by only a few plants. Agoseris glauca, a small tap-rooted composite, commonly grows on these eroded sites.

Transects A and C each have bunchgrass areas at lower slope positions. This occurrence in Transect A is possibly attributable to water seepage and local topography which becomes gradually steeper and therefore may have less snow accumulation; both conditions being more favorable to bunchgrass growth. For Transect C, three stands, one of which is an ordination reference stand, occur at the bottom of the slope and contain significant coverage of Festuca idahoensis. The remainder of the stands in the Festuca idahoensis cluster on the plot are mid-slope in location. Most lower slope stands are in the group along the lower Y axis and exhibit the typical dominant species of downslope, snow accumulation sites, Sitanion hystrix. In these two cases the reference stand E2 was similar in species composition to mid-slope stands and caused a shift in placement of stand groups in the plot. However, the same basic vegetation segments remain represented by the stand clusters in all cases.

Direct Gradient Analysis

To observe the changes in the major species populations and their dominance as expressed by percent ground cover along the study area slope, direct gradient analysis was employed. The topograhic gradient is assumed to reflect a complex micro-environmental gradient from crest to lower slope affected mostly by differences in snow cover, wind, soil moisture, and snow melt water erosion. The gradient scale is the distance in meters from the crest along the field transect. Since the slope is entirely west-facing and nearly uniform in angle and morphology from north to south, distance of transect plots from the crest was considered a good representation of the micro-environmental gradient. Most of the dominant species, as indicated in the stand ordination of the preceding section, were plotted along the topographic gradient, Figures 25 through 33. Each figure is a composite, ten meter interval transect for which both average percent cover and species frequency among the six transects were plotted. Beyond 430 meters from the crest on these composite transects, individual transects enter rocky transition ground and terminate; therefore, the direct ordinations should be cautiously interpreted at the downslope end.

Astragalus whitneyi (Fig. 25), a low-growing milk vetch, and Erigeron compositus var. glabratus (Fig. 26), a caespitose composite, are confined almost entirely to the crest. These species are least abundant at the south end of the grassland. Their frequencies are high at the crest but drop off rapidly within 50 meters of the crest. Trifolium longipes ssp. multipedunculatum (Fig. 27), a subalpine clover, and Lupinus lepidus var. lobbii (Fig. 28), a prostrate prairie lupine, are absent at the crest but are spread across the remaining length of the composite transect. Trifolium longipes ssp. multipedunculatum is most frequent between 250 and 400 meters from the crest and is an abundant species in the lower slope communities. Lupinus lepidus var. lobbii although occurring in the transect series at frequencies of 50 percent or less, is prominent in the downslope areas as well as at midslope between the dense bunchgrass communities. The presence of

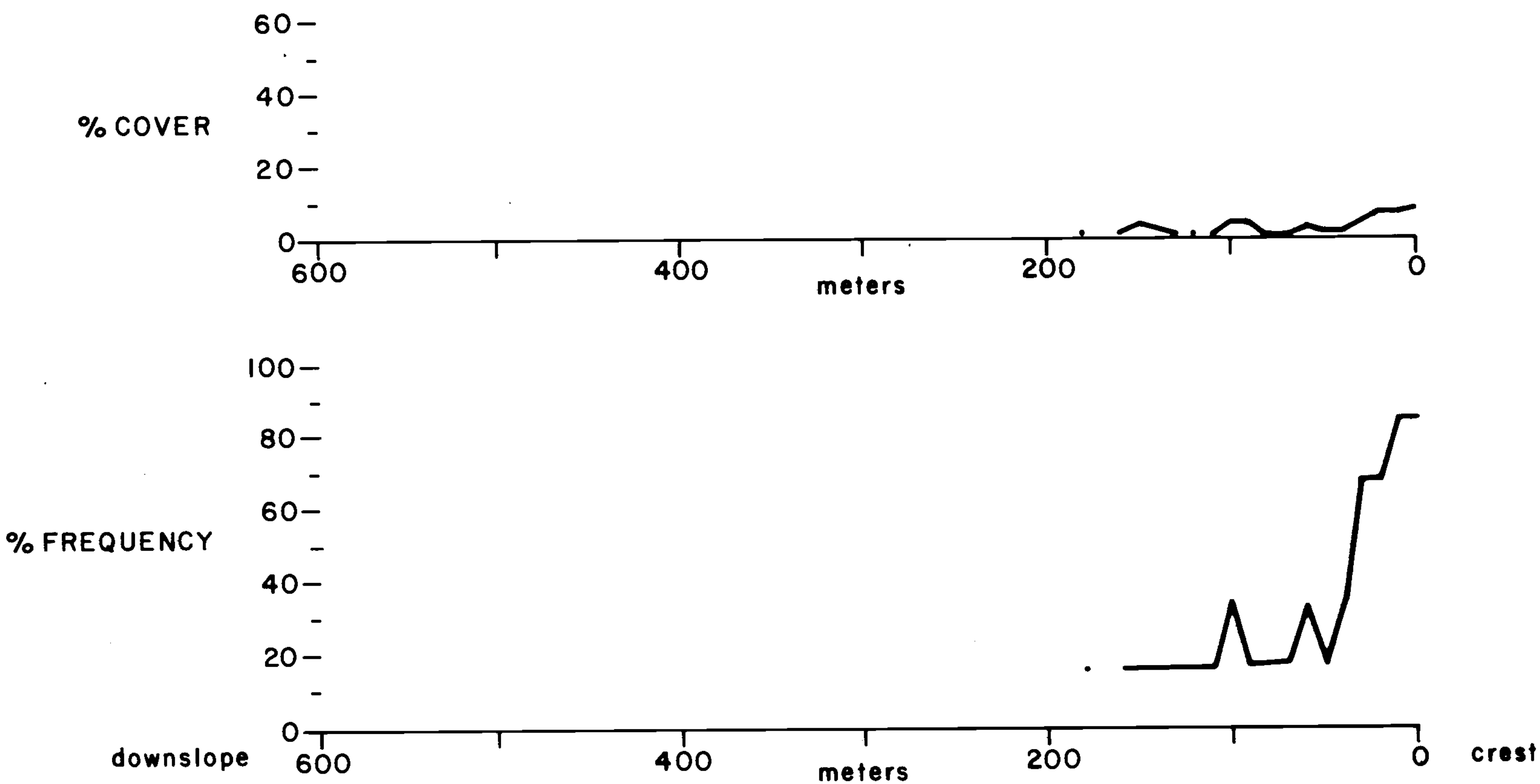

Figure 25. Direct ordination of *Astragalus whitneyi* based on distance from crest and average percent cover and frequency over the six transects.

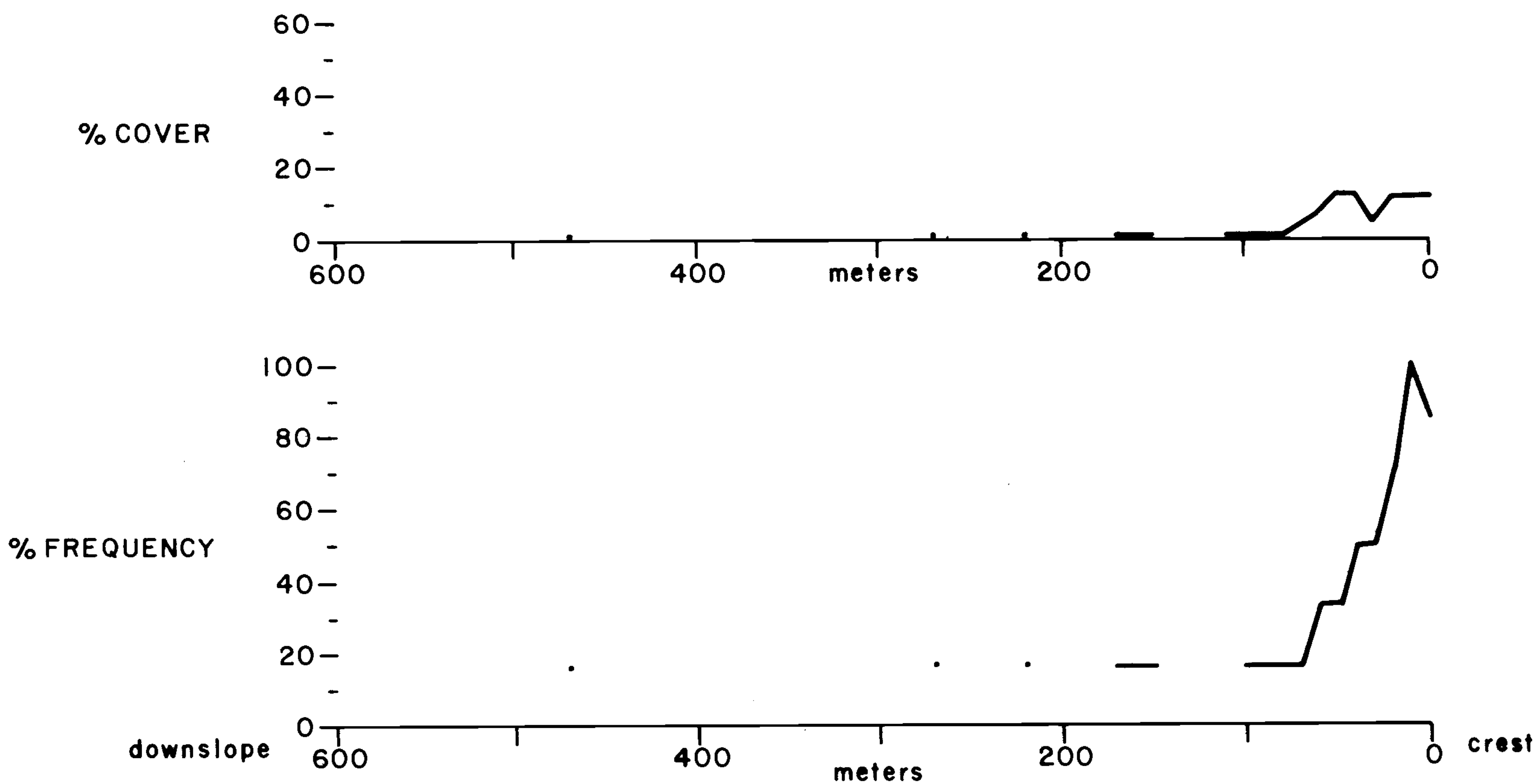

Figure 26. Direct ordination of Erigeron compositus var. glabratus based on distance from crest and average percent cover and frequency over the six transects.

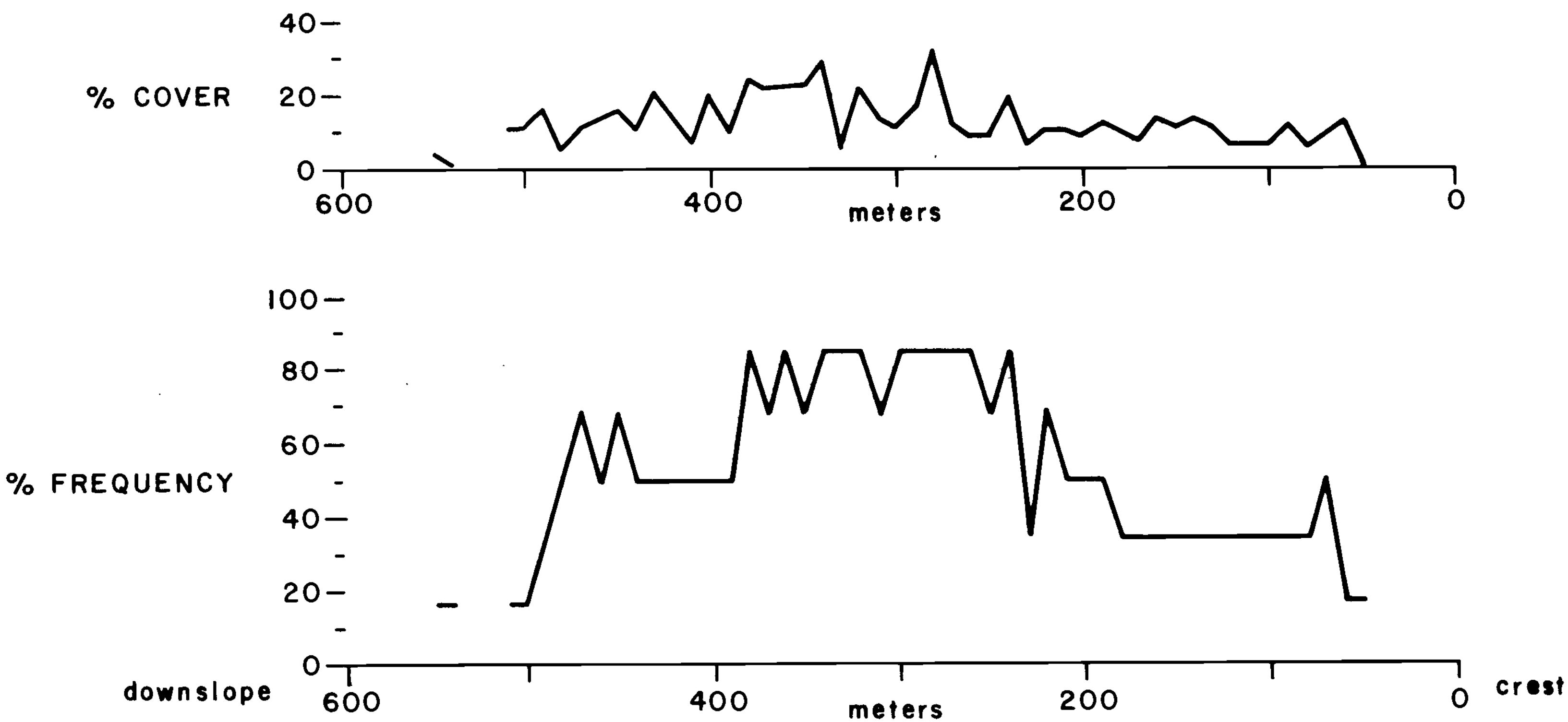

Figure 27. Direct ordination of <u>Trifolium longipes</u> ssp. <u>multipedunculatum</u> based on distance from crest and average percent cover and frequency over the six transects.

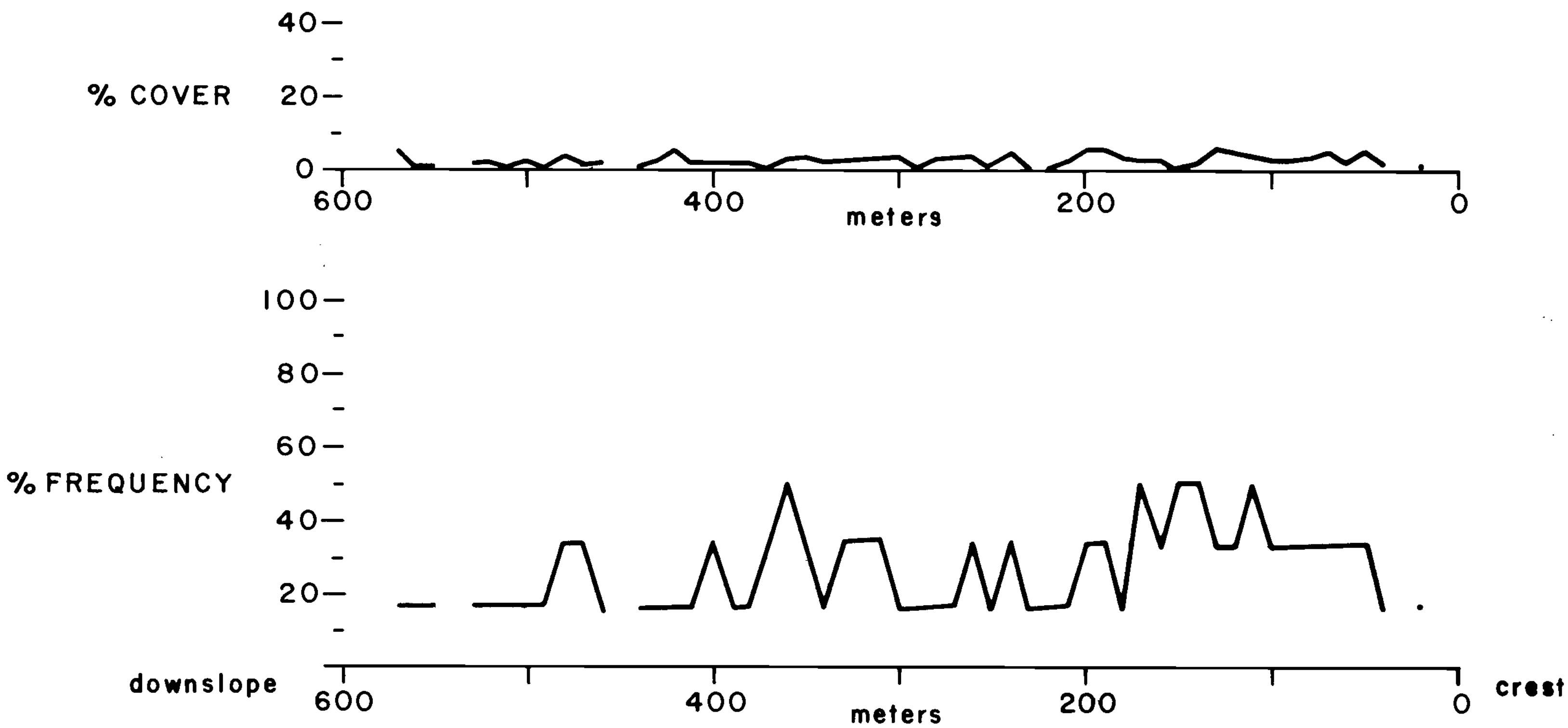

Figure 28. Direct ordination of Lupinus lepidus var. lobbii based on distance from crest and average percent cover and frequency over the six transects.

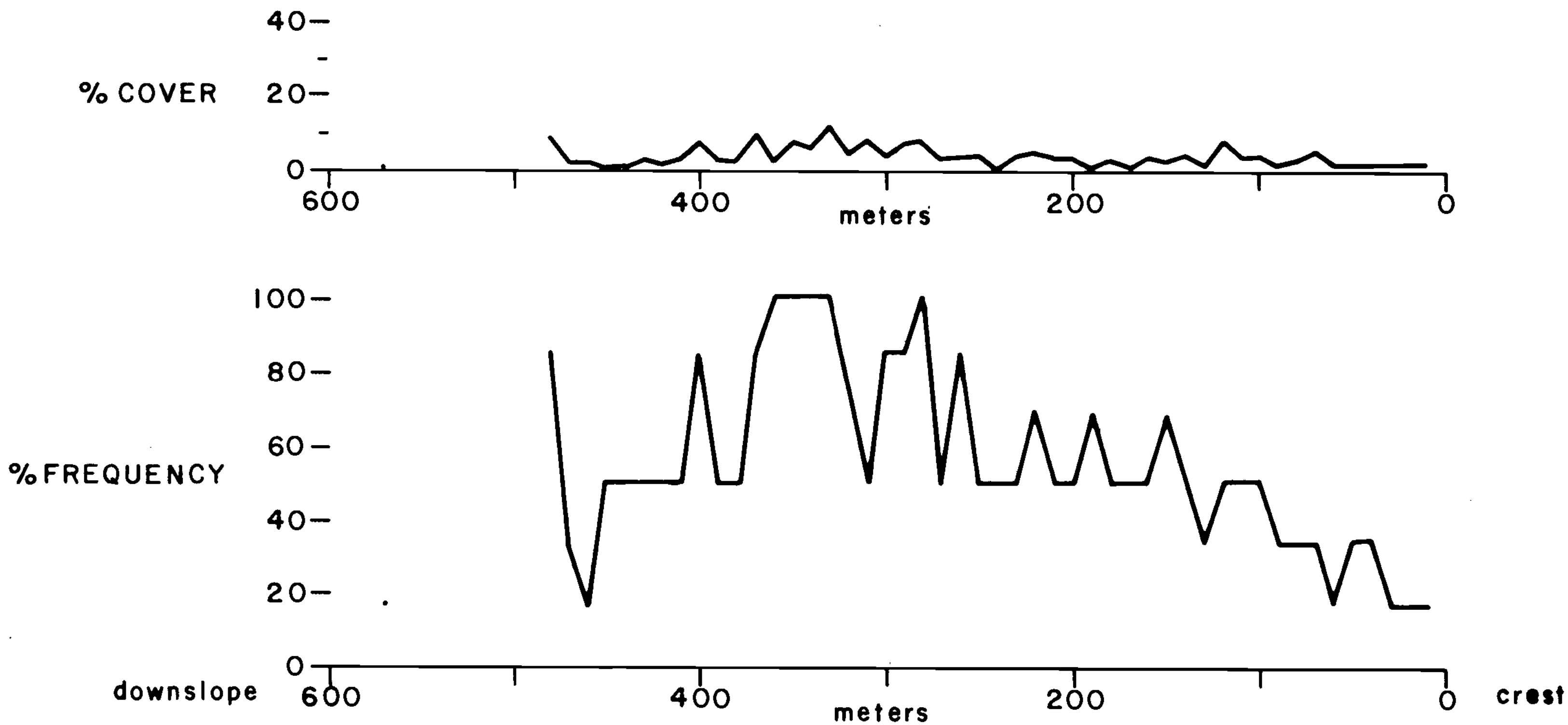

Figure 29. Direct ordination of <u>Agoseris glauca</u> var. <u>dasycephala</u> based on distance from crest and average percent cover and frequency over the six transects

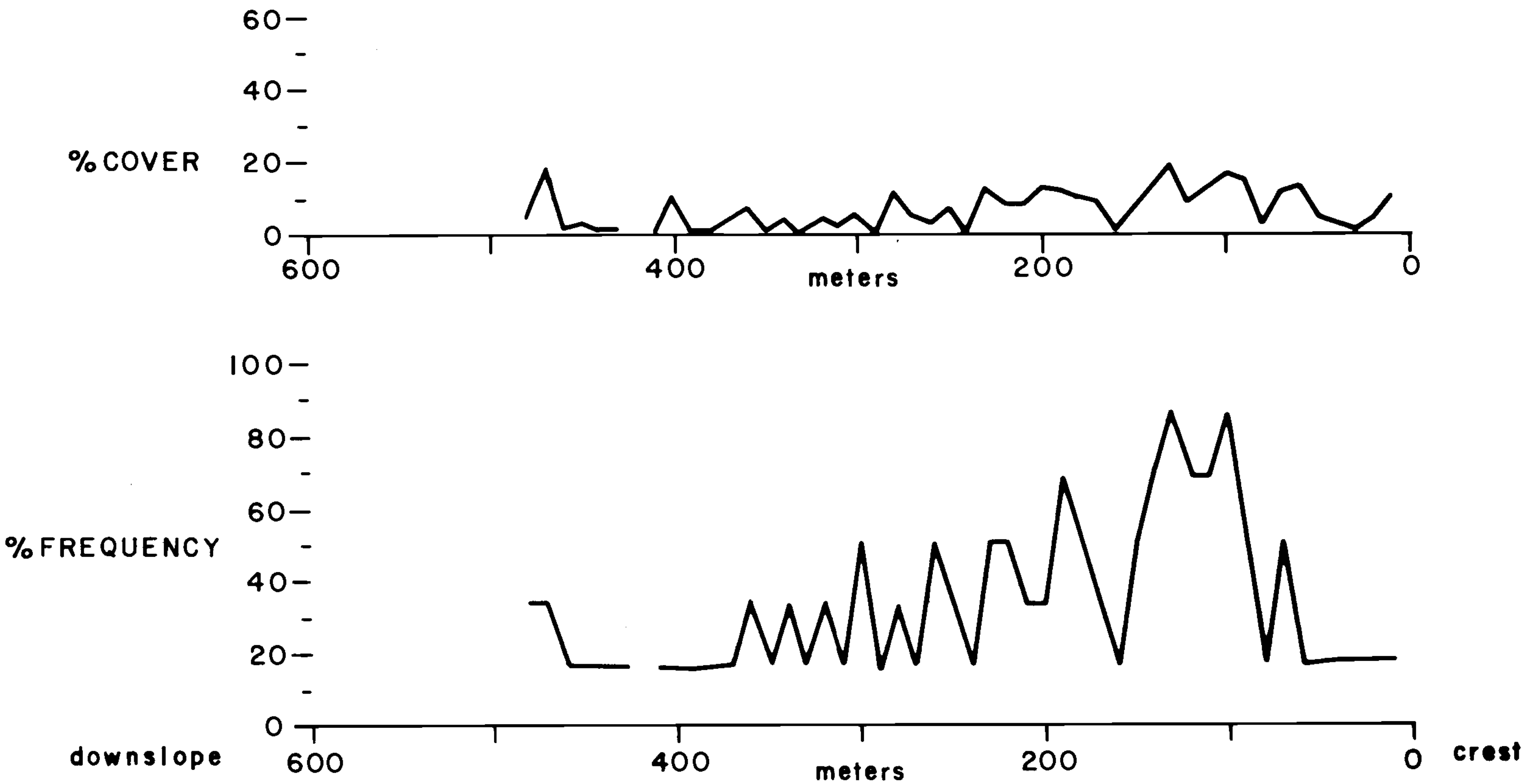

Figure 30. Direct ordination of <u>Festuca idahoensis</u> var. <u>idahoensis</u> based on distance from crest and average percent cover and frequency over the six transects.

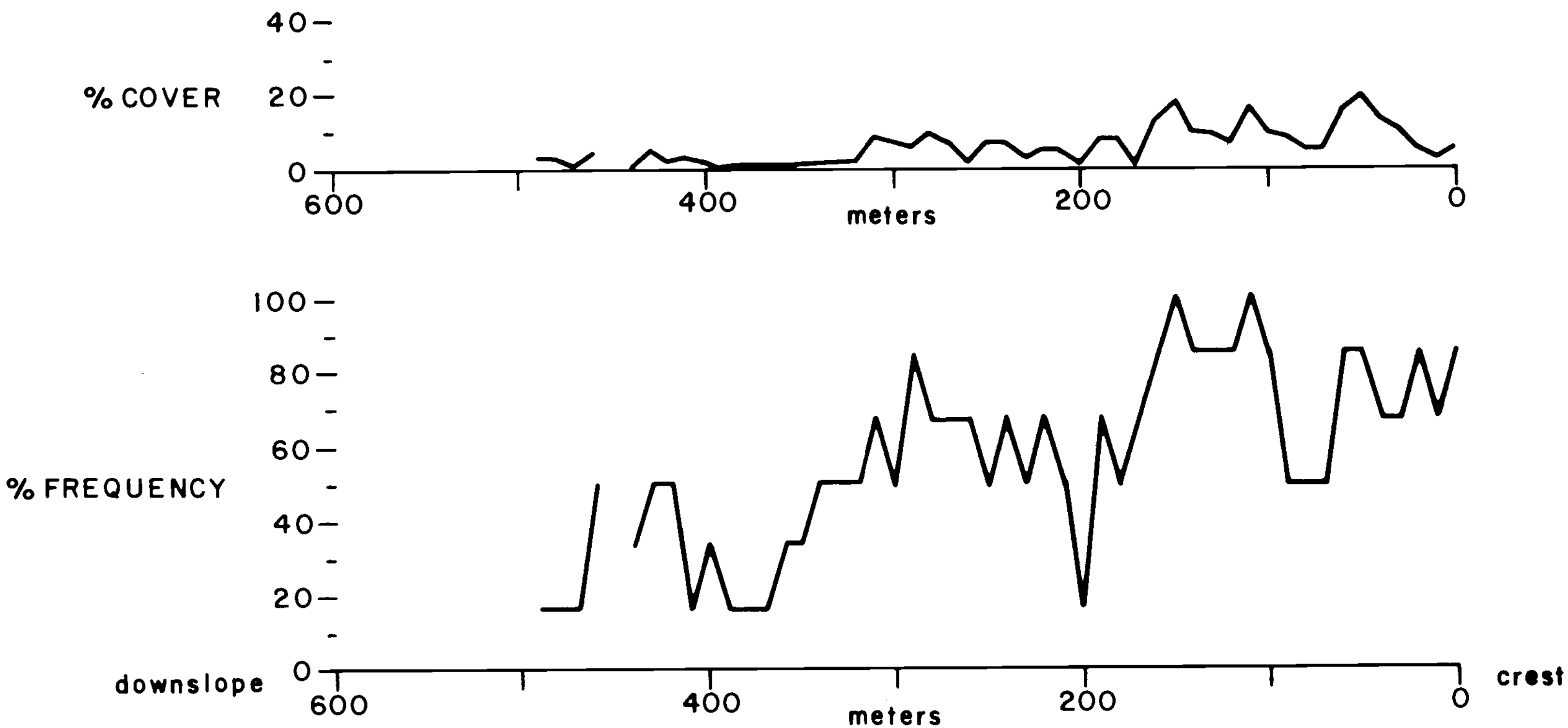

Figure 31. Direct ordination of Poa sandbergii based on distance from crest and average percent cover and frequency over the six transects.

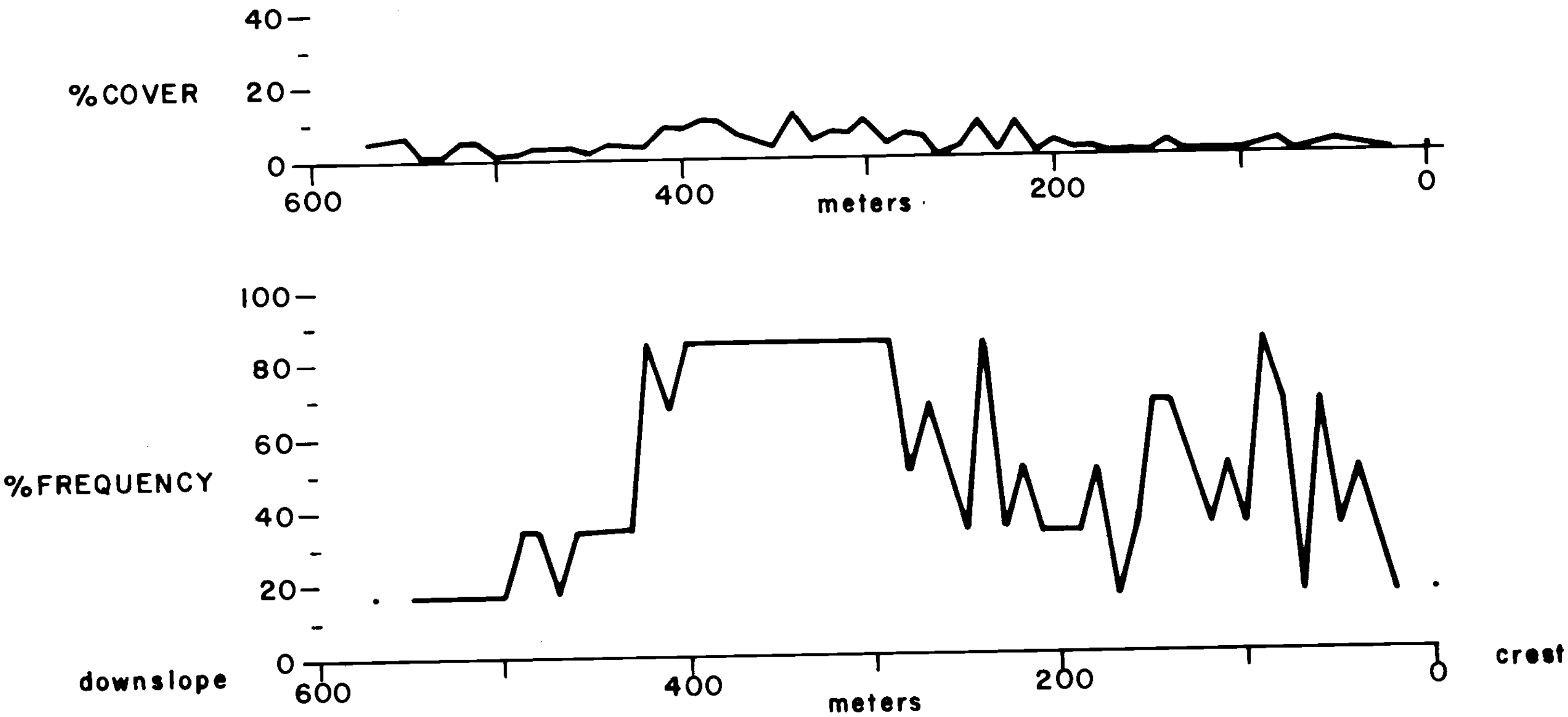

Figure 32. Direct ordination of Sitanion hystrix var. hystrix based on distance from crest and average percent cover and frequency over the six transects.

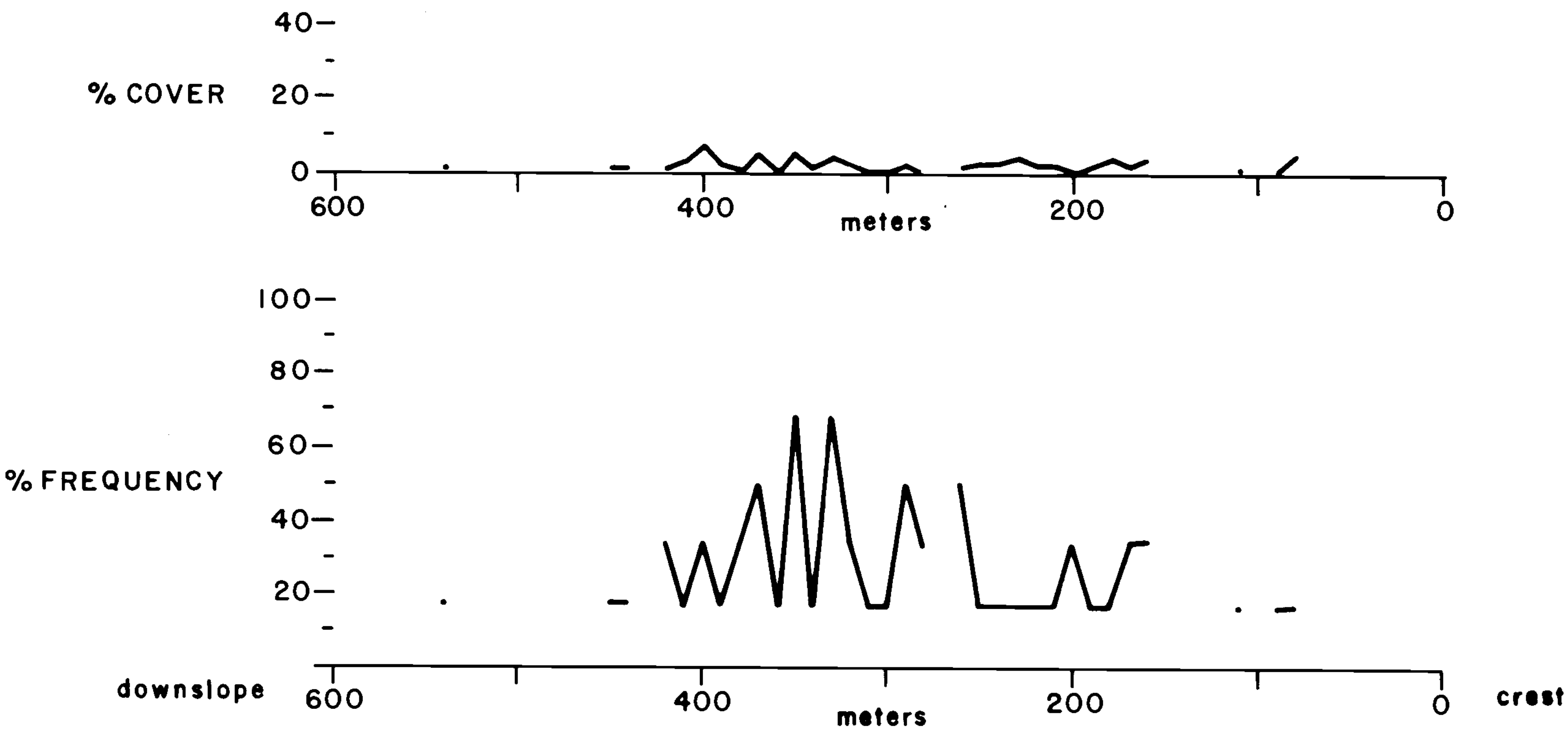

Figure 33. Direct ordination of _Trisetum spicatum_ based on distance from crest and average percent cover and frequency over the six transects.

this species declines at the south end of the grassland. Agoseris glauca var. dasycephala (Fig. 29), a small mountain dandelion, has a distribution similar to Trifolium longipes ssp. multipedunculatum and appears strongly in the lower slope vegetation on gravelly soil surfaces.

Among the grass species, Festuca idahoensis var. idahoensis (Fig. 30) and Poa sandbergii (Fig. 31), while nearly ubiquitous, have the highest frequency and average cover at approximately 100 to 300 meters from the crest and are considered dominants in the midslope vegetation segments. Although Sitanion hystrix var. hystrix (Fig. 32) is found throughout the grassland its composite cover and frequency indicate it is most common at the lower end of the topographic gradient. Trisetum spicatum (Fig. 33) is limited to the lower slope and is found in areas that have heavy winter snow accumulation.

Phytosociological Analysis Using CAPHY-PHYTO

CAPHY-PHYTO Programs

General Description. The Fortran IV programs CAPHY and PHYTO developed by J. J. Moore (1970) arrange relevés and species in a phytosociological table of species dominance estimates, usually cover/abundance measures, following the Braun-Blanquet procedure. These companion programs have been modified for use on the CYBER 70, KRONOS 2.1.2 operating system at the Oregon State University

Milne Computer Center. The program CAPHY prepares relevé data and stores it on disk for subsequent use in core by PHYTO. Both programs may be run together with a data set or CAPHY output stored to avoid repetitous runs of CAPHY, since nearly all user manipulation of the data is done through PHYTO.

The PHYTO options are typically carried out in three steps using several computer runs. The "autodivide" option allows the user to subdivide the relevé-species table on the basis of pairs of differential species, or those species pairs which tend to occur together most often in the relevés. Once the differential pairs are determined, the "differential" option is used to order species groups according to mutual exclusiveness. This procedure is aided through the information provided by the "autodivide" run and perhaps from ecological observation in the field. The phytosociological table in the vertical, or species, dimension may be organized in a preliminary way using the "differential" option. The "dictation" option is the final step in constructing the table. It merely allows the user to dictate the order of the relevés, the horizontal dimension, as well as the species for a final arrangement. The relevé ordering, for the most part derived from information from previous runs which list relevé order as part of the output, is the most important part of this phase of the analysis giving the computer-printed table a block-like structure which presents groups of relevés based on plant association.

Differential Algorithm. One of the preparatory procedures accomplished by CAPHY is to transform species dominance estimates, e.g., using Braun-Blanquet or Domin cover/abundance scales, or Daubenmire cover scale, by setting the lowest scale values to a user-selected constant, KNST (default = 10), and adding this constant to the remainder of the scale values. For example, the Braun-Blanquet scale (disregarding r) +, 1, 2, 3, 4, 5 would become 10, 11, 12, 13, 14, 15 when KNST = 10. The values recorded for species cover/abundance in the data set are transformed accordingly and transferred to disk.

When the "autodivide" option of PHYTO is in effect pairs of differential species are detected according to the following relationship:

$$D = C - S$$

where D is the measure of differentiality for each possible pair of species in the data collection. C is the sum of: 1) the combined transformed values of a species pair being tested when the two species occur jointly, i.e., in the same relevé, and 2) the transformed values of single occurrences of these species. These values are summed into C only when they are greater than or equal to 2 x (KNST). S, in the expression above, is the sum of the transformed values for single occurrences of species of a pair being tested when these values are less than 2 x (KNST).

The species cover scale employed in the present study is given in Table 9. When using this scale, setting KNST relatively high, e.g., KNST = 9, causes all joint occurrences of a given species pair to be summed in C and all

Table 9. Species cover class scale.

Cover Class	Field-Estimated Percent Cover Range
1	less than 5
2	5 - 12
3	13 - 22
4	23 - 32
5	33 - 47
6	48 - 72
7	73 - 87
8	88 -100

single occurrences to be summed in S giving a balanced value for D derived from the difference in value sums between joint occurrences and single occurrences. A value of KNST = 9 or less causes some of the single occurrences of species high in dominance in a pair being tested to be summed in C in addition to joint occurrences. For example, when KNST = 5, the maximum transformed value for species cover is 13 and the minimum 5, thus a single occurrence of a species with a value greater than 9 would be summed in C since 2 (KNST) = 10. Therefore D can vary significantly for a given species pair depending on the value of KNST and the degree of emphasis a user of CAPHY-PHYTO wishes to place on dominance in determining differential species. It is possible, by setting KNST relatively low, to give added weight to a species pair which not only occurs frequently but whose individual species have consistently high dominance (cover/abundance estimates) and occur frequently independent of one another. Since species in the recorded data set did not tend to have high cover estimates, setting KNST low in the autodivide option did not cause significant changes in the determination of differential species. Therefore, the default value KNST = 10 was used in the analysis.

Initial Arrangement of Grassland Association Table

A raw data table of 72 species and 346 (meter square) relevés or sample plots was scanned by PHYTO so that species with a frequency of from 10 to 60 percent only could be selected as differential species. In this range *Poa sandbergii* with 59.5 percent frequency and *Festuca idahoensis* with 52.9 percent frequency was the species pair with greatest mutual occurrence over the entire sample collection. These species occurred together in 40 percent of the relevés. In addition to *Poa sandbergii* and *Festuca idahoensis*; *Sitanion hystrix*, *Agosersis glauca*, and *Trifolium longipes* also have high constancy (greater than 50 percent frequency) in the data collection but are considered ubiquitous species characterizing the grassland alliance or the general vegetation type in the study area.

The frequency range for candidate differential species was subsequently narrowed to 10 to 50 percent. Then the PHYTO program was able to place the majority of relevés into two major groups with differential pairs *Erigeron compositus*-*Astragalus whitneyi* and *Spraguea umbellata*-*Trisetum spicatum* respectively. Over one hundred relevés remained outside these two groups and were run separately through the "autodivide" option of PHYTO. *Lupinus lepidus*-*Eriogonom ovalifolium* was identified as the differential species pair for most of the relevés in this third group.

This preliminary grouping was interpreted as being a division of the relevés into a ridge crest or snow deflation vegetation unit differentiated by *Erigeron compositus*-*Astragalus whitneyi*, a midslope or transitional unit differentiated by *Lupinus lepidus*-*Eriogonom ovalifolium*, and downslope or snow accumulation unit differentiated by *Spraguea umbellata*-*Trisetum spicatum*.

Diagnostic Species

After several runs using the "autodivide" and "differential" options of PHYTO on each of the three groups of relevés, it was possible to distinguish a group of character species for each vegetation unit. It was also possible to detect additional differential species for subgroups or relevés within the units, and to reassign relevés to a more appropriate unit when necessary. The final arrangement of plant associations within vegetation units is summarized in Table 10. The complete association table for the grassland is in Table 14 (in pocket). It was found that personal judgement based on field observation of species distributions and micro-environmental conditions was helpful in arranging relevés and identifying diagnostic species for some of the associations within the three major units.

Plant Communities

The nine floristic associations identified in Table 10 were mapped, Figure 34 (in pocket), as thirteen plant communities described as follows:

1. *Erigeron compositus-Astragalus whitneyi*
2. *Erigeron compositus-Astragalus whitneyi-Poa cusickii*

   Communities along the ridge crest subject to winds year-round, having little winter snow accumulation and relatively shallow, rocky soil.

3. Arenaria nuttallii-Castilleja steenensis
Arenaria nuttallii-Castilleja steenensis-Erigeron compositus-Astragalus whitneyi

Communities along crest exposed to high winds lacking winter snow accumulation.

5. Lupinus lepidus-Eriogonum ovalifolium

A midslope community of moderate winter snow accumulation with scattered grass (Festuca idahoensis) islands and areas of meltwater and wind erosion.

6. Festuca idahoensis inclusions

Vegetation almost entirely dense Festuca idahoensis cover; small patches scattered throughout midslope communities; only two large areas mapped; "islands" are typically surrounded by eroded surfaces.

7. Festuca scabrella

The characteristic grass, Festuca scabrella, has a scattered distribution among vegetation dominated by Festuca idahoensis and Poa sandbergii; a midslope community in north portion of grassland.

8. Helenium hoopesii Poa spp.

A midslope community with much exposed soil surface frequently lacking bunchgrass Festuca idahoensis.

9. Spraguea umbellata-Trisetum spicatum
10. Lewisia pygmaea-Draba sphaeroides-Spraguea umbellata-Trisetum spicatum
11. Arenaria aculeata-Sedum lanceolatum-Cerastium berringianum

Communities downslope in study area marked by heavy winter snow accumulation and subsequent spring snow cover persistence; most areas have extensive exposed surfaces, severe meltwater erosion, and relatively gravelly soils; bunchgrasses are lacking.

12. Agropyron caninum-Deschampsia cespitosa
13. Deschampsia cespitosa

Downslope communities apparently without persistent spring snow cover and with soil moisture maintained during growing season through seepage; Deschampsia cespitosa communities are usually associated with seasonal meltwater from adjacent snow patches.

Table 10. Summary of diagnostic species in the major vegetation units in the grassland. Groups of character species refer to plant associations in the grasslands.

Crest Deflation Unit
86 relevés

52 relevés:
- *Erigeron compositus*
- *Astragalus whitneyi*
- *Poa cusickii*
- *Senecio werneriaefolius*

34 relevés:
- *Arenaria nuttallii*
- *Castilleja steenensis*
- *Senecio fremontii*
- *Erigeron bloomeri*

Downslope Accumulation Unit
112 relevés

18 relevés:
- *Spraguea umbellata*
- *Trisetum spicatum*

42 relevés:
- *Lewisia pygmaea*
- *Draba sphaeroides*

28 relevés:
- *Agropyron caninum*
- *Potentilla diversifolia*
- *Deschampsia cespitosa*
- *Aster alpigenus*
- *Carex phaeocephala*

24 relevés:
- *Arenaria aculeata*
- *Sedum lanceolatum*
- *Cerastium berringianum*

Midslope Transition Unit
112 relevés

54 relevés:
- *Lupinus lepidus*
- *Eriogonum ovalifolium*

28 relevés:
- *Festuca scabrella*

30 relevés:
- *Helenium hoopesii*
- *Poa* spp., *sandbergii* group

Undifferentiated
36 relevés

***Subalpine Grassland Alliance Species**

- *Poa sandbergii*
- *Festuca idahoensis*
- *Sitanion hystrix*
- *Agoseris glauca*
- *Trifolium longipes*

*Ubiquitous species characterizing the grassland as a whole.

All the communities listed above are derived from association or sub-associations apparent in Table 14 (in pocket) with the exception of No. 7 which is considered a mappable inclusion in midslope areas.

It should be noted that the nearly ubiquitous character species that make up the grassland alliance, with the exception of Sitanion hystrix, have frequency patterns related to their distribution in the three major community areas: snow deflation (crest), transition (midslope), and snow accumulation (downslope). The bunchgrasses, Poa sandbergii and Festuca idahoensis, occur with greater frequency at mid and upper slopes and have significantly low frequencies in the Spraguea umbellata-Trisetum spicatum communities in the accumulation unit. These grasses, especially Festuca idahoensis, form the relatively dense islands in midslope areas. Agoseris glauca, the small tap-rooted composite, and Trifolium longipes, a low-growing clover, have a tendency to occur at mid to lower slopes in the transition and accumulation areas. Agoseris glauca is particularly characteristic of broad surfaces of apparent wind and meltwater erosion. Trifolium longipes has greatest dominance in the accumulation areas.

Deflation Communities. The deflation communities along the crest are in a narrow continuous belt between Kiger Gorge and Wildhorse Canyon. The ground surface in this belt is, for the most part, exposed fractured basalt with only a few areas of shallow soil development. The higher velocity winds at the ridge crest contribute to winter deflation of snow and the subsequent early exposure of the ground surface in spring to extreme diurnal temperatures. Another environmental factor affecting vegetation along the crest is intense wind erosion and dessication in summer months. The plant communities here are characterized by small, caespitose, stout-rooted and -branched species such as Erigeron compositus, Arenaria nuttallii, Senecio werneriaefolius, and Senecio fremontii. A grass, Poa cusickii, is abundant where soil conditions permit and there appears to be some protection from wind.

Transition and Midslope Communities. Between the deflation crest area and downslope area of persistent snow cover are communities, that while distinct, have characteristic species which tend to occur in adjacent deflation and accumulation communities. Lupinus lepidus-Eriogonum ovalifolium and Helenium hoopesii and the typical differential species of the transition communities. However, Lupinus lepidus and Eriogonom ovalifolium occur in deflation communities, particularly the Arenaria nuttallii Castilleja steenensis community, as well as in accumulation communities, particularly the Spraguea umbellata-Trisetum spicatum community. Helenium hoopesii, a relatively tall composite prominent on the landscape, is primarily distributed at midslope and associated in part with Lupinus lepidus and Eriogonom ovalifolium, but occurs in downslope communities as well. The association table, Table 14 (pocket) shows the extended distribution of the transition community character species.

An areally small, but distinct, community type making up part of the midslope vegetation unit is characterized by a grass, Festuca scabrella, and is restricted to the northern portion of the grassland. The ubiquitous bunchgrass, Festuca idahoensis, is important in these Festuca scabrella communities. Typically Festuca idahoensis individuals are quite dense compared to Festuca scabrella which is scattered throughout the community.

Accumulation Communities. The species characteristic of areas of heavy snow accumulation in winter and subsequent persistence in spring are primarily Spraguea umbellata, a prostrate, fleshy-leaved species (Portulacaceae), and the grass, Trisetum spicatum. Sometimes associated with Spraguea umbellata-Trisetum spicatum are 1) Lewisia pygmaea, similar in general structure to Spraguea umbellata, and 2) Draba sphaeroides, a small mustard, which forms its own association in the same habitat. Both of these communities, Spraguea umbellata-Trisetum spicatum and Lewisia pygmaea-Draba sphaeroides cover extensive areas downslope in the south portion of the study area.

Generally, the Lewisia pygmaea-Draba sphaeroides and Spraguea umbellata-Trisetum spicatum communities do not provide much vegetation cover and occupy areas of gentle slope and flat, gravelly surfaces. The lingering snow cover and coarse soil, which becomes dry rapidly after spring snow melt, are conditions apparently not conducive to bunch-grass growth since Festuca idahoensis and Poa sandbergii have conspicuously low amplitudes in these xeric areas.

Included in the accumulation areas are communities that consistently occur downslope but apparently have either less average winter snow accumulation or more soil moisture throughout the growing season from seepage and snowpatch runoff, or both. The Arenaria aculeata-Sedum lanceolatum-Cerastium berringianum community is found at the head of Big Indian Canyon and is related to the Spraguea umbellata-Trisetum spicatum community except that it is on relatively steep, rocky ground and has less snow accumulation. The communities where water seepage or meltwater is present from the few snowpatches that remain into the growing season are characterized by grasses Deschampsia cespitosa and Agropyron caninum. These communities are found primarily in the north section of the grassland between Kiger Gorge and Little Blitzen Canyon although two or three sites of this type are found in the lower grassland at the head of Big Indian Canyon. Other species in these wetter sites are Potentilla diversifolia, Carex phaeocephala, Carex raynoldsii, Aster alpigenus, Juncus drummondii, Deschampsia atropurpurea, Festuca ovina, Caltha leptosepala. Agropyron caninum as a dominant grass has only been observed in the north section.

Synthesis of the Ordination and Phytosociological Analysis

The ordination of six transects totalling 278 sample plots or stands resulted in the identification of vegetation segments between the mountain crest and the west edge of the study area: 1) Astragalus whitneyi-Erigeron compositus-exposed crest, 2) Festuca idahoensis-Poa sandbergii-Festuca scabrella - midslope bunchgrass, 3) Lupinus lepidus-Trifolium longipes with Festuca idahoensis and Poa sandbergii - sparse midslope segments, 4) Sitanion hystrix-Trisetum spicatum with Agoseris galuca and Arenaria aculeata - sparse downslope segments of winter snow accumulation. Direct ordination of important species supplemented the stand ordination in revealing the relationship of species distributions to upper, mid, and lower portions of the topographic gradient. From these relationships, responses to vegetation composition and cover to the environmental factors of winter snow accumulation, effective growing season, and wind and meltwater erosion can be inferred.

The plant association analysis using CAPHY-PHYTO in the initial stage of grouping relevés according to differntial species pairs, divided the collection of 346 samples or relevés into three major vegetation units corresponding to the environmental variation suggested by the ordination analysis: 1) relevés in exposed crest or deflation areas, 2) relevés at midslope generally representing bunchgrass areas but including extensive areas of flat, sparsely vegetated surfaces, 3) relevés downslope in areas of heavy winter snow accumulation. This not only fortified the ordination results but expanded interpretation of vegetation variation along the topographic gradient. For example, from the distribution of midslope character species in the association table (Table 14, in pocket) it is possible to describe the midslope vegetation as transitional between crest and downslope vegetation. Although there is significant representation of the grassland alliance species *Poa sandbergii* and *Festuca idahoensis* here as there is farther upslope, the crest character species become uncommon while the species *Lupinus lepidus* and *Eriogonum ovalifolium*, which have significant representation (48 and 27 percent frequency respectively) in crest communities, are identified as differential species at midslope. *Lupinus lepidus* and another differential species of a midslope community, *Helenium hoopesii*, are found in downslope communities (at 16 and 30 percent frequency respectively) as well. The table also shows the extension of the differential species *Spraguea umbellata* and *Trisetum spicatum* of the downslope community into midslope areas further reinforcing the description of the midslope communities as floristically and environmentally transitional in character.

Continued tabular analysis produced several plant associations which remained within the classification framework suggested by ordination analysis (Table 10). All nine plant associations recognized were related to an appropriate segment of the environmental gradient. Considering supplemental interpreted vegetation cover information from aerial photographs and field observations the grassland was finally divided into 13 mappable community types (Fig. 34, in pocket).

V. ANALYSIS OF VEGETATION RELATED ENVIRONMENTAL FACTORS

Snow Depth and Cover

Effect of Snow Depth

One of the elements affecting vegetation pattern in subalpine grassland on Steens Mountain is the depth and persistence of winter snow cover. In general, snow depth within the grassland study area increases with distance from the crest. Exposure of the crest to high winds is inimical to heavy snow accumulation and contributes to deflation of the snow that is able to temporarily cover the area. As a result, the relatively thin snow cover is removed by melting and/or evaporation relatively early in the spring. The crest ground surface is exposed at this time of year to strong winds and extreme cold temperatures -- conditions not conducive to plant establishment and growth. Downslope, where snow accumulates more readily, perennial vegetation is protected from desiccating winds and cold temperatures by a moderating snow cover which persists until late in spring. In areas still farther downslope where snow tends to accumulate to its greatest depth the effective growing season is significantly shortened, restricting vegetation to a few adapted species. The effect of meltwater erosion is most noticeable here as evidenced by the eroded soil surfaces.

Winter snow depth measurements, represented graphically in Figure 35 for five different slope locations in the grassland, substantiate the general snow depth distribution described above. The data were taken at twelve sites at three dates during the 1972-1973 snow season. Snow depth increased at nearly all sites over the period of measurement. The exception is at the crest sites where there was a slight decrease in accumulated snow for the spring date probably due to a high melting and evaporation rate at the crest. Snow depth was consistently greater on a given date the more distant the measurement sites were from the crest, ranging from approximately 50 centimeters at the crest to 180 centimeters or more downslope. The map, Figure 8, p. 59, shows the location of snow measurement sites.

Snow Cover Recession

With the snow accumulation and depth differential from crest to slope, it is expected that the release of vegetation from snow cover would progress downslope. To support this contention, LANDSAT-1 satellite data were analyzed for four spring and early summer dates in 1974 and one in 1973 in order to outline the typical pattern of snow cover recession. Multi-spectral scanner (MSS) digital data for

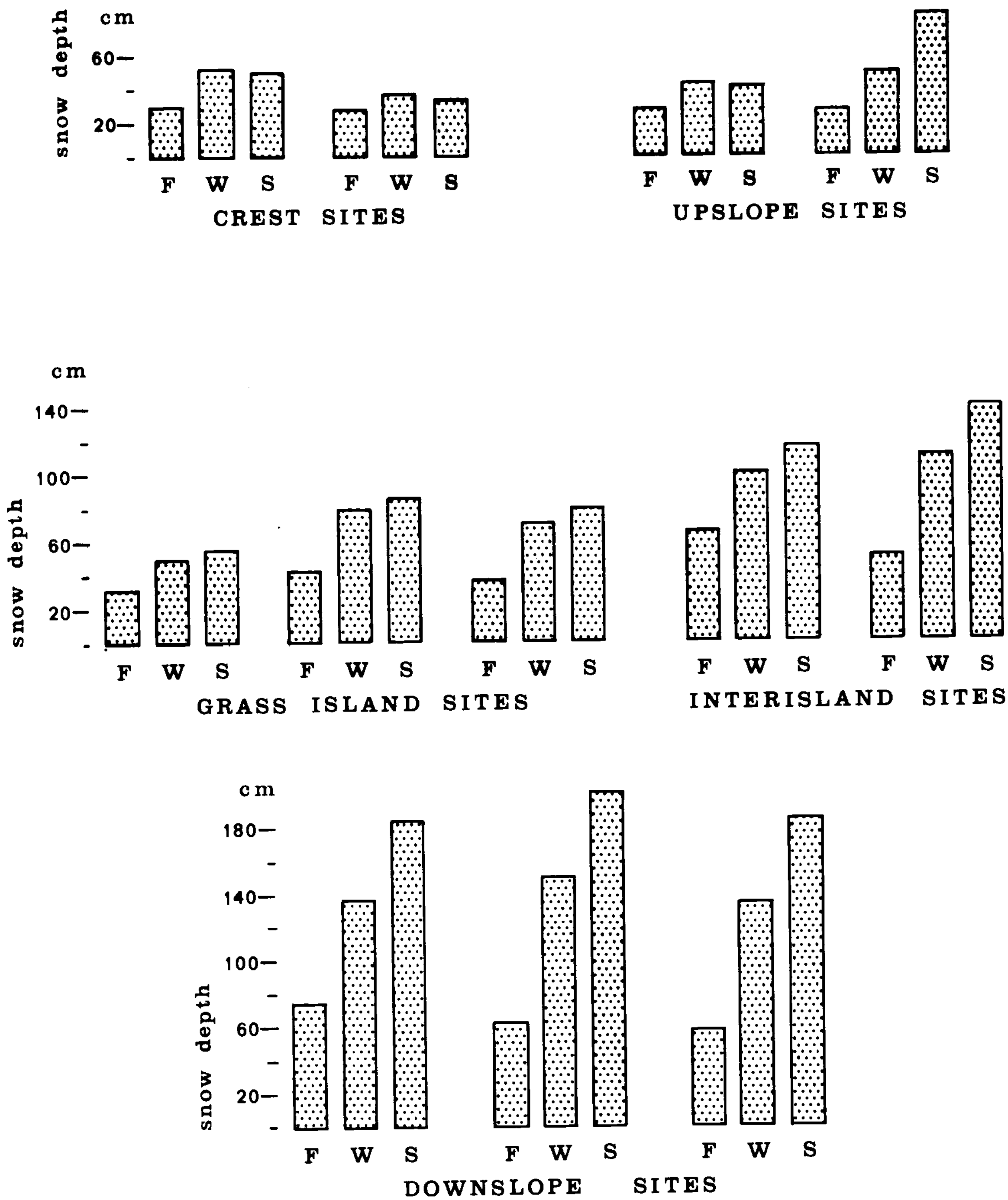

Figure 35. Snow depth measurements Steens Mountain subalpine grassland. F = Nov. 23, 1972. W = Jan. 28, 1973. S = March 25, 1973. The map, Figure 8, shows the locations of measurement sites.

the study area were processed using the PIXSYS computer programs developed at Oregon State University (Simonson, *et al.*, 1974). Levels of reflected solar energy detected and recorded by satellite at a resolution size of 0.47 hectare are represented pictorially by the various symbols on computer line printer output maps, Figures 36 and 37. Snow surfaces have characteristically high reflectivity in the MSS Band 5 (0.5 to 0.6 microns) and this was useful in contrasting snow cover with non-snow covered surfaces. The computer procedure recognized those portions of the mountain having high reflectivity on four sequential dates: 4 May 1974, 9 June 1974, 27 June 1974, and 2 July 1973. Snow covered areas for each date are depicted as blank areas on the maps; snow-free areas having lower levels of reflectivity are represented by various symbols. For a given date, the extent of snow cover is apparent.

The Figures 36a through 37b show that, except for canyon bottoms and some steeper slopes, the highest portion of the mountain along the crest becomes snow-free first. It is evident that the snow remains longest in pockets and on slopes that are protected from prevailing winds and prolonged periods of direct sunlight. The area between the head of Little Blitzen and Big Indian Canyons is rugged in rocky micro-relief and less uniform than the area along the crest of the mountain. Small patches of accumulated

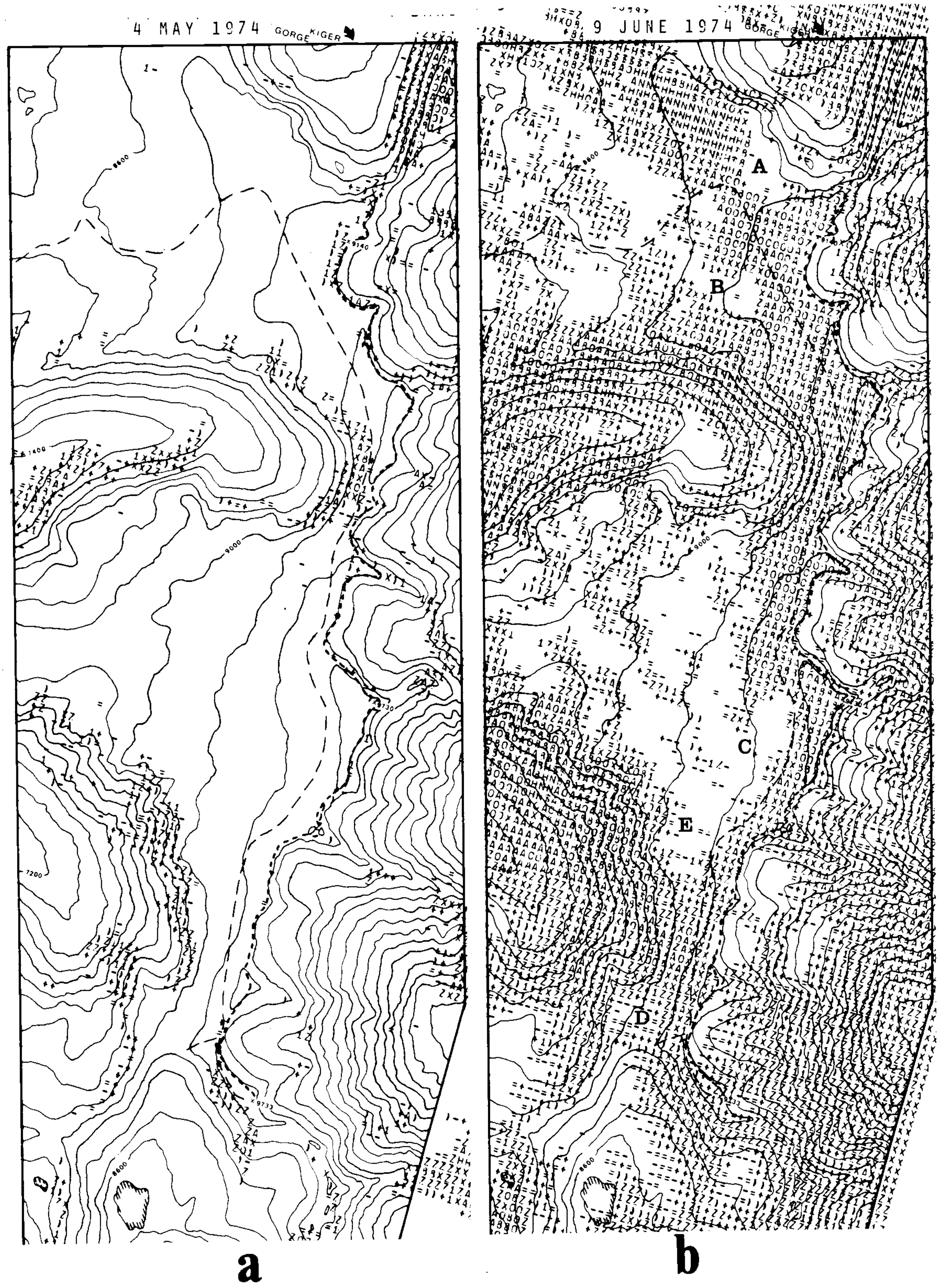

Figure 36. LANDSAT-1 snow cover maps, 4 May and 9 June 1974, Steens Mountain. Blank areas represent snow cover; characters snow-free areas. Scale: one centimeter represents 500 meters.

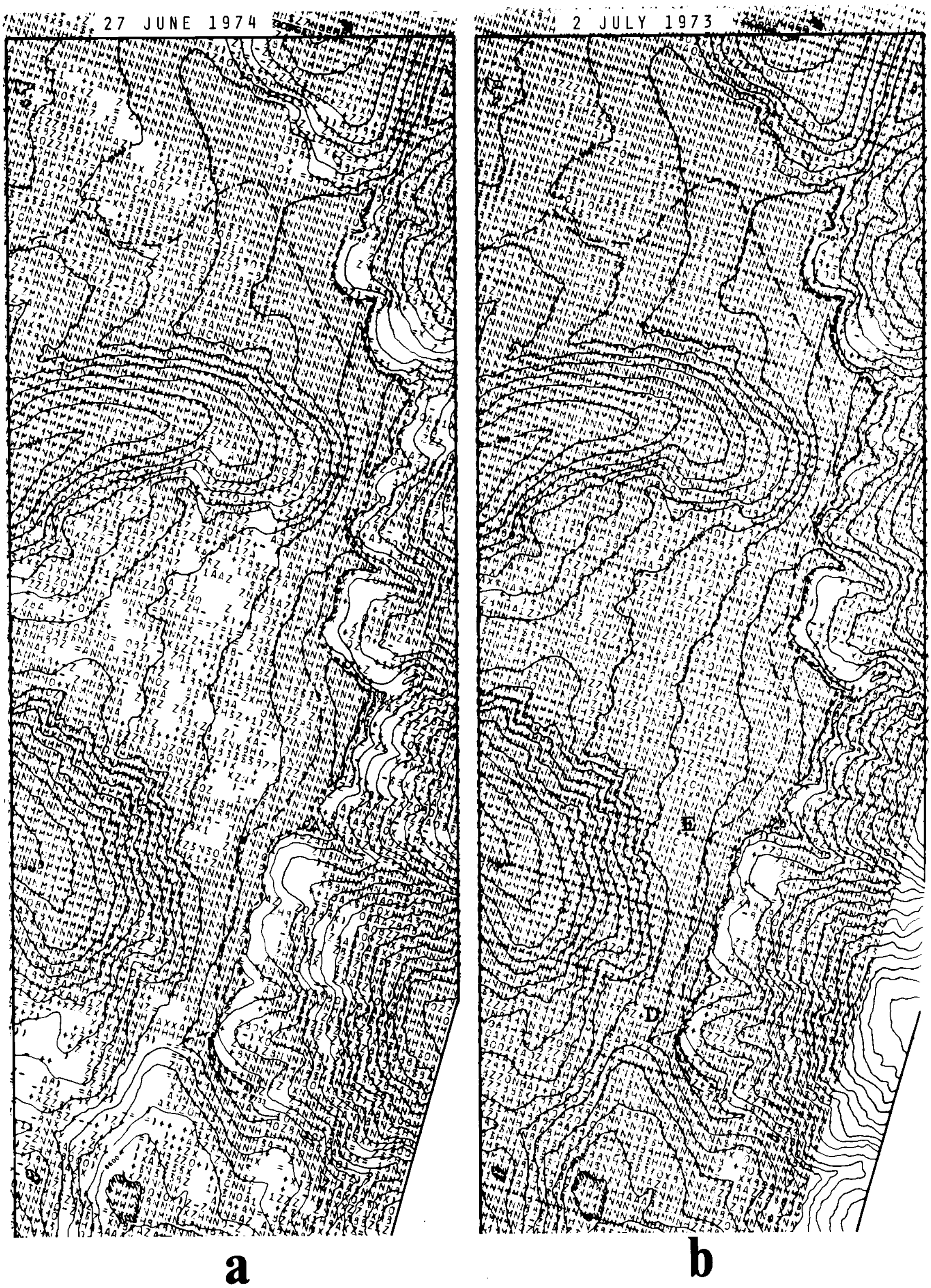

Figure 37. LANDSAT-1 snow cover maps, 27 June 1974 and 2 July 1973, Steens Mountain. Blank areas represent snow cover; characters snow-free areas. Scale: one centimeter represents 500 meters

snow persist here as shown on the 27 June 1974 map, Figure 37a.

On the May 1974 map, Figure 36a, some snow-free surfaces are apparent particularly on the narrow portion of the grassland between Little Blitzen Canyon and the cirque walls at the head of Willow Creek and at certain points along the crest. These represent areas of little snow accumulation during winter and are marked by *Erigeron compositus*-*Astragalus whitneyi* or deflation plant communities (Fig. 34). As the snow cover recedes downslope, Figure 36b, more of the upper slope is exposed with snow patches remaining in areas A, B, C, and D. The snow at point A lies in a depression at the head of Kiger Gorge and marks the north end of the study area. Surface meltwater and seepage from this area provides moisture well into the growing season to the *Agropyron caninum*-*Deschampsia cespitosa* and *Deschampsia cespitosa* communities just to the southwest which are without snow cover at this early June date. Snow in area B spatially corresponds to a *Spraguea umbellata*-*Trisetum spicatum* community which is the typical community of snow accumulation areas. The snow in area C is overlying *Spraguea umbellata*-*Trisetum spicatum*-*Lewisia pygmaea*-*Draba sphaeroides* communities; *Festuca idahoensis* grass islands occur at the upper edge of the snow extent in this area (Fig. 4). Area D is a snow accumulation depression at the head of Big Indian Canyon at the base of the steepest slope in the grassland. A small portion of this persistent snow remains well into the growing season supplying a Deschampsia cespitosa community with meltwater; a similar situation occurs at E. Note the + symbols at D and E in Figure 37b, 2 July 1973, indicating that small patches of snow are still affecting the reflectivity at those points and LANDSAT-1 is recording a slightly higher value in Band 5 than the surrounding area.

By July, snow in the grassland is virtually gone but the vegetation on the landscape reflects the variation in depth and recession pattern of winter snow cover. Figure 38 is a view of communities near East Rim View. In the foreground is a Lupinus lepidus-Eriogonum ovalifolium community, with a strong component of Ivesia gordonii, and to the left center near the road and in the center of the scene (lighter areas) are Festuca idahoensis grass islands. Both of these communities are typical at midslope. Downslope, to the right of center, is a Spraguea umbellata-Trisetum spicatum-Lewisia pygmaea-Draba sphaeroides community (darker areas) where winter snow accumulation is heavy. Figure 39 is a view of Erigeron compositus-Astragalus whitneyi communities (lighter areas) along the crest near the south end of the ridge. Extreme wind deflation and lack of winter snow cover creates a windswept environment and vegetation is typically sparse but with a significant component of bunchgrass.

Figure 38. Plant communities near East Rim Viewpoint. Lighter areas in background are grass dominated. Down slope areas (darker) to the right are snow accumulation plant communities. Foreground is a Lupinus lepidus-Eriogonum ovalifolium community with a strong component of Ivesia gordonii.

Figure 39. Crest or snow deflation plant communities near south end of grassland. Lighter areas are *Erigeron compositus*-*Astragalus whitneyi* communities with a bunchgrass component.

Soil Characteristics

Generally, soil throughout the Steens Mountain subalpine grassland is not well developed. It is extremely stoney, lacks horizon development, and may be provisionally classified as a Lithic Cryoboroll (p. 12).

Soil Depth

Soil varies in depth from small, shallow pockets along the crest a few centimeters deep to extensive areas farther downslope measuring 60 centimeters in depth at sampled sites. Due to the exposed, deflated environment of the crest the shallowness and sparseness of the soil cover is to be expected. Downslope areas have soil of greater depth with erosion channels along lines of meltwater runoff. These erosion channels have been observed as deep as 150 centimeters. It is suggested that much of the soil in the downslope area is recent depositional material derived from either upslope wind or water erosion rather than developed in place.

Average soil depth at the crest, where soil occurs, is about 26 centimeters. In grass islands it is about 53 centimeters; between grass islands 33 centimeters. At midslope in areas without grass islands and in downslope areas average soil depth is about 38 centimeters (Table 11).

Table 11. Soil texture and depth grouped by ecological area.

Ecological Area and Sample Site Number		Percent				Approximate Depth to Bedrock (cm)
		Sand	Silt	Clay	Coarse*	
Downslope	8	59	33	8	44	35
	12	53	33	14	51	45
	15	59	37	4	58	35
Midslope	3	55	41	5	40	35
	6	50	41	9	59	35
	14	61	34	5	48	45
Between grass islands	2	61	34	5	34	30
	10	60	31	9	52	35
Grass islands	1	46	50	4	33	45
	7	48	47	5	52	60
	9	52	39	9	31	50
	11	51	40	9	43	55
Crest	4	48	44	8	40	30
	5	58	30	12	43	25
	13	54	38	8	30	25

*Percent weight of portion of sample greater than 2 mm in size.

Soil depth correlates with vegetation composition and cover. Vegetation is sparse at the crest and increases in density downslope; at least until persistent snow cover influences the type and cover. Mat-forming plants with tap roots capable of penetrating cracks are typical of the crest whereas dense bunchgrass species with more ramified root systems are more common at midslope where wind action is less and a moderating winter snow cover is more protective of vegetation and soil surfaces. Vegetation surfaces at midslope are less subject to severe wind and meltwater erosion and therefore soil develops to its greatest depth. Here bunchgrasses are the most abundant plant types. Farther downslope, where snow accumulation is greatest soil surfaces are usually sparsely vegetated with little bunchgrass due to a diminished growing season in addition to action of meltwater erosion. Soil, while not very shallow, is less deep than in the grassy areas at midslope.

Soil Texture

Texture analysis of composite soil samples without the coarse fraction (>2mm particle size) from the fifteen sites in the grassland reveals almost all sites have sandy loams, Figure 40.

Although soil texture is much the same throughout the grassland, there is some variation in texture among soil samples collected in the five ecological areas: 1) down-

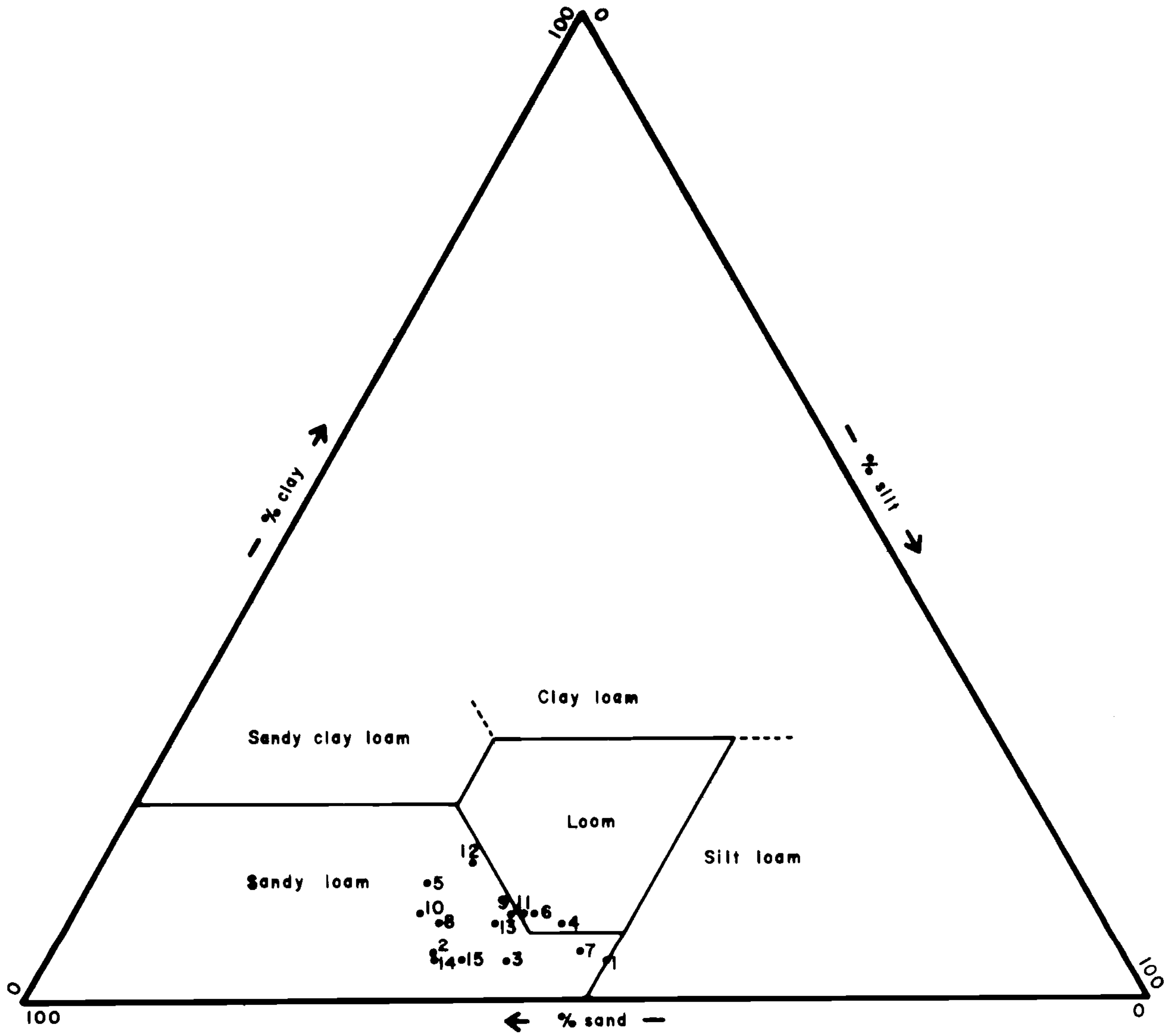

Figure 40. Soil texture classification diagram for fifteen sites in Steens Mountain subalpine grassland.

slope, 2) midslope, 3) mid to upper slope between grass islands, 4) grass islands, and 5) crest. Table 11 groups soil sample sites by area. Soil sampling sites are approximately located on the map, Figure 8, page 59. Sites between grass islands and sites downslope, areas subject to snow accumulation and/or meltwater erosion, have soils which tend to have a relatively higher proportion of sand. Midslope and grass islands (found at midslope) have less sand and higher proportion of silt. These slightly finer soils of the grassy areas may be due to the stability of the soil surface which is protected from erosion and the interaction of roots with soil particles. Also, except for one site, the soil sampled in the grass islands has a lower percentage of coarse particles than in other areas.

Soil Moisture

Soil moisture measurements as percent of dry weight were taken from soil samples collected during the 1972 and 1974 growing season. Rainfall in the area during July, 1974 was above normal and three to four centimeters of snow fell in the study area on July 11. This precipitation is reflected in the steeper seasonal moisture curves for 1974, Figure 41, when compared to the 1972 season curves. Normally, summers lack significant precipitation and soil dries rapidly after rain under the influence of evaporation and plant transpiration. Although moisture levels are

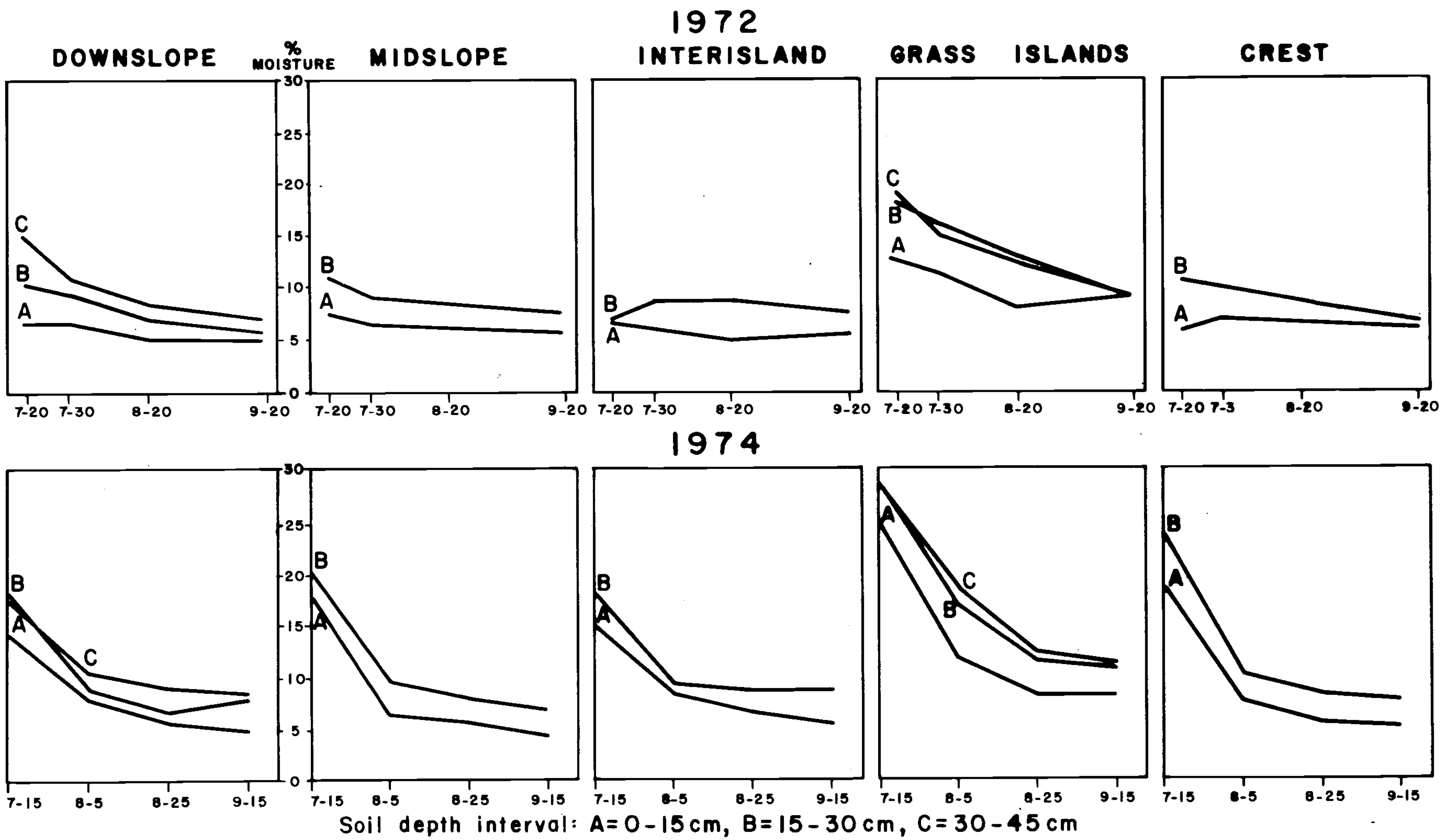

Figure 41. Average percent soil moisture curves for five ecological areas in Steens Mountain subalpine grassland, 1972 and 1974 growing season.

initially high in 1974 they rapidly fall to levels equivalent to those of 1972 in August and September.

The soil moisture curves in Figure 41 are average curves for two to four sampling sites in each area described. In both years, 1972 and 1974, soil moisture in all areas except grass islands decreased to between five and ten percent by mid September. In the densely vegetated grass islands moisture was retained for a longer time and dropped to between eight and twelve percent by mid September. Apparently midslope, interisland (between large, prominent grass islands), and crest areas have similar soil moisture regimes. The relatively coarse soil in these areas dries out rapidly bringing soil moisture levels to around five to ten percent at all depths. Downslope and grass island areas have slightly higher moisture through the growing season particularly at greater soil depths. In downslope areas the moisture is a result of greater snow accumulation and runoff. Soil moisture depletion occurs later in the summer. No evaluation was attempted of the soil moisture that might have been in crevices or associated with coarse debris.

Soil Moisture Retention

Soil moisture retention curves were constructed to determine differences in the moisture retention characteristics of soils in the five ecological areas. Assuming that

15 bars approximates the soil suction of most plants at the point of permanent wilting (Brady, 1974: 191), the percent soil moisture by weight in a soil sample at 15 bars reflects the percent moisture level at which plants in the field associated with that soil type come under moisture stress.

The moisture retention curves, Figure 42, indicate that plants in all areas except the grass islands may experience moisture stress when soil moisture levels reach approximately nine to thirteen percent. Grass island vegetation appears under moisture stress when percent moisture is approximately 20 percent. If this is the case, the soil moisture data for 1972 indicate there was insufficient soil moisture available in the root zone after mid-July for all areas sampled. The possible exception would be downslope where the soil below the surface remained above ten percent until the first week in August. From the data collected in 1974 it appears sufficient moisture was available to plants two to three weeks longer in all areas.

The data suggest that moisture availability or non-availability varies considerably from year to year depending on precipitation amounts, seasonal pattern, and occurrence and snow melt conditions. Also, the 15 atmosphere index for permanent-wilting point was intended for crop plants. Native plants in the field may reach maturity rapidly and thus may have a higher tolerance of soil moisture depletion. Therefore, without intensive additional

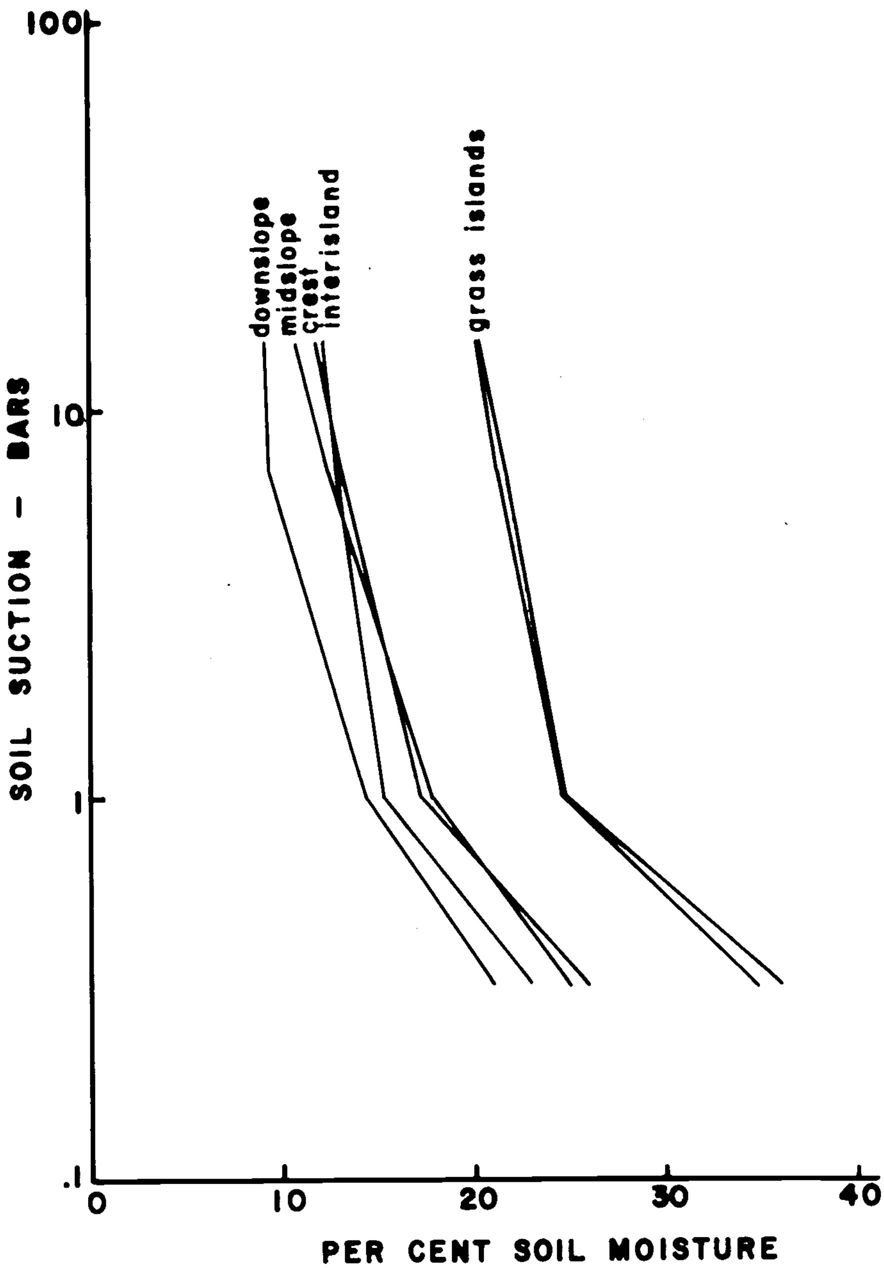

Figure 42. Soil moisture retention curves for five ecological areas. Soil moisture measurements taken at 1/3, 1, 7, and 15 bars.

in-field testing it is difficult to determine when, if at all, moisture stress is experienced by species in the subalpine grassland environment.

Summer Temperature Characteristics

Long-term annual temperature data for Steens Mountain proper is non-existent. The nearest climatic stations to the mountain are located near Andrews Weston Mine and P Ranch (Fig. 1). Normal monthly or annual average temperature and precipitation figures are not compiled for these stations due to short or intermittent data records. Daily temperature data recorded from July 12 to October 14, 1974 in the study area were compared with data for these two nearby stations for the same period (U.S. Environmental Data Service, 1974). A comparative summary of mean maximum and mean minimum temperatures for the recording period are given in Table 12. Complete daily data for the study area are in Appendix C.

For August, the peak of the subalpine growing season, daily maximum temperatures averaged approximately 18.7°C and daily minimum temperatures averaged approximately 6.3°C. The low temperature mean was nearly the same for P Ranch at the western base of the mountain, but daily high temperatures in the subalpine area typically were 10°C lower. Andrews Weston Mine, near the eastern slope base, had both higher daily maximum and higher minimum temperatures than

Table 12. Comparison of mean minimum and mean maximum temperatures (°C) with nearby stations, Summer, 1974.

	Study Area		Andrews-Weston Mine		P Ranch	
	mean max.	mean min.	mean max.	mean min.	mean max.	mean min.
July 12-31	22.1	8.4	30.8	16.5	30.8	9.1
August 1-31	18.7	6.3	28.5	14.3	28.8	6.3
September 1-30	15.7	3.9	26.4	11.5	28.6	0.4
October 1-14	9.2	-1.0	19.6	4.9	22.7	-2.8

the subalpine station. One would expect lower minimum temperatures than were recorded in the study area considering the elevation, however, the higher minimums may be due to the fact that the recording instrument was not in a standard climate data recording shelter but positioned on the ground in the shade of rocks. Nocturnal heat radiation from from the rocks may have caused a higher temperature to be recorded as the minimum. However, overlooking this possibility, it may be that the minimum temperatures may be explained by the recurring development in the late summer of a nighttime temperature inversion. August daily minimum temperatures averaged nearly the same as the P Ranch station and September minimum temperatures were higher at the subalpine recording site (Table 12). The data for the first half of October, 1974 suggest the same comparative temperature trend for that month also. The minimum figures for Andrews Weston Mine (elevation 1460 meters) in the summary table indicate even warmer nighttime temperatures on the lower east face of the mountain.

Although no firm interpretation can be made due to the scarcity of climatic data, it appears that the summer minimum and maximum daily temperatures in the summit ridge area of Steens Mountain are only moderately extreme, ranging 10° to 15°C and are comparable to P Ranch station except that daily maximum temperatures tend to be cooler by a few degrees. Only occasionally do summer temperatures fall below 0°C at night in the grassland. These moderate temperature conditions are a favorable factor to the rapid seasonal development of the subalpine vegetation.

Topography and Wind

The nature of the topography in and surrounding the study area has a great influence on the vegetation pattern. The huge canyons as well as the large cirques on the eastern escarpment channel wind in persistent currents up and over the subalpine grassland. Greatest velocities of wind are at the rims of these features and this is reflected in the deposition of winter snow which is thin on ridges and rims of escarpments (except for cornices) and deeper on flat open, as well as protected, slopes. The snow depth pattern in turn influences the density and composition of the subalpine vegetation. The length of the effective growing season and the rate of drying of the soil as determined by the timing of snow release are important environmental factors indirectly influenced by winter wind patterns.

Spring and summer wind over the local topography are assumed to be similar to winter patterns. Cold early spring winds on exposed surfaces apparently limit the vegetation to only a few species such as Erigeron compositus, Astragalus whitneyi, and Arenaria nutallii. The crest line is constantly being deflated in summer leaving little possibility of soil development, further adding to the sparseness of the vegetation. The resulting rockiness adds to the paucity of persistent snow cover at the crest caused, in addition to deflation, by the rapid heating of the surface during the day in early spring and re-radiating heat at night melting adjacent snow.

General slope and aspect of the grassland varies little so that differences due to exposure to sunlight or prevailing wind are not apparent. Most important for the vegetation pattern is the relatively wind-sheltered downslope area contrasted with unsheltered crest area.

VI. SUMMARY AND CONCLUSIONS

Summary

The relationship of the subalpine grassland vegetation on the summit ridge of Steens Mountain to snow cover and depth, selected soil characteristics, topography, and other climatic elements has been the central concern of this research. Both transect and areal vegetation sampling in the study area between Kiger Gorge and Wildhorse Canyon provided a dual data base for analysis of vegetation segmentation. Both indirect ordination and tabular plant association techniques were applied in a complementary manner to identify plant communities.

Selected similarity indexes commonly used by plant ecologists in vegetation ordination of sample units (stands) were compared using a combination of hypothetical and Steens Mountain data. For this study, it was concluded that the Sorensen (1948) similarity index demonstrated the best stand grouping attributes among the similarity indexes compared when species dominance values were retained rather than presence-absence data. Subsequent ordination of 278 samples along six transects for the purpose of identifying stand groupings, revealed vegetation segments within three areas along a topographic gradient: upper slope and crest segment (dominated by *Astragalus whitneyi*, *Erigeron* *compositus*); mid-slope segments (dominated by *Festuca idahoensis*, *Poa sandbergii*, *Lupinus lepidus*, *Trifolium longipes*); and lower slope segments (dominated by *Trisetum spicatum*, *Sitanion hystrix*, *Agoseris glauca*, *Arenaria aculeata*). Vegetation analysis, following the principles of Braun-Blanquet, was applied to the 346 areal sample units (relevés) from which nine plant associations were identified. These nine associations, grouped within three vegetation units are associated with snow deflation and snow accumulation and are related to slope position. The units are respectively: Crest Deflation Unit, Midslope Transition Unit, and Downslope Accumulation Unit. For mapping purposes, associations were combined in some cases resulting in the designation of thirteen plant communities (p. 127). These mapping communities may be arranged in order of their release time from snow cover in a normal year, Table 13.

The two-step variation ordination-tabular plant association analytical procedure proved to be compatible with the objectives of the research. The classificatory use of ordination, i.e. the identification of stand groups in a two-dimensional similarity array, together with supplemental direct ordination of key species along the slope gradient, suggested a vegetation pattern related to topography. The Braun-Blanquet association table allowed a more detailed breakdown of the vegetation within this

Table 13. Relative release date of communities from snow cover in the Steens Mountain subalpine grassland.

mid to late April	Arenaria nuttallii-Castilleja steenensis Arenaria nuttallii-Castilleja steenensis-Erigeron compositus-Astragalus whitneyi Erigeron compositus-Astragalus whitneyi Erigeron compositus-Astragalus whitneyi-Poa cusickii
late May	Helenium hoopesii-Poa spp. Festuca scabrella Festuca idahoensis (grass islands) Lupinus lepidus-Eriogonum ovalifolium
early June	Agropyron caninum-Deschampsia cespitosa Deschampsia cespitosa Arenaria aculeata-Sedum lanceolatum-Cerastium berringianum
late June	Lewisia pygmaea-Draba sphaeroides-Spraguea umbellata-Trisetum spicatum Spraguea umbellata-Trisetum spicatum

pattern into nine plant associations. This enhanced the description of the vegetation.

Snow depth measurements in winter and early spring substantiated the general pattern of snow deposition relative to topography: winter snow accumulation increased with distance from the crest within the study area. The spring recession of snow, first from the crest and later in downslope areas, was verified by LANDSAT-1 digital data for selected spring and summer dates. It was possible to broadly correlate early snow-free areas on digital representations with deflation plant communities and late snow-free areas with accumulation communities.

Lack of soil development, occurrence of erosion, and soil drought are factors affecting vegetation pattern in the Steens Mountain subalpine grassland. Nowhere in the study area did soils exhibit profile development or considerable depth (maximum depth was 60 cm). Erosion from meltwater and wind is evident. Soils tend to be shallowest near the crest and deeper downslope, but with the deepest occurring in association with the grass "islands" at midslope. The "islands" are apparently remnants of a more extensive dense grass cover that existed before heavy domestic summer grazing began in the area in the late nineteenth century. Percent soil moisture and soil moisture retention curves indicate that all plant communities within the study area are subject to moisture depletion by mid-summer with little, if any, soil moisture available after that time. Most plants reach seasonal maturity by this time. Soil moisture data collected in 1972 and 1974 suggest that summer season moisture availability is extremely variable from year to year and is dependent on the occurrence of late spring rains. Plant moisture stress early in the growing season, mid-June to mid-August, may be deleterious to the vegetation. If such a condition were to recur frequently, young plants would have difficulty surviving. Coarse soil texture, especially in eroded areas, contributes to the rapid depletion of available soil moisture.

Conclusions

The distribution of plant communities in the subalpine grassland on Steens Mountain is related primarily to differential winter snow deposition. Plant communities at the crest are released from snow cover early in spring and those communities farther downslope are released in late spring or early summer. Differential exposure and protection is a result of the snow recession pattern and has a marked effect on plant community composition and productivity. Drought conditions for plants after snow melt is considered a critical factor in the establishment and maintenance of vegetation in the area. The typically well-drained, coarse soil lacks the capacity for making moisture available to plants during the dry summer. Past grazing has triggered and/or accelerated erosion from wind and snow-melt runoff in many areas. Dense bunchgrass communities, prominent at midslope, are in a position between the exposed crest communities and the late-snow-release communities downslope. In these midslope grass communities the effective growing season is adequate, soil relatively deep, and a protective vegetation cover helps conserve soil moisture in summer. Any effort to retain the character and productivity of the subalpine environment on Steens Mountain should be directed first toward the protection and preservation of the midslope bunchgrass communities.

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APPENDICES

APPENDIX A

APPENDIX A1

Soil Texture Data for Sample Sites

Soil Site	Percent Sand	Percent Silt	Percent Clay	Percent of sample > 2mm
1	46	50	4	33
2	61	34	5	34
3	55	41	5	40
4	48	44	8	40
5	58	30	12	43
6	50	41	9	59
7	48	47	5	52
8	59	33	8	44
9	52	39	9	31
10	60	31	9	52
11	51	40	9	43
12	53	33	14	51
13	54	38	8	30
14	61	34	5	48
15	59	37	4	58
Mean (%)	54	38	8	43

APPENDIX A2

Soil Moisture Retention Data for Selected Sites

Soil Site	Container Number	Container Weight (grams)	Gross Weight at Equil. (grams)	Gross Dry Weight (grams)	Moisture Content (grams)	Net Dry Weight (grams)	Percent Moisture	Two-Sample Average Percent Moisture
				15 BAR				
5	153	84.57	104.95	102.94	2.11	18.29	11.58	
	162	83.47	108.32	105.63	2.69	22.16	12.15	11.86
8	189	77.52	97.65	96.94	1.70	19.42	8.75	
	223	79.08	102.34	101.26	2.12	22.18	9.56	9.15
10	315	84.86	105.03	102.87	2.16	18.01	11.99	
	206	79.26	100.75	98.39	2.36	19.13	12.34	12.17
11	123	78.13	101.78	97.72	4.06	19.59	20.74	
	171	78.33	100.46	96.80	3.66	18.47	19.82	20.28
14	191	78.61	99.49	97.44	2.05	18.83	10.88	
	337	78.22	99.51	97.39	2.12	19.17	11.07	10.97
11/2*	327	95.60	117.06	113.44	3.62	17.84	20.29	
	151	82.43	104.54	100.83	3.71	18.40	20.18	20.24

*This is a soil sample of the second depth interval only of site 11.

Appendix A2 - Soil Moisture Retention Data for Selected Sites (continued)

Soil Site	Container Number	Container Weight (grams)	Gross Weight at Equil. (grams)	Gross Dry Weight (grams)	Moisture Content (grams)	Net Dry Weight (grams)	Percent Moisture	Two-Sample Average Percent Moisture
				7 BAR				
5	325	78.45	105.17	101.35	3.82	22.90	12.67	
	225	81.48	109.10	105.25	3.85	23.77	12.31	12.47
8	318	80.08	106.13	103.88	2.25	23.80	9.45	
	228	78.42	104.72	102.50	2.22	24.08	9.22	9.34
10	221	82.23	106.54	103.82	2.72	21.59	12.60	
	199	81.53	105.56	102.86	2.70	21.33	12.66	12.63
11	203	78.08	95.80	92.65	3.15	14.57	21.62	
	176	82.20	100.60	97.41	3.19	15.21	20.97	21.30
14	159	77.40	102.28	99.51	2.77	22.11	12.53	
	142	79.60	106.22	103.22	3.00	23.62	12.70	12.62
11/2*	193	83.64	101.01	98.11	2.90	14.47	20.04	
	216	77.69	94.99	91.77	3.22	14.08	22.87	21.46

*This is a soil sample of the second depth interval only of site 11.

Appendix A2 - Soil Moisture Retention Data for Selected Sites (continued)

Soil Site	Container Number	Container Weight (grams)	Gross Weight at Equil. (grams)	Gross Dry Weight (grams)	Moisture Content (grams)	Net Dry Weight (grams)	Percent Moisture	Two-Sample Average Percent Moisture
				1 BAR				
5	175	80.37	102.40	99.50	2.90	19.13	15.16	
	319	79.38	101.00	98.14	2.86	18.76	15.26	15.21
8	172	82.75	105.59	102.67	2.92	19.92	14.66	
	165	77.48	101.31	98.33	2.98	20.85	14.29	14.48
10	147	77.13	99.45	96.23	3.22	19.10	16.86	
	140	82.85	106.12	102.65	3.47	19.80	17.53	17.20
11	146	75.05	97.59	92.97	4.62	17.92	25.78	
	196	82.19	105.69	101.19	4.50	19.00	23.70	24.74
14	136	85.01	107.25	103.93	3.32	18.92	17.55	
	152	95.42	120.71	116.88	3.83	21.46	17.85	17.70
11/2*	192	79.99	102.04	97.66	4.38	17.67	24.79	24.70

*This is a soil sample of the second depth interval only of site 11.

Appendix A2 - Soil Moisture Retention Data for Selected Sites (continued)

Soil Site	Container Number	Container Weight (grams)	Gross Weight at Equil. (grams)	Gross Dry Weight (grams)	Moisture Content (grams)	Net Dry Weight (grams)	Percent Moisture	Two-Sample Average Percent Moisture
				1/3 BAR				
5	224	77.21	103.46	98.66	4.80	21.45	22.38	
	164	77.63	105.97	100.51	5.46	22.88	23.86	23.12
8	209	77.18	105.67	100.57	5.10	23.39	21.80	
	99	79.20	107.92	102.94	4.98	23.74	20.98	21.39
10	213	78.67	108.39	102.22	6.17	23.55	26.20	
	336	78.48	107.89	102.02	5.87	23.54	24.94	25.57
11	143	81.41	107.92	101.05	6.87	19.64	34.98	
	332	80.46	105.32	98.77	6.55	18.31	35.77	35.38
14	148	78.85	108.14	102.39	5.78	23.54	24.43	
	150	78.05	107.11	101.30	5.81	23.25	24.99	24.71
11/2*	226	80.91	101.57	96.05	5.52	15.14	36.46	
	139	82.78	106.60	100.30	6.30	17.52	35.96	36.21

*This is a soil sample of the second depth interval only of site 11.

APPENDIX B

APPENDIX B

Procedure for Soil Texture Analysis (after Asphalt Institute, 1963)

Hydrometer method - fraction passing #10 sieve (less than 2 mm)

Items: 250 ml beakers
1000 ml grad. cylinders
CALGON
distilled water
standard soil hydrometer
glass rod
electric mixer

1. Randomly sample and weigh out of 50 gm portion of soil sample.

2. Place in a 250 ml beaker and cover with 125 ml of stock solution of CALGON dispersing agent.

<u>Stock Solution</u>

45.7 gm CALGON (Sodium hexametaphosphate/sodium carbonate) $NaPO_3$

per liter of distilled water. Stir with glass rod until dissolved.

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3. Thoroughly stir soil sample and solution and let soak at least 12 hours.

4. After soaking, mechanically stir mixture for five minutes. A milkshake machine or electric mixer may be used for this purpose. Some distilled water may be added to facilitate stirring.

5. Transfer mixture to 1000 ml graduated cylinder and add distilled water having the same temperature as the room (which should remain constant) to attain a volume of 1000 ml without the hydrometer in the suspension.

6. With palm of hand firmly over the cylinder opening shake for about a minute.

7. Mark the exact time when the cylinder is set upright after shaking. Then carefully insert hydrometer and take a reading on the scale at the top of the meniscus formed by the suspension around the stem of the hydro-

meter at exactly 40 seconds. (See explanation following.) The hydrometer must be at rest before the 40 sec. reading.

8. Remove hydrometer and rinse and dry. Correct hydrometer reading for CALGON solution and suspension temperature. See Asphalt Institute, 1963. Record corrected reading.

9. Repeat hydrometer reading at exactly 120 minutes. (See explanation following.) Correct and record.

Explanation of Procedure

Classification of soils based on texture, analyzes particle sizes in a mineral or near mineral soil sample in which the largest particles are less than 2 mm. The less-than-2mm fraction is separated by sieving through a #10, or 2mm screen. Ideally, before sieving, the organic matter in soils should be removed by the hydrogen peroxide method. The soil sample is then thoroughly air dried usually 24-28 hrs at a temperature not exceeding 50°C. Some samples with high clay content may need to be gently ground after drying to break up consolidated particles.

The hydrometer or Bouyoucos method can be used to determine the percent, by weight sand (less than 2mm), silt (.05mm to .002mm), and clay (less than .002mm) fractions. The method is based on the principle, that the specific gravity or grams per liter of a particle suspension in which a sample of known weight has been placed, can be measured periodically with a scaled hydrometer so that the weight of the particles which have settled-out can be calculated. This principle is described by Stokes law:

$$d = \sqrt{\frac{30nL}{980(G-G_1)T}}$$

The law states that the diameter of particle sizes which remain in suspension after a certain period of time can be determined if the viscosity of the settling medium (H_2O), and the period of sedimentation are known.

In order that the particles of the 50 gm soil sample (step 1 in procedure) may be completely dispersed for accurate measurements, it is necessary to use a dispersing agent. In the case of the procedure outlined above, CALGON is used. CALGON is a sodium salt which reacts with the calcium ions of the soil sample in such a way as to make the particles repell one another. Disperson is mechanical as well as chemical as described in steps 2, 3, 4 above. NOTE: A pneumatic bulb or similar device filled with distilled water may be useful to wash larger particles from the sides and bottom of containers when transferring suspension from one to another.

The sample in suspension is placed in a liter cylinder and the cylinder filled to 1000 ml with distilled water. The solution is then mixed thoroughly so that all particles are in suspension before the cylinder is placed upright. Immediately the largest particles of the 50 gm sample begin to settle to the bottom of the cylinder. Note the time exactly 40 seconds from the moment the cylinder is placed upright. After that interval, according to Stokes law, all particles of size greater than .05mm have settled out. The hydrometer, since it is calibrated to grams/liter, at this moment measures the weight of the particles remaining in the suspension (the silt and clay fractions).

For example, if the hydrometer reads 33 gm/liter at 40 sec. this indicates that (50 gm - 33 gm = 17 gm or 17/50 x 100 = 34%) 17 gm or 34% of the sample is classified as sand.

A second reading is taken at 120 minutes. At this point all particles greater than .002mm have settled out of the suspension. If the hydrometer reads 10 gm/liter then 20% of the sample is clay size particles. By subtraction 46% of the sample is silt size particles. Using a standard soil texture triangle the sample may be described as "loam."

NOTE: The hydrometer readings must be corrected for both suspension temperature (if not 20°C) and the CALGON in solution before calculations are made. See step 8.

APPENDIX C

APPENDIX C

Daily Minimum and Maximum Recorded Temperatures in Study Area, July 12 to October 14, 1974, Degrees C

Date	Min.	Max.	Date	Min.	Max.
July 12	1.1.	16.7	Aug. 21	2.2	16.7
13	5.6	20.0	22	5.6	17.8
14	9.4	23.3	23	5.6	18.3
15	9.4	19.4	24	5.6	20.0
16	6.1	18.9	25	7.2	22.2
17	6.7	20.6	26	9.4	22.8
18	8.9	22.8	27	12.2	25.0
19	9.4	22.8	28	12.2	22.5
20	7.2	21.7	29	12.2	22.8
21	8.3	22.8	30	10.0	23.3
22	8.3	22.2	31	9.4	22.8
23	6.7	21.7	Sept. 1	7.8	20.0
24	7.8	22.2	2	7.2	20.0
25	8.9	22.8	3	9.4	21.1
26	9.4	24.4	4	7.2	18.3
27	11.7	23.3	5	4.4	17.2
28	8.9	24.4	6	6.7	18.9
29	13.3	22.8	7	8.9	18.3
30	10.0	24.4	8	6.7	16.7
31	11.1	25.6	9	6.1	16.1
Aug. 1	11.1	17.8	10	3.3	12.2
2	6.7	21.1	11	-3.3	8.9
3	7.2	22.8	12	-2.2	8.3
4	8.9	22.2	13	-2.8	8.9
5	10.0	21.7	14	1.7	12.8
6	7.2	16.1	15	0.0	16.1
7	5.6	15.6	16	4.4	17.8
8	2.2	16.7	17	7.8	18.9
9	1.1	16.7	18	5.6	18.9
10	4.4	18.9	19	6.1	19.4
11	6.1	19.4	20	6.7	17.2
12	6.7	17.2	21	6.1	16.7
13	5.0	14.4	22	2.2	16.7
14	-1.1	14.4	23	5.6	17.2
15	2.2	18.3	24	6.7	16.7
16	6.7	20.0	25	3.3	17.2
17	7.2	20.0	26	3.9	11.7
18	7.2	17.8	27	-6.1	8.9
19	1.1	3.3	28	-1.7	12.2
20	-2.8	10.6	29	2.2	13.9

Appendix C - continued

Date	Min.	Max.
Sept. 30	3.3	13.9
Oct. 1	3.3	15.0
2	5.6	14.4
3	-2.8	7.8
4	-5.0	4.4
5	-6.7	4.4
6	-3.9	7.8
7	0.0	10.6
8	1.7	10.6
9	1.1	7.8
10	-3.3	7.8
11	-3.3	6.1
12	-3.3	10.0
13	1.1	11.1
14	1.1	11.1
Mean	4.9	17.1

APPENDIX D

APPENDIX D

Plant Species List

The following is a list of vascular plant species collected and identified in the Steens Mountain subalpine grassland during the summers of 1971, 1972, and 1974. Nomenclature follows Hitchcock (1973) except where noted by an asterisk (*). Voucher specimens are kept in the Department of Geography, Oregon State University. # indicates no specimen available. Arabis spp. have been tentatively identified as A. drummondii Gray, A. holboellii Hornem. var. holboellii, and A. microphylla Nutt. var. microphylla.

BORAGINACEAE

Mertensia oblongifolia (Nutt.) G. Don	leafy bluebells
Mertensia viridis A. Nels.	green bluebells

CAROPHYLLACEAE

Arenaria aculeata Wats.	prickly sandwort
Arenaria capillaris Poir. var. americana (Mag.) Davis	mountain sandwort
Arenaria congesta Nutt. var. congesta	capitate sandwort
Arenaria nuttallii Pax var. fragilis (Mag. & Holmg.) Hitchc.	Nuttall's sandwort
Arenaria nuttallii Pax var. nuttallii	Nuttall's sandwort
Arenaria rubella (Wahlenb.) J.E. Smith	reddish sandwort
Cerastium arvense L.	field chickweed
Cerastium berringianum Cham. & Schlecht.	alpine cerastium
Silene oregana Wats.	Oregon silene
Stellaria longipes Goldie var. altocaulis (Hulten) Hitchc.	longstalk starwort

COMPOSITAE

#Achillea millefolium L. ssp. lanulosa (Nutt.) Piper var. alpicola (Rydb.) Garrett	common yarrow
Agoseris glauca (Pursh) Raf. var. dasycephala (T. & B.) Jeps.	pale agoseris
Antennaria alpina (L.) Gaertn. var. media (Greene) Jeps.	alpine pussy-toes
Antennaria anaphaloides Rydb.	tall pussy-toes
Antennaria microphylla Rydb.	rosy pussy-toes
Antennaria umbrinella Rydg.	umber pussy-toes

Appendix D - continued

COMPOSITAE -- continued

Artemisia arbuscula Nutt. ssp. *thermopola* Beetle	low sagebrush
**Artemisia tridentata* Nutt. ssp. *vaseyana* form. spiciformis (Osterhout) Bettle	big sagebrush
Aster alpigenus (T. & G.) Gray var. *haydenii* (Porter) Cronq.	alpine aster
Chrysothamnus viscidiflorus (Hook.) Nutt. var. *lanceolatus* (Nutt.) Greene	green rabbitbrush
**Cirsium peckii* Hend.	Steens Mountain thistle
Erigeron bloomeri Gray	scabland fleabane
Erigeron compositus Pursh var. *glabratus* Macoun	cut-leaved daisy
Haplopappus macronema Gray var. *macronema*	discoid goldenweed
**Helenium hoopesii* Gray	tall mountain helenium
Senecio canus Hook.	woolly groundsel
Senecio fremontii T. & B. var. *fremontii*	dwarf mountain butterweed
Senecio werneriaefolius Gray	rock butterweed
Taraxacum officinale Weber	common dandelion

CRASSULACEAE

Sedum lanceolatum Torr. var. *lanceolatum*	lance-leaved stonecrop

CRUCIFERAE

Arabis spp. L.	rockcress
**Draba sphaeroides* (Pays.) var. *cusickii* (Robins.) C.L. Hitchc.	Steens Mountain whitlow-grass
Lesquerella occidentalis Wats. var. *diversifolia* (Greene) Hitchc.	western bladderpod

CYPERACEAE

Carex multicostata Mack.	many-ribbed sedge
Carex phaeocephala Piper	dunhead sedge
Carex raynoldsii Dewey	Raynold's sedge
Carex scirpoidea Michx. var. *pseudoscirpoidea* (Rydb.) Cronq.	Canadian single-spike sedge
Carex subnigricans Stacey	dark alpine sedge

Appendix D - continued

GENTIANACEAE

Frasera speciosa Dougl.	giant frasera

GRAMINEAE

Agropyron caninum (L.) Beauv. ssp. majis (Vasey) Hitchc. var. latiglume (Scribn. & Smith) Hitchc.	broadglumed wheatgrass
Agropyron cristatum (L.) Gaertn.	crested wheatgrass
Agrostis scabra Willd.	winter bentgrass
Deschampsia atropurpurea (Wahl.) Scheele var. latifolia (Hook.) Scribn.	mountain hairgrass
Deschampsia cespitosa (L.) Beauv. var. cespitosa	tufted hairgrass
Festuca idahoensis Elmer var. idahoensis	Idaho fescue
Festuca ovina L. var. brevifolia (R. Br.) Wats.	sheep fescue
Festuca scabrella Torr.	rough fescue
Phleum alpinum L.	alpine timothy
Poa cusickii Vasey var. cusickii	Cusick's bluegrass
Poa gracillima Vasey var. gracillima	Pacific bluegrass
Poa nervosa (Hook.) Vasey var. wheeleri (Vasey) Hitchc.	Wheeler's bluegrass
Poa nevadensis Vasey	Nevada bluegrass
Poa sandbergii Vasey	Sandberg's bluegrass
Sitanion hystrix (Nutt.) Smith var. hystrix	bottlebrush squirreltail
Trisetum spicatum (L.) Richter	spike trisetum

GROSSULARIACEAE

Ribes montigenum McClatchie	alpine prickly currant

HYDROPHYLLACEAE

Phacelia sericea (Grah.) A. Gray var. ciliosa Rydb.	silky phacelia

JUNCACEAE

Juncus drummondii E. Meyer var. subtriflorus (Meyer) Mitchc.	Drummond's rush

Appendix D - continued

LEGUMINOSAE

#*Astragalus whitneyi* Gray var. *sonneanus* (Greene) Jeps.	balloon milkvetch
Lupinus lepidus Dougl. var. *lobbii* (Gray) Hitchc.	prarie lupine
**Trifolium longipes* Nutt. ssp. *multipedunculatum* (Kennedy) Gillett	long-stalked clover

LILIACEAE

Lloydia serotina (L.) Sweet	alpine lily

ONAGRACEAE

Gayophytum humile Juss.	dwarf gayophytum
**Oenothera tanacetifolia* T. & G.	tansy-leaved evening primrose

POLEMONIACEAE

Phlox hoodii Rich	Hood's phlox

POLYGONACEAE

Eriogonum caespitosum Nutt.	mat buckwheat
Eriogonum ovalifolium Nutt. var. *depressum* Blank.	cushion buckwheat
Eriogonum ovalifolium Nutt. var. *nivale* (Canby) Jones	cushion buckwheat
Eriogonum umbellatum Torr. var. *hausknechtii* (Dammer) Jones	sulphurflower buckwheat
Oxyria digyna (L.) Hill	mountain sorrel
Polygonum austiniae Greene	Austin's knotweed
Polygonum bistortoides Pursh	western bistort
Polygonum douglasii Greene var. *latifolium* (Engelm.) Greene	mountain knotweed
Polygonum kelloggii Greene	Kellogg's knot-weed
Polygonum watsonii Small	water knotweed

PORTULACACEAE

Lewisia pygmaea (Gray) Robins. var. *pygmaea*	alpine lewisia

Appendix D - continued

PORTULACACEAE - continued

#Spraguea umbellata Torr. var. caudicifera Gray	Mt. Hood pussypaws

PRIMULACEAE

Dodecatheon conjugens Greene var. conjugens	desert shooting star

RANUNCULACEAE

Caltha leptosepala DC. var. leptosepala	elkslip (marshmarigold)
Ranunculus alismaefolius Geyer var. hartwegii (Greene) Jeps.	water-plantain buttercup
Ranunculus eschscholtzii Schlecht. var. trisectus (Eastw.) Benson	subalpine buttercup

ROSACEAE

Geum triflorum Pursh var. ciliatum (Pursh) Fassett	old man's whiskers
Horkelia fusca Lindl. var. capitata (Lindl.) Peck	tawny horkelia
Ivesia gordonii (Hook.) T. & G.	Gordon's ivesia
Potentilla diversifolia Lehm. var. diversifolia	diverse-leaved cinquefoil
*Potentilla gracilis Dougl. var. blaschkeana (Turca.) Jeps.	slender cinquefoil
Potentilla fruticosa L.	shrubby cinquefoil
Sibbaldia procumbens L.	creeping sibbaldia

SAXIFRAGACEAE

Heuchera cylindrica Dougl. var. aplina Wats.	roundleaf alumroot
Lithophragma tenella Nutt. var. tenella	slender fringecup

SCHROPHULARIACEAE

*Castilleja steenensis Penn.	Steens Mountain paintbrush
*Penstemon davidsonii Greene var. praeteritus Cronq.	Davidson's penstemon

Appendix D - continued

SCHROPHULARIACEAE - continued

Penstemon procerus Dougl. var. *procerus*	tiny bloom penstemon
Penstemon rydbergii A. Nels. var. *varians* (A. Nels.) Cronq.	Rydberg's penstemon