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AN ABSTRACT OF THE THESIS OF Paul Collins for the Master of Science in Biology presented June 2, 1978.

Title: Alpine Vegetation of Steens Mountain

APPROVED BY MEMBERS OF THE THESIS COMMITTEE:

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Earl Rosenwinkel Chairman

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Robert Tinnin

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Byron Lippert

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Q. Dean Clarkson

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Gilbert Benson

A determination was made that the summit of Steens Mountain is an alpine tundra. The assessment was based on floristics, vegetation and community structure, environmental parameters, and geomorphological criteria. Microhabitats of *Oxyria digyna* at low elevations were found to approximate alpine conditions.

ALPINE VEGETATION OF STEENS MOUNTAIN

by

PAUL COLLINS

A thesis submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE
in
BIOLOGY

Portland State University

1978

TO THE OFFICE OF GRADUATE STUDIES AND RESEARCH

The members of the Committee approve the thesis of Paul Collins presented June 2, 1978.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Steens Mountain is located in Harney County, in southeastern Oregon. The area has been classified by Franklin and Dyrness (1973) as part of the Basin and Range Province, which is characterized by fault-block mountains that encircle basins of inland drainage. Cronquist (1972) lists this area in his Lake section, which includes most of Harney and Malheur Counties in Oregon, and parts of Washoe and Humboldt Counties in Nevada. The Lake section is made up of two different provinces on a physiographic basis. The northern section is part of the Columbia Plateau Province (Fennemann 1931), and is a relatively flat area marked with cinder cones. Elevation is just over 1220 m. and has horizontal beds with almost no block-faulting. This northern section does not include the study area and will not be considered further. The southern part of the Lake section falls into the Basin and Range proper and is a block-faulted lava plateau, overlain with young lava flows, which have tended to obscure the features of the fault blocks, except on some of the higher ranges. Steens Mountain is one of those prominent ranges.

GEOLOGIC PROFILE

Steens Mountain is an extensive fault-block mountain which runs approximately SSW to NNE for a distance of 97 Km. The geologic history of the mountain is well detailed by Bentley (1970) and Mairs

(1977). The west face is a gentle dip slope which extends for approximately 30 Km. The east face of the mountain is a steep scarp with a relative relief of 1670 m. from the summit to the Alvord Desert on the eastern side. Absolute relief is 2970 m.

The mountain is composed of three stratigraphic layers. The lowest is the Alvord Creek Formation with a maximum thickness of 243 m. This layer is overlain by the Pike Creek Formation with a maximum thickness of 457 m. The upper layer is the Steens Mountain Basalts, which is the most extensive with a thickness up to 914 m. (Bentley 1970). Uplift presumably occurred after the formation of the Steens Mountain Basalts were formed and erosional processes have been active on the mountain, with estimates that the east facing scarp has retreated 2.4 Km. from its original position (Williams and Compton 1953).

Bentley (1970) has accumulated evidence for the glaciation of Steens Mountain. He divides the glaciation into two phases; the Fish Lake phase and the Blitzen phase. During the Fish Lake phase extensive valley glaciers were formed, along with at least ten glacial cirques on the east facing scarp. The floors of the cirques produced in the Fish Lake phase are found at an elevation of 1700 m. to 2075 m. The severe conditions of this glaciation produced an ice sheet along most of the upper west slope and covered an area of 127 $km.^2$

The Blitzen glaciation was the second phase of glaciation on the Steens and occurred under milder conditions, so glacial ice accumulation was limited to the higher portion of the mountain. The higher snowline produced by the milder conditions was responsible for a higher set of cirques on the east face, that are located 460 m. above the cirques produced in the Fish Lake phase of glaciation. (Bentley 1970).

VEGETATION OF STEENS MOUNTAIN

There is disagreement in the literature as to the classification of the vegetation on Steens Mountain. The area around Steens Mountain is classified as the Shrub-Steppe vegetation zone while the lower slopes are included in the *Juniperus occidentalis* zone (Franklin and Dyrness 1973). They note the presence of timberline conditions on Steens Mountain and include the summit area as a timberline and alpine region. Hansen (1956) divided the mountain into a series of vegetation belts with the Tall Sage (*Artemisia tridentata* var. *tridentata*) as the lower belt which extended up to 1675 m. Above this up to 1975 m. in elevation was the Juniper belt (*Juniperus occidentalis*). From 1975 to 2425 m. was the Aspen belt (*Populus tremuloides*) and above this to 2950 m. was the Subalpine Bunchgrass belt.

Cronquist (1972) following a previous classification by Billings (1951) for the Great Basin Region, recognized 4 zones on Great Basin mountains. From highest to lowest they are the Limber Pine zone, the Upper Sagebrush zone, the Pinyon-Juniper zone, and the Sagebrush zone. Both the Pinyon Pine and the Limber Pine are species which are not represented on Steens Mountain.

Faegri (1966) on his excursion through the Steens, recognized four regions which he said corresponded to the montane-alpine zonation used in Scandinavia. His lowest region was the montane zone which included the *Juniperus occidentalis* belt. Above this he designated a subalpine region which included the Populus tremuloides forests. Above this was a lower alpine zone which was dominated by *Artemisia*. His highest region was a middle alpine region which included the grassland communities found along the summit ridge. A high alpine region was not reached on the Steens.

Mairs (1977) in his study of the vegetation communities along the summit ridge, used a classification system drawn from previous works. He recognized 5 zones. In ascending order they were, the Lower Sagebrush zone (*Artemisia tridentata* var. *tridentata*), the Juniper zone, the Aspen zone, the Upper Sagebrush (*Artemisia tridentata* var. *vaseyana*), and the Subalpine Grassland.

A reason for the difficulty in classifying the top of Steens Mountain is that there are no well accepted timberline tree species occurring on the Steens. There is an obvious paucity of tree species and forests and fewer still which extend into the higher elevations of the mountain. The Juniper forest has its greatest coverage at 1800 m. and thins out considerably at higher elevations, with its highest occurrence around 2450 m. Between 1950 and 2400 m., groves of *Populus tremuloides* become predominant and extend up to 2600 m., where krummholz forms are found (Price 1978). The highest erect *Populus tremuloides* is at 2500 m. A few species in the genus *Populus* are found at lower elevations but are limited in their extent. The family Pinaceae is very poorly represented with only a few isolated stands of Sierran White Fir (Abies concolor var. lowiana), and these are also limited to the lower elevations of the mountain. The flora of the High Steens is not well described, so the alpine affinities of flora and vegetation are not adequately determined.

The purpose of this study was to determine to what extent and in what way the conditions near the summit of Steens Mountain are representative of an alpine tundra. To make this assessment, a measurement of environmental parameters, floristics, vegetation and community structure was made in or around a high cirque basin adjacent to the summit.

CHAPTER II

REVIEW OF LITERATURE

TIMBERLINE AND ALPINE DEFINITIONS

There are a variety of comcepts used in the description of mountainous areas. These concepts are defined in terms that fit the purposes of the various investigators. Love (1970) notes that there has been scant discussion about the term alpine, as it has taken the common sense meaning of a cold and windy, treeless high area. The treeless alpine tundra is sometimes divided into low alpine, alpine, and high alpine areas. The high alpine area corresponds closely to the geomorphological term, the nival belt, which is lacking any substantial vegetation except lichens.

The distinction of a treeless condition shifts the emphasis on delineating high mountain areas by being above a timberline. The timberline was defined by Thompson (1968) as being a transition zone of variable but limited depth, not usually exceeding 300 m. The lower limit of the zone was the highest occurrence in the area of a close high-crowned forest and extended upward to the limit of erect individual trees. Thompson also noted that dwarfed scrub timber (krummholz) would extend further above this zone. The transition belt from the dense forests to the alpine tundra was referred to as the forest-tundra ecotone, particularly in western North America (Clements 1936, Marr 1948). Troll (1973b) emphasizes that this belt rarely has sharply defined limits due to the individual nature of tree growth struggling against severe conditions. Following the terminology of Hustich (1953), Troll points out a variety of lines which can be distinguished. There is an economic treeline, a generative treeline, a biological limit of forests, or a vegetative limit of closed forest, a limit of individual trees or clumps, and a species limit designated where the same species can take on different growth forms.

Love (1970) has attempted to consolidate the various terms by focusing on a definition of the subalpine zone. She emphasizes that in scientific literature the prefix sub takes on the meaning of being part of and not separate from the root word. Thus the subalpine zone is part of the alpine area. The subalpine zone is described as the belt from the upper altitudinal treeline to the closed montane forest at lower elevations. It is an ecotone area with dwarfed tree growth and meadows, forming a mosaic of biota.

The idea of defining the treeline climatically has much support in the literature. Koeppen (1920) in describing the boundary between the forest and tundra climates, used the 10 C. mean July isotherm to approximate the treeline. Griggs (1946) noted a good correspondence between conifer growth and a summer temperature of 10 C. and suggested that in an area where the trees are in stable adjustment to their environment, the treeline would be expected to reach but not exceed the July 10 C. isotherm. A tension zone would be created where trees are constantly entering the higher ground through dispersal and persistently being killed off by the harsh climate. Pearson's (1931) studies of the timberline in the San Francisco Mountains in Arizona, found a close accordance with the 10 C.

July mean isotherm boundary.

Other formulations for a thermal climatic treeline are given by Nordenskjold and Mecking (1928) who devised a formula using both the mean temperature of the warmest and the coldest month. This method was devised for the Arctic treeline boundary and shows good correlation, except in western Alaska. The lack of agreement in western Alaska has been interpreted by Griggs (1934) as evidence of climatic amelioration, which is allowing the northern treeline to expand further into the Arctic. Hopkins (1953) devised a method to account for this variation in the Alaskan treeline. He plotted the number of mean annual degree-days above 10 C. against the mean temperature of the coldest month. Tundra regions fall into the area near the origon of the axis. The tundra areas plotted had less than 130 degree-days above 10 C. but appeared to be relatively indifferent about whether the area had a mild or cold winter.

Kozlowski (1962) stated that the decisive factor affecting the radial growth of trees in the northern areas, is the temperature of the growing season. For the extreme northern areas this corresponded best with the July temperatures. Further south, other factors affect the correlation by affecting temperature. Also, the growing season is longer further south and these weather conditions affect growth. In working with Scots Pine (Pinus sylvestris), which forms the treeline in Finland, he found a minimum temperature requirement of 10.5 C. for four months for ripening of seed. Vegetative growth for this species required a minimum temperature of 8.5 C. for four months. These requirements cause large growth variations with slight changes in temperature. Statements made on the expansion and contraction of the timberlines must be viewed in light of these requirements.

Other authors are convinced that the treeline is in reality determined by a complex assortment of factors. Butzer (1964) emphasizes that the true treeline falls somewhere between 10 and 12 C, for the mean July isotherm, depending on the maritime or continental character of the climate. He states that it is not a true climatic boundary but rather a transitional belt wherein different tree species are found in different areas and that tree growth is largely determined by exposure, relief, and surface drainage, which combine to produce specific temperature and soil moisture regimes. He states that there is increasing doubt that either polar or alpine treelines are simple functions of macroclimate. The position of the treeline is not then equivalent to a particular monthly isotherm and while this correspondence to midsummer isotherms should not be totally disregarded, it should be viewed with caution.

Love (1970) finds the 10 C. mean monthly isotherm for the warmest month valid as an upper limit for tree growth, but finds that the transition zone does not relate to any particular climatic frontal system. She finds wind to have as important a role as temperature on tree growth and formation of krummholz. Slope will be important in the effects it has on precipitation runoff and snow accumulation. The exact altitudinal position then, of the treeline will be determined by the geographical position of the mountain.

Bliss (1963) in his work on the Presidential Range in New Hampshire, concluded that the upper limit of krummholz was extensively determined by exposure to wind and winter snow depth. Fog belts at higher elevation played a role by reducing photosynthetic rates on certain exposures. This is in concurrence with Monahan (1933) who concluded winter snow depth, frozen soils, and dessication of shoots exposed to strong winds, were the causes of timberline.

Holtmeir (1973) states that the most important cause of timberline is the incomplete development of young needles and annual shoots, due to unfavorable periods in the already short growing season. Exposure to the harsh winter will then damage the plant. The distribution of snow cover, which is dependent on windflow near the ground and exposure to insolation, plays the key role in the extent to which the vegetation is subjected to the injurious weather. Blowing snow may cause severe mechanical damage to any vegetation above the snow cover. Wind and insolation will act to intensify transpiration rates and with a frozen substrate the vegetation will be killed by dehydration. Holtmeir thinks it is incorrect to speak of a vegetation period in terms of temperature sums, such as degree-day formulations, because in relation to the species involved, there are several vegetation periods rather than one, due primarily to differential vegetative growth patterns.

Geomorphological criteria have also been applied to describe the alpine zone. Thompson (1968) working largely from aerial photographs of the Colorado Rockies, described three arrays of nearly flat high summits (alpine summit accordances) in the mountains of the western United States. The lower accordance has three consistent characteristics. It is normally found in association with glacial gorges, usually below the crests of glacial trough walls or the headwalls of large valley-head cirques. These summits, also called alp slopes, are less steep than the walls of the gorges on which they have formed and the alpine cliffs which rise above them. The third distinctive characteristic is that these alp slopes lie very consistently at the timberline.

Troll (1973b) has established a set of criteria to distinguish high mountain belts based both on biological and geomorphological criteria. No one criterion alone serves to distinguish the high mountain range, but taken in conjunction they offer a workable proposal. The first criterion is the upper timberline. Though this can usually be agreed on, in certain areas, particularly arid and semi-arid regions of continental highlands, tree growth is either not possible or absent for unknown reasons. This necessitates the use of the following two criteria. The second part of Troll's definition is the Pleistocene snowline. This is more precisely considered to be the snow line of the last glaciation, which is determined by the lowest level at which cirques occur. The snow line and the actual timberline move up and down the mountain in the same direction throughout the temperate mountain systems of the world and are separated from each other by only a short distance. There arise situations where the upper timberline and the Pleistocene snowline cannot clearly delimit the high mountain belt. A useful criterion is one found in all climatic zones and that is the lower limit of solifluction or actual periglacial dynamics. These are soil and surface weathering effects which result in a variety of patterned soils, cryoturbate soils, and various structured soils typical of high mountain areas.

These three guidelines taken together serve to distinguish the high mountain landform complex. Usually present in this complex are steep crests undercut by glacial cirques, which may or may not still contain living glaciers. Other distinguishing landforms are cirque lakes and striated rock walls. Troll (1973) thinks it unsuitable to use the term alpine timberline in any worldwide sense. The upper timberline in different parts of the world are not climatically equivalent. Both the plant formations and the life forms at timberline exhibit extreme heterogeneity with changes in latitude. He states that even a small mountain system like the Alps is not climatically equivalent throughout its range. In areas of seasonal thermic contrast, large scale limitations are placed on the altitudinal limit of tree growth by growing season temperatures which can be measured in a variety of ways, but topoclimatic differentiation of tree growth is a function of the deposition of winter snow and exposure to damaging winds.

THE PROBLEM OF TREELESS BALDS

Treeless balds is the name given to open areas (treeless) on mountains, where tree growth is not believed to be thermally limited. Billings and Mark (1957) found treeless balds to be a widespread phenomenon. They related bald areas found in the Appalachians with bald areas common in the Great Basin Province, and in the mountains of Wyoming.

In the Great Basin Region of Nevada, they found that mountains with summits between 2290 and 3050 m. were capped with balds. These areas of shrubby or herbaceous vegetation were found above Pinyon-Juniper woodland and below or around the Limber Pine - Bristlecone Pine forest. In the Medicine Bow Mountains of Wyoming, they found numerous balds even though the theoretical climatic treeline would occur above the highest peak in the range.

In discussing the causes of these widespread treeless balds, they concluded that the balds appear to be primarily ecotonal or forest margin occurrences. The destruction of the forest, by whatever factors near tolerance limits of the species involved would result in persistent balds. For the Appalachian balds, they thought that the treeline was determined by climate, soil, and competition at the lower edges of the Spruce-Fir forest. No direct cause for the balds in the Medicine Bow Mountains was established, but they noted the importance of distinguishing between factors related to bald origin and those related to bald maintenance. The limitations of seed dispersal were considered a primary cause of the persistence of the balds in this area. For the Great Basin balds, they concluded that these areas were beyond the tolerance limits of any species now present and could be called climax in the sense that they will remain balds under present conditions. In no situation did they find the treeless areas embedded within a forest area, which reaffirmed their position that these areas were a problem existing near the tolerance limits of principal forest dominants.

Following along with this reasoning, Mark (1958) did a further detailed study of the Appalachian balds and tied their occurrence to Post-Wisconsin climatic fluctuations in the environment.

He argues that a xerothermic (warming) period could have restricted the upper Spruce-Fir forest 90-300 m. higher than its present limits. This would have resulted in the elimination of the Spruce-Fir forest from many peaks with insufficient elevations to provide refugia. In areas where it was not eliminated, a reduction in biotypes would have occurred and this depletion would hinder the process of reinvasion and regeneration of the Spruce-Fir forest.

Gersmehl (1969) challenged the conclusion that the Appalachian balds were due to tolerance limits of the surrounding species. He suggested that their maintenance was due to the absence of a suitable intermediate species which would be able to compete with and eventually subdue the bald vegetation, leaving it open to reinvasion by the Spruce-Fir forest. In a study of the environmental parameters in the bald areas, Gersmehl (1971) stated that the limited bald regeneration which occurred was not due to the severity of the bald environment. He cited limited reproductive capabilities of the species, in particular low dispersal distances and low germination capabilities as causative factors. In a summary article, Gersmehl (1973) concluded that the treeless balds were Nineteenth Century cultural relicts which were originated and maintained by grazing and deliberate ground fires. He stated that their short term persistence after cessation of disturbance, was due to the limited seed dispersal capabilities of high elevation species, and that similar delayed responses may be characteristic of other vegetation types, particularly in severe environments.

The problem of treeless balds was also discussed by Hollerman

(1973) in his study of the California section of the Basin and Range Province. He found numerous treeless areas above the Pinyon-Juniper woodland. In areas, the upper limit of the Pinyon-Juniper forest had the appearance of a true timberline, with the occurrence of dwarfed and stunted trees. He stated that this phenomenon was more localized than that which occurred further east in the Basin and Range Province, but that it appeared consistently within the ecotone of two forest types. He found no conclusive proof that the treeless areas were beyond the tolerance limits of the species involved, or that there was a macroclimatic explanation. He offered as the most likely explanation, that the areas were produced by a microclimatic-edaphic aridity of the soil, produced by a combination of factors such as slope, exposure, topography, and substrate. He also introduced the possibility of origin through fire and that the most reasonable theory was that the balds had a multiple origin.

CHAPTER III

MATERIALS AND METHODS

Vegetation, floristics, and environmental parameters were measured on the high Steens, as little is known about these factors. The Big Alvord Cirque was chosen for this study due to its proximity to the summit, from which it is hoped that environmental parameters will approximate the most severe found on the mountain. This cirque was presumably formed during the Blitzen phase of glaciation, and is located just to the north of the summit, with drainage into Big Alvord Creek. The Big Alvord Cirque also has, from preliminary examination, what appeared to be the best developed tundra vegetation of any area on Steens Mountain.

FIELD TECHNIQUES

TEMPERATURE MEASUREMENTS

To determine whether the high Steens has a climate like that of tundra, timberline, or subalpine, ambient air temperatures were taken at various sites. These temperatures were measured with max-min thermometers placed in sheet aluminum shelters. Shelters were supported by tripods constructed for that purpose. Shelters were painted white to reflect incident radiation and to prevent heat build up, which could distort temperature readings. Shelters were open on the ends and lower sides to provide adequate ventilation. In order to compare these data with standard U.S. weather stations, shelters were positioned lengthwise on a north-south axis with the bottom of the thermometer pointed towards the north. Shelters were placed so that the thermometers would record ambient air temperature at the 1.2 m. level. Readings were recorded daily when possible. Some intervals were longer, but when stations were checked all were checked on the same day. Readings for a period greater than one day will reflect the maximum and minimum temperatures of that recording period.

Four temperature shelters were placed within the study area. Tripod 1 (T1) was placed on the west facing slope adjacent to Big Alvord Cirque, at about 30 m. below the ridge road (el. 2870 m.). Tripod 2 (T2) was placed on the east facing slope of the cirque, which constituted the major area of study. T2 was placed at approximately the same elevation as T1. Tripod 3 (T3) was placed on the floor of the cirque and tripod 4 (T4) was placed at the eastern lip of the cirque (See Figure 1). The floor of the cirque slopes down to the east, putting T3 at an elevation of 2800 m. and T4 at 2745 m.

Ambient surface air temperature was measured with recording thermographs manufactured by the Taylor Instrument Co. Measurements were made to determine microhabitat variation within the cirque and its relation to the vegetation cover. Thermographs had a recording period of one week. All thermographs were positioned out of direct sunlight by using vegetation or rock outcrops as cover. Adequate ventilation was maintained to minimize reradiation effects and to get a true measure of ambient air temperature at this level. Thermographs A, C, and E were placed at the sites of tripods 1, 3, and 4, respectively. Thermograph B was placed at the summit of the mountain.

Thermographs D and F were placed on the north facing and south facing walls of the cirque, respectively.

To compare temperature regimes of the microhabitat of *Oxyria digyna*, a principal alpine plant, at different elevations, 4 Max-min thermometers were used to measure ambient surface air temperatures. Two of the sites were located in *Oxyria* patches within Big Alvord Cirque. The other two sites were in Jackman Park at an elevation of 2380 m. These measurements were made to determine if the areas where *Oxyria* grew were alpine areas by temperature considerations, and if these sites varied with elevation, and if temperature was a controlling factor in the distribution at lower levels.

Site 1 (G1) was located on the east facing ridge wall of the cirque at an elevation of 2870 m., while site 2 (G2) was located on the north facing wall of the cirque at 2800 m. (Figure 1). Both sites were located next to several *Oxyria* plants. All of these plants were found on talus slopes located near a late lying snowbank. The plants are shaded in their location from direct sunlight during the middle of the day and received direct sunlight only in the early morning or late afternoon hours. The thermometers were positioned so they did not receive direct sunlight at any time. Sites 3 and 4 (G3 and G4) were located at Jackman Park. G3 was located on a northwest facing ridge wall which had late-lying snow around it into the beginning of August. *Oxyria* plants were found in sheltered cracks within this wall and were never observed to be getting direct sunlight at any time. G4 was set up at the same elevation in a wet shrub and marsh community just at the edge of a *Populus tremuloides* grove. The thermometer was placed so as not to receive direct insolation at any time.

Soil temperature was measured with a Tele-thermometer, Model 46 TUC manufactured by Yellow Springs Instrument Company, Inc., Ohio, which allowed measurements at three different depths to be done simultaneously. By comparing the temperature change with depth, a measure of soil structure variability could be determined. With the large number of measurements, the temperatures had to be read on two consecutive days in the mid-afternoon. On both of the days there was little or no cloud cover and the air temperature each day was within a degree C. Soil temperatures were measured at three levels: surface, 3 cm., and 10 cm. in established transects (See Vegetation). Ten different sites were measured in the transect at every 3 m. Exact location of these sites was established by crossing the transect with a 2 m. line marked in cm. A random number was then drawn from tables to locate the exact position of the sites.

SOIL MOISTURE

Soil moisture was measured using the calcium carbide quick test method with a pressure bomb manufactured by the Alpha-lux Company of Philadelphia, Pennsylvania. Soil samples were taken along designated transects, sealed in a plastic bag, and returned to a field laboratory, where soil moisture was measured that night. Values were converted to % moisture of dry weight values by using a conversion chart provided with the equipment. Soil moisture was measured at 5 sites within each transect at every 6 m. These sites were the same as the locations at which the soil temperature measurements were made.

SOIL pH

Soil pH was measured from the soil samples and at the same time as the soil moisture readings were taken. A slurry of soil was made from each sample by a 50/50 ratio of soil to water by weight. Soil pH was measured using a soil pH meter, Model 7, manufactured by the Corning Co. The meter was standardized with a buffer solution from the Coleman Co. at a pH of 7.0. After each reading, the meter was rechecked using the buffer solution.

SNOW RECESSION RATES

The rate of recession was measured by placing stakes around perimeter of the snowbank and then periodically measuring the distance from the stake to the snowbank. After each measuring period the stakes were repositioned at the edge of the snowbank. After the initial measuring period, all snowbanks were standardized by using the same number of stakes (5) for each.

The rate of snow recession was measured on four persistent snowbanks found within the confines of the Big Alvord Cirque. These snowbanks are outlined in Fig. 1. They occupy positions on west end of the south facing slope (SB1), on the northwest and southwest corners of the east facing slops (SB2 and SB3), and on the west end of the north facing slops (SB4). Measurements were begun on July 12 and terminated on July 30. The elapsed time was equal for the first two measuring periods, but thereafter only two snowbanks were checked on any one day due to the length of time these measurements required.

Consequently the time periods for each measurements are not equal and occur in overlapping periods. Group means with their standard deviations are given in Table XII. Along with these data are given the length of the measuring period and the average air temperature for the period, taken from tripod 2, which was the nearest air temperature station.

VEGETATION

Vegetation sampling was done in the study to identify species present, establish community patterns and cover percentages, and to determine the extent of alpine tundra vegetation. Initially samples of all species found within the study area were collected and identified. Labeled specimens were prepared to assist in identification of sampling areas. Surveys of the vegetation were made by field excursions and by viewing from the adjacent ridges of the cirque. The latter technique allowed the whole sample area to be observed at one time and mosaic patterns of vegetation to be discerned. Early discriminating criteria for stand selection were color patterns and height of vegetation. Vegetation sampling was done using the line transect method and cover values were recorded to the nearest cm. Transects were 30 m. in length except for transect 14, which had to be broken into two 15 m. lengths to accommodate the shape of the stand, which was disrupted by large rock outcrops. Exact location of the transects within the subjectively chosen stands, was determined by placing a tape marked in cm. across the width of the stand and drawing a random number from tables to identify a position along the tape.

Major topographic features associated with the stands were small ridge formations and running or standing water, all of which aided in initial stand discrimination.

Positions of the transects are shown in Figure 1. Transect 1 was placed at the first level area reached at the base of the west wall. Transects 2 and 3 were placed along the first major ridge formation which dissected the cirque basin into east-west sections. Transect 4 was in a level area close to transect 1 but which was set off by an east-west running ridge formation. These first four transects were located at the same level on the first of three step-like formations, which descend in elevation as you move towards the east. The next four transects, 5, 6, 7, and 8, were located on the second plateau, which was also divided down the middle by an east-west running ridge formation. Transect 5 was located on the south side of this dividing ridge in a level area containing an open shrub community. Transect 6, on the north side of the dividing ridge, stood out initially as a tall grass community, which upon closer inspection was seen to have many different species contained within it. Transect 7 was another grass community located between ridge walls and a shrub community. Transect 8 was located along the east-west running ridge which dissected the second plateau and was composed of large shrubs on uneven terrain.

Transect 9 was located on the third plateau area just at the base of the second plateau, and its most evident feature was abundant standing water leading to marsh or bog-like conditions. Transects 10 and 11 were located on either side of an exposed rock surface which occupied the lower section of the third plateau. Transect 12 was located at the narrowest part of the cirque, through which meltwater from the higher snowbanks is funneled. Transect 13 was located at the lower edge of the north facing wall. Transect 14 was located at the lower edge of the south facing wall. The south facing wall is continuously disrupted by rock in all areas except at the lower edge. Vegetation was sampled at the end of July and the beginning of August, when most plants were in full bloom and could be more easily identified.

ANALYTICAL TECHNIQUES

TEMPERATURE

To compare max-min temperature stations on a monthly basis, temperature averages were calculated for July, August, and September. In July the thermometers were checked 12 times over a period of 19 days with the exception of T2 and T3, which had 1 and 2 less observations respectively, due to dislodgement by high winds. In August there were 20 observations over a 31 day period, and in September there were 10 observations over a 12 day period, at each station. Observations were stopped after September 12, 1976.

Values were calculated for the missing observations using the formula:

$$X = \frac{AT + bB - S}{(a-1)\ (b-1)}$$

where A equals the number of tripods, b equals the number of observations, T equals the sum of the items within the treatment with the missing observation, and B equals the sum of the observations for the day with the missing observation, and S equals the sum of all the observations for the month. The missing data were subjected to an iterative process using the formula, until the values remained constant. Missing values needed to be estimated, to analyze data by the 2-way Anova technique. The 2-way Anova requires that for the sites used, data must be available from each site on the same day. The formula calculates values for the missing data without affecting the variances among the stations. Analysis was done for each of the three months using a 2-way Anova, with a loss of a degree of freedom for each of the estimated values in the month of July. Analysis was done on the minimum, maximum, and mean values for each tripod. When differences were obtained, further analysis was done using a Student-Nueman-Keuls test, which is a valid method for a posteriori analysis. Treatment means were ranked and horizontal lines connecting the ranked treatment means show groups which did not differ significantly at the 0.05 level of significance. Overlapping lines constitute a problem in interpreting differences between groups. Overlap could be interpreted as a continuum, or as a distinct group lying between adjacent groups.

Values of ambient surface air temperature from thermographs were analyzed using a 2-way Anova, with 11 recording days in July, 25 in August and 12 in September. The data from thermograph A were not analyzed in July due to too few observations in common with the other thermographs. The deficit resulted from equipment failure. SNK tests were used for a posteriori analysis.

Values of ambient surface air temperature from max-min thermometers were also analyzed using a 2-way Anova. One of the positions (C4) was not established until after July, leaving only 3 sites to be compared for the month of July. SNK tests were used for a posteriori analysis. There were 11 recording days in July, 20 in August, and 10 in September.

VEGETATION

All vegetation values were converted to relative cover. Values for bare ground and water were not used in the analysis. Data were analyzed by a computer program clustering routine, written by Goldstein and Grigal (1972), and modified to run on the Harris 220 at Portland State University. The clustering routine recomputes a new similarity matrix every time a new cluster has been formed. Analysis begins with all the original transects as distinct groups and proceeds by joining one group with its closest neighbor as determined by the similarity matrix formed. Computation ends when all groups have been joined into one group.

The program has several options which can be employed to arrive at different clustering patterns. Two similarity measures were used. One is the standard distance and is well described by Orloci (1967). Standard distance allows a comparison of communities with unequal species numbers by first standardizing the original data values. Standard distance has the advantage of not exaggerating the difference between species rich communities or over-estimating the similarity of species poor communities, which can occur with the use of absolute distance. This method employs the within group sum of squares and will fuse 2 groups if the increase of the within group sum of squares in the new fusion is less than it would be with a fusion of any of the remaining groups.

The data set in this method is represented by the matrix X; x_{ij} is the value of the ith species for the jth stand. Standard distance is then given by $d_{jj'}$, where j' is the stand compared with j and

$$d^2_{jj'} = \sum_i \left(\frac{x_{ij}}{V_j} - \frac{x_{ij'}}{V_{j'}} \right)^2$$

and where

$$V^2_j = \sum_i X^2_{ij} \qquad \text{(Goldstein and Grigal 1972)}$$

The second similarity measure used is the product-moment correlation coefficient. This measure has found frequest use in classification work. It has been used in plant and animal taxonomy (Michener and Sokal, 1957: Soria and Heisner, 1961; Hendrickson and Sokal, 1968) and in ecology by Fujii (1969). A review of its use in plant community classification is given by Greig-Smith (1964). Theoretical considerations of the product-moment correlation coefficient are well discussed by Sneath and Sokal (1973).

With this program a new matrix G is established by column centering and standardizing the original data matrix X. The new matrix G is given by

$$g_{ij} = \frac{X_{ij} - \frac{1}{r} \sum_i X_{ij}}{\sqrt{\sum_i (x_{ij} - \frac{1}{r} \sum_i X_{ij})^2}}$$

where r is the number of species in the original data matrix X. From this $Q = G^tG$ where $q_{jj'} = q_{j'j}$ is the correlation coefficient between stands j and j'. The superscript t is the transpose of matrix G (Goldstein and Grigal 1972).

A weighted pair-group option and an unweighted pair-group option of linkage was used with each of the similarity measures. Thorough discussions of these methods are given in the literature. (Sokal and Sneath, 1963: Sneath and Sokal, 1973). With the weighted pair-group method, the position of a newly formed cluster is given by the midpoint of a line joining the two newly joined groups. The unweighted pair-group method uses the center of mass of the newly formed group in which uneven size clusters will shift the new center towards the larger of the two clusters. Comparing resulting dendrograms with original similarity matrices, Sneath (1969) found less distortion with the unweighted pair-group method. The weighted pair-group method will place more importance on clusters joined at later iterations. Still the choise of weighting is unresolved and both methods were used in this study.

A vector representation of the two methods is given by the following discussion taken from Goldstein and Grigal (1972). If a group is located at $\vec{r}_a$ and has n_a individuals, and a group b at $\vec{r}_b$ with n_b individuals, then the fusion of the two groups into a group c can be seen as $\vec{r}_c = \frac{\vec{r}_a + \vec{r}_b}{2}$ with the weighted pair-group method.

The unweighted pair-group can be represented by $\vec{r}_c = \frac{n_a\vec{r}_a + n_b\vec{r}_b}{n_a + n_b}$

The number of groups at any level can be determined from the dendrograms by drawing a horizontal line out from the Y axis. The number of intersections of this line with vertical transect lines, is the number of groups at the level of the horizontal line (see Figure 4). Groups represent plant communities as determined by species cover data.

Since the dendrograms formed with the clustering routine offer no clear decision on the number of communities, an analysis of environmental variables measured in each stand was done corresponding to the various groupings produced by the clustering routines. The analysis was done using a stepwise multiple discriminant analysis program contained within the BMD statistics package (Dixon 1970). The stepwise multiple discriminant analysis (SMDA) program, BMD07M, performs a multiple group discriminant analysis by computing a set of linear classification functions by selection of the independent variables in a stepwise manner. A variable may be deleted from the process when its F value becomes too low.

From the wealth of information determined by the SMDA routine, 3 values were used for the analysis of the transect variables. The first is the U statistic for each grouping which gives a measure of how much of the variance is accounted for by the groups in which the data has been placed. The idea is that the stands which are natural communities will have similar environments and that the variance within the community types will be small. Other data extracted from the SMDA output is a matrix of F values showing which communities are different from analysis of the environmental variables. A table of classifications is shown with a listing of the classification of sites within communities.

The analysis was run using the soil temperatures and soil moisture taken at every 6 m. Soil temperatures were at the surface and

3 cm. levels. The 10 cm. level could not be run due to 2 of the stands having insufficient soil depth. The analysis was done on 2 - 10 groups, which were determined by the dendrogram analysis. At the 3, 4, 7, and 8 group level, there were 2 different ways of arranging the transects. The analysis was done both ways except for the 8 group level, which was done only one way as it would have required an extensive rearrangement of the data file to do it both ways.

U.S. WEATHER BUREAU DATA

Since temperature measurements were taken for one season only, variability among years can not be accounted for. Consequently, data from three U.S. Weather Bureau stations is shown in order to make a generalization about the temperature and moisture of the summer of 1976 on the Steens. The stations used were from the Hart Mountain Refuge at an elevation of 1700 m., the P-Ranch Refuge at an elevation of 1280 m., and the Andrews Weston Mine at an elevation of 1406 m. These stations approximate a triangle around the Steens and are shown in Figure 2.

Information on temperature and precipitation were used from these stations for the test year (1976) and the previous 5 years. These values are tabulated for 4 months (June-September) and the 5 year averages are calculated. Temperature totals are shown in Table 1. All stations show June 1976 to be a cooler month than the previous five year average. This difference will not affect the interpretation of the measured temperature data on the Steens as no measurements were taken in this month. July 1976 approximates the 5-year average to within 0.06 C. August 1976 is seen to be appreciably colder than the 5-year average, while September 1976 is seen to be slightly warmer. Even with these variations, July is normally the warmest month and was found to be so in 1976. No simple correction factor was calculated, since this would assume that variations seen at these stations were consistent with variations at the summit of Steens Mountain. Due to the unique nature of weather patterns at high elevations this assumption was unwarranted, and any correction factor could be misleading.

Precipitation totals for the same three stations are shown in Table II, for the same 5-year period and for 1976. The figures indicate a much wetter 4 months for the summer of 1976, particularly in the month of August. The summer average is greater for all the stations except Hart Mountain Refuge. This is indicative of how greatly precipitation can vary, even over the small area contained within the weather stations. It is believed that this variance is due to precipitation being caused by local convectional showers, which were observed frequently over and around the Steens.

CHAPTER IV

RESULTS

TEMPERATURE DATA

Results of the analysis for the tripod stations are given in Tables III-V. It is felt that the difference in the minimum temperatures for July and August are due to the effects of wind. T1, which sits on the west facing slope of the mountain, is an open area with no topographic protection. T4, which sits on the lip of the cirque, receives the winds which are funneled down through the cirque and exit at the site of this station. Wind-water interaction may also play a role here as this is the drainage opening for meltwater from higher snowbanks. In August, the maximum temperatures for T1 and T4 are different, which is most likely due to the shortening day length, which causes the area around T1 to fall into the shadow of the summit for a longer period of time. The consistent higher temperatures for T3 and T2 are believed to be due to aspect effects. T2, on the east facing ridge of the cirque, receives the morning sun earlier than the other sites and is high enough not to be blocked out by the summit in the afternoon. The high temperature for T3 both in its maximum and minimum temperatures, are thought to be due to the gentle slope at this site. The angle of incidence for incoming radiation is greater, thus causing more radiation to be absorbed per unit area, while the slope is enough to keep cold air moving downslope at night.

Results of the analysis for the thermographs are given in Tables VI-VIII. The lowest mean temperature was at D, which is

TABLE I

MONTHLY TEMPERATURE MEANS
U.S. WEATHER BUREAU

	ANDREWS WESTON MINE				HART MT. REFUGE				P-RANCH REFUGE			
	JUNE	JULY	AUG.	SEPT.	JUNE	JULY	AUG.	SEPT.	JUNE	JULY	AUG.	SEPT.
1975	59.7	74.2	66.3	65.1	52.5	63.5	57.6	....	58.1	68.4	62.0	57.4
1974	68.7	71.3	70.6	66.1	59.7	61.2	60.5	57.1	65.3	65.8	63.7	58.2
1973	64.3	73.9	73.0	60.9	56.6	63.6	61.8	54.8	61.0	66.7	67.0	56.6
1972	64.8	72.0	72.9	57.0	56.9	63.5	63.2	50.4	62.2	66.4	66.0	53.5
1971	60.4	70.7	76.3	56.3	51.6	63.3	66.7	50.6	59.3	67.6	71.1	59.7
5 yr. ave.	63.6	72.4	71.8	61.1	55.5	63.0	62.0	53.2	61.2	67.0	66.0	55.9
1976	59.7	72.5	63.4	62.6	52.3	63.0	56.4	56.5	57.6	66.9	60.8	58.2

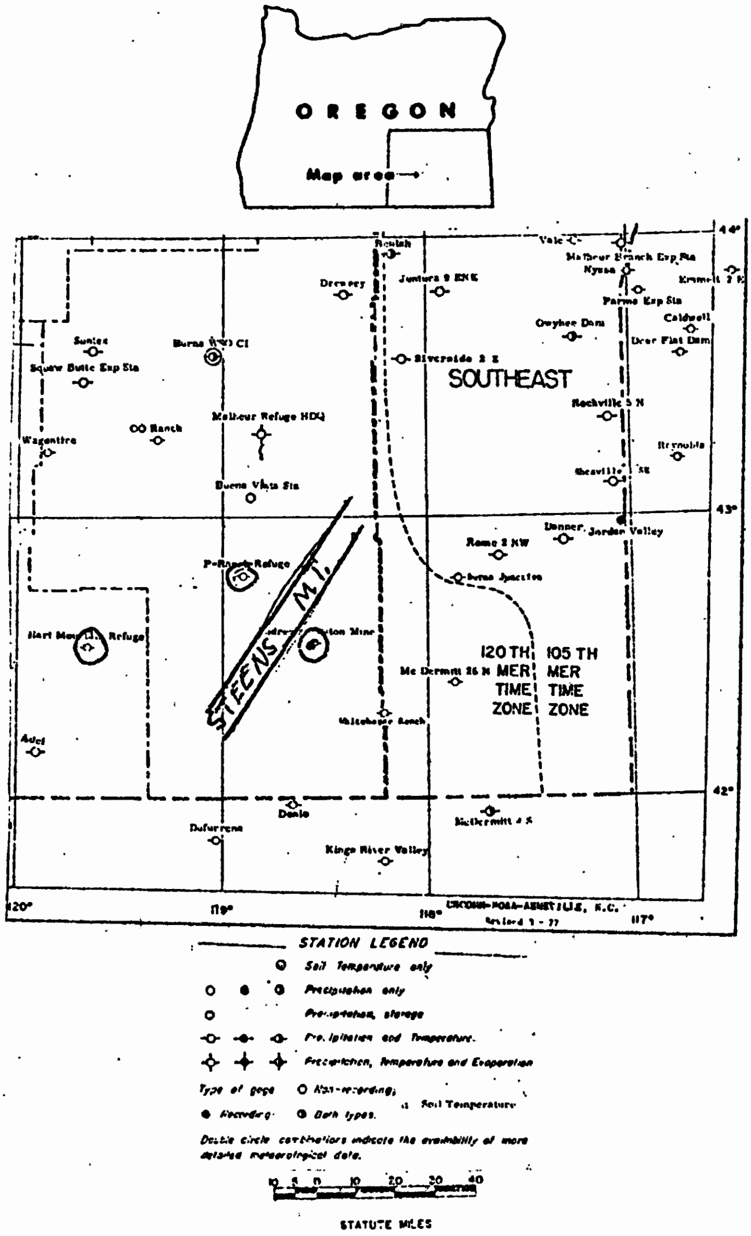
TABLE II

MONTHLY PRECIPITATION MEANS/TOTALS
U.S. WEATHER BUREAU

	ANDREWS WESTON MINE					HART MOUNTAIN REFUGE					P-RANCH REFUGE				
	JUNE	JULY	AUG.	SEPT.	TOT.	JUNE	JULY	AUG.	SEPT.	TOT.	JUNE	JULY	AUG.	SEPT.	TOT.
1975	1.11	0.43	1.91	0.09	3.54	4.51	1.82	0.21	0.43	6.97	2.24	1.35	0.78	0.01	4.38
1974	0.38	1.38	0.03	0.00	1.79	0.16	0.56	0.19	0.00	0.91	0.32	0.45	0.19	0.00	0.96
1973	0.66	0.24	0.23	1.28	2.41	0.06	0.04	0.49	1.09	1.68	0.26	0.15	0.24	1.20	1.85
1972	0.92	0.00	0.37	0.63	1.92	0.19	0.03	0.23	1.03	1.48	0.50	0.00	0.00	0.57	1.07
1971	1.48	1.16	0.08	2.34	5.06	1.21	0.71	0.00	1.71	3.63	1.87	0.34	0.16	1.66	4.03
5 yr. ave.	0.91	0.64	0.52	0.88	2.94	1.23	0.63	0.22	0.85	2.93	1.04	0.46	0.27	0.69	2.46
1976	0.47	1.50	2.31	1.60	5.88	0.45	0.37	1.33	0.39	2.54	1.23	0.48	3.07	1.28	6.06

FIGURE 2

U.S. WEATHER BUREAU STATIONS



located on the north facing wall of the cirque. The temperature differential between ground and shelter level at T1 for August and September is 3.63 and 3.97 C. At T3 the differentials for the three months of observations were 4.25, 2.31, and 4.58 C. At T4 the differentials were 0.08, 0.05, and 1.14 C. The smaller temperature difference between surface and shelter level at T4 supports the observation of greater wind in this area, which is causing a mixing of the air between the two measured levels. Temperature comparisons on a monthly basis for tripods and their companion thermographs, for mean temperatures from all data collected are given in Figure 3. Comparisons between tripods and associated thermographs are not strictly accurate due to variability in number of recording days between the two methods. They are considered useful in that they appear consistent and reflect observed conditions of greater persistent winds at T4.

Results of the analysis of Max-min temperatures which were in sites where Oxyria digyna were found are given in Tables IX-XI. In July, the mean temperatures are masking significant differences in the extreme values between the sites. G3 has an extreme range of 7.98 C., while G1 and G2 have extreme ranges of 14.75 and 13.48 C. G4 at Jackman Park, was not established until August. It shows the largest extreme range with values of 15.50 and 20.06 C. for August and September respectively. Over this same time period G3, also at Jackman Park, maintains the lowest extreme range with values of 6.17 and 10.47 C. In August and September, G1 had extreme range values of 12.24 and 13.39 C. and G2 had extreme range values of 10.22 and 11.33 C. respectively.

TABLE III

JULY TRIPODS
ANOVA TABLE MINIMUM TEMPS.

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	11	1047.2293	95.2027		
TREATMENT	3	44.8958	14.9653	3.4441	2.92
ERROR	30	130.3542	4.3451		
TOTAL	44	1222.4792			

ANOVA TABLE MAXIMUM TEMPS.

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	11	520.6667	47.3333		
TREATMENT	3	44.1667	14.7222	2.3513	2.92
ERROR	30	187.8333	6.2611		
TOTAL	44	752.6667			

ANOVA TABLE MEAN TEMPS.

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	11	503.1406	45.7401		
TREATMENT	3	32.0573	10.6858	5.4330	2.92
ERROR	30	59.0052	1.9668		
TOTAL	44	594.2031			

RANKED TREATMENT MEANS

	MIN.	MAX.	MEAN
	3- 5.833	3-19.306	3-12.569
	2- 5.185	2-18.982	2-12.083
	1- 4.861	4-18.657	4-11.713
	4- 4.352	1-17.870	1-11.343
Y=	5.0579	18.7037	11.9271
s=	1.1042	1.3254	0.7429

TABLE IV

AUGUST TRIPODS
ANOVA TABLE MINIMUM TEMPS

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	19	2738.6375	144.1388		
TREATMENT	3	25.8375	8.6125	3.2747	2.84
ERROR	57	149.9125	2.6300		
TOTAL	79	2914.3875			

ANOVA TABLE MAXIMUM TEMPS.

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	19	2780.7375	146.3546		
TREATMENT	3	173.2375	57.7458	17.1423	2.84
ERROR	57	192.0125	3.3686		
TOTAL	79	3145.9875			

ANOVA TABLE MEAN TEMPS.

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	19	2339.3625	123.1243		
TREATMENT	3	69.9125	23.3042	13.8781	2.84
ERROR	57	95.7125	1.6792		
TOTAL	79	2504.9875			

RANKED TREATMENT MEANS

	MIN.	MAX.	MEAN
	3- 2.278	2-14.333	3- 8.250
	2- 1.944	3-14.222	2- 8.139
	1- 1.639	4-13.583	4- 7.514
	4- 1.444	1-12.278	1- 6.958
Y=	1.8264	13.6042	7.7153
s=	0.9009	1.-197	0.7199

TABLE V

SEPTEMBER TRIPODS
ANOVA TABLE MINIMUM TEMPS.

SOURCE	DF	SS	MS	F	F(.05
REPLICATION	9	3576.7250	397.4139		
TREATMENT	3	62.0750	20.6917	2.1893	2.96
ERROR	27	255.1750	9.4509		
TOTAL	39	3893.9750			

ANOVA TABLE MAXIMUM TEMPS.

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	9	2576.1000	286.2333		
TREATMENT	3	75.8000	25.2667	3.9274	2.96
ERROR	27	173.7000	6.4333		
TOTAL	39	2825.6000			

ANOVA TABLE MEAN TEMPS.

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	9	2923.2500	324.8056		
TREATMENT	3	64.0250	21.3417	6.0911	2.96
ERROR	27	94.6000	3.5037		
TOTAL	39	3081.8750			

RANKED TREATMENT MEANS

	MIN.	MAX.	MEAN
	2- 2.222	2-15.889	2- 9.139
	1- 1.389	3-14.667	3- 7.917
	3- 1.167	4-14.278	1- 7.611
	4- 0.278	1-13.833	4- 7.277
Y=	1.2638	14.6667	7.9861
s=	1.7079	1.4091	1.0399

TABLE VI

JULY THERMOGRAPHS
ANOVA TABLE MINIMUM TEMPERATURES

SOURCE	DF	SS	MS	F	F(.05
REPLICATION	10	139.3455	13.9345		
TREATMENT	4	154.4364	38.6091	29.9504	2.61
ERROR	40	51.5636	1.2891		
TOTAL	54	345.3455			

ANOVA TABLE MAXIMUM TEMPS.

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	10	364.8364	36.4836		
TREATMENT	4	1001.2727	250.3182	81.0563	2.61
ERROR	40	123.5273	3.0822		
TOTAL	54	1489.6364			

ANOVA TABLE MEAN TEMPS.

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	10	111.2000	11.1200		
TREATMENT	4	353.9273	88.4818	88.3228	2.61
ERROR	40	40.0727	1.0018		
TOTAL	54	505.2000			

RANKED TREATMENT MEANS

	MIN.	MAX	MEAN
	F- 9.727	C-26.455	C-16.818
	B- 8.455	F-21.727	F-15.818
	C- 7.273	E-18.182	B-12.636
	D- 5.909	B-16.727	E-11.636
	E- 5.091	D-14.182	D-10.091
Y=	7-2909	19.4545	13.4000
s=	1.]354	1.7573	1.0009

TABLE VII

AUGUST THERMOGRAPHS
ANOVA TABLE MINIMUM TEMPERATURES

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	24	1739.5067	72.4794		
TREATMENT	5	304.9333	60.9867	20.6308	2.29
ERROR	120	354.7333	2.9561		
TOTAL	149	2399.1733			

ANOVA TABLE MAXIMUM TEMPS.

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	24	6492.0000	270.5000		
TREATMENT	5	1847.0733	369.4147	55.5678	2.29
ERROR	120	797.7600	6.6480		
TOTAL	149	9136.8333			

ANOVA TABLE MEAN TEMPS.

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	24	3453.8267	143.9094		
TREATMENT	5	646.3533	129.2707	52.6175	2.29
ERROR	120	294.8133	2.4568		
TOTAL	149	4394.9933			

RANKED TREATMENT MEANS

	MIN.	MAX.	MEAN
	F- 5.360	C-18.840	│A-10.640
	│A- 4.280	A-16.840	│C-10.560
	│B- 3.840	│E-12.760	F- 9.160
	│C- 2.520	│F-12.760	│E- 7.560
	│E- 2.200	B-11.160	│B- 7.360
	D- 1.080	D- 8.240	D- 4.680
Y=	3.2133	13.4333	8.3267
s=	1.7193	2.5784	1.5674

TABLE VIII

SEPTEMBER THERMOGRAPHS
ANOVA TABLE MINIMUM TEMPERATURES

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	11	1403.1111	127.5556		
TREATMENT	5	305.2778	61.0556	12.7817	2.45
ERROR	55	262.7222	4.7768		
TOTAL	71	1971.1111			

ANOVA TABLE MAXIMUM TEMPS.

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	11	1871.0000	170.0909		
TREATMENT	5	1651.8333	330.3667	71.2089	2.45
ERROR	55	255.1667	4.6394		
TOTAL	71	3778.0000			

ANOVA TABLE MEAN TEMPS.

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	11	1345.1528	122.2866		
TREATMENT	5	428.5694	85.7139	38.8760	2.45
ERROR	55	121.2639	2.2048		
TOTAL	71	1894.9861			

RANKED TREATMENT MEANS

	MIN.	MAX.	MEAN
	F- 6.833	C-24.250	C-12.500
	B- 5.167	A-18.500	F-11.667
	A- 4.667	F-16.833	A-11.583
	D- 1.917	E-14.833	B- 9.000
	E- 1.750	B-12.667	E- 8.417
	C- 1.333	D- 8.917	D- 5.417
Y=	3.6111	16.0000	9.7639
s=	2.1856	2.1539	1.4849

FIGURE 3

MONTHLY MEAN TEMPERATURES OF TRIPODS
AND COMPANION THERMOGRAPHS
ALL DATA

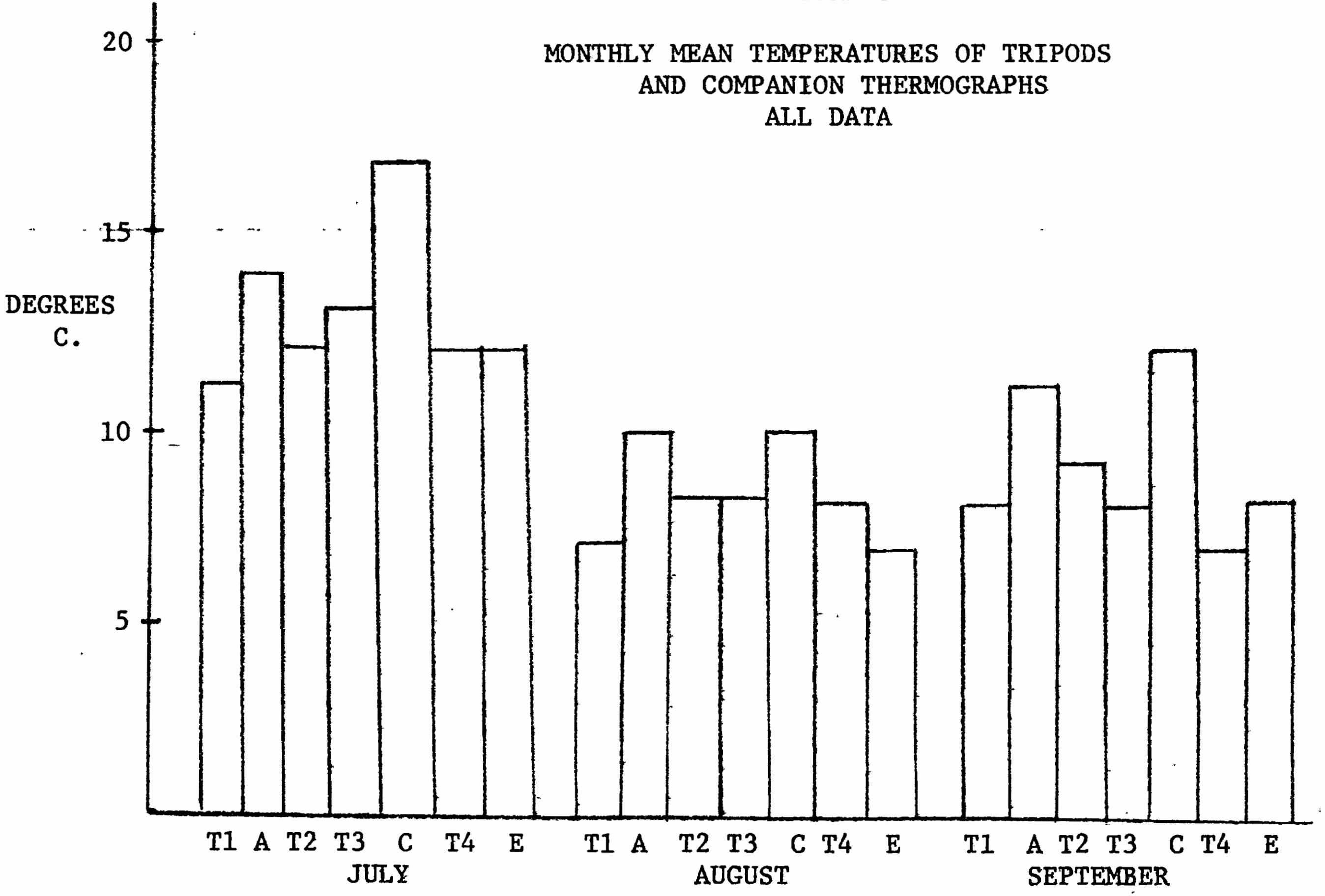


TABLE IX

JULY GROUND TEMPERATURES
ANOVA TABLE MINIMUM TEMPERATURES

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	10	442.0606	44.2061		
TREATMENT	2	142.9697	71.4848	7.118	3.49
ERROR	20	201.0303	10.0515		
TOTAL	32	786.0606			

ANOVA TABLE MAXIMUM TEMPS.

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	10	288.9697	28.8970		
TREATMENT	2	358.6061	179.3030	10.504	3.49
ERROR	20	341.3939	17.0697		
TOTAL	32	988.9697			

ANOVA TABLE MEAN TEMPS.

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	10	199.8485	19.9848		
TREATMENT	2	24.8636	12.4318	2.1626	3.49
ERROR	20	114.9697	5.7485		
TOTAL	32	339.6818			

RANKED TREATMENT MEANS

	MIN.	MAX.	MEAN
	G3- 8.434	G1-20.808	G1-13.536
	G1- 6.061	G2-19.394	G3-12.424
	G2- 5.909	G3-16.414	G2-12.399
Y=	6.801	18.872	12.752
s=	1.7613	2.2953	1.3320

TABLE X

AUGUST GROUND TEMPERATURES
ANOVA TABLE MINIMUM TEMPERATURES

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	19	1828.0500	96.2132		
TREATMENT	3	604.0500	201.3500	28.447	3.23
ERROR	57	403.4500	7.0781		
TOTAL	79	2835.5500			

ANOVA TABLE MAXIMUM TEMPS.

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	19	1625.2500	85.5395		
TREATMENT	3	1333.0500	444.3500	23.794	3.23
ERROR	57	1064.4500	18.6746		
TOTAL	79	4022.7500			

ANOVA TABLE MEAN TEMPS.

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	19	1567.5750	82.5039		
TREATMENT	3	218.9000	72.9667	13.049	3.23
ERROR	57	318.7250	5.5917		
TOTAL	79	2105.2000			

RANKED TREATMENT MEANS

	MIN.	MAX.	MEAN
	G3- 5.472	G4-17.222	G4- 9.472
	G1- 2.472	G1-14.917	G1- 8.694
	G2- 1.833	G2-12.056	G3- 8.556
	G4- 1.722	G3-11.639	G2- 6.944
Y=	2.875	13.958	8.417
s=	1.4780	2.4008	1.3137

TABLE XI

SEPTEMBER GROUND TEMPERATURES
ANOVA TABLE MINIMUM TEMPERATURES

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	9	1839.1000	204.3444		
TREATMENT	3	395.6000	131.8667	14.538	2.99
ERROR	27	244.9000	9.0704		
TOTAL	39	2479.6000			

ANOVA TABLE MAXIMUM TEMPS.

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	9	1657.4000	184.1556		
TREATMENT	3	1512.5000	504.1667	31.954	2.99
ERROR	27	426.0000	15.7778		
TOTAL	39	3595.9000			

ANOVA TABLE MEAN TEMPS.

SOURCE	DF	SS	MS	F	F(.05)
REPLICATION	9	1666.9000	185.2111		
TREATMENT	3	157.0250	52.3417	6.6866	2.99
ERROR	27	211.3500	7.8278		
TOTAL	39	2035.2750			

RANKED TREATMENT MEANS

	MIN.	MAX.	MEAN
	G3- 4.000	G4-19.278	G4- 9.250
	G1- 2.444	G1-15.833	G1- 9.139
	G2- 1.222	G2-12.556	G3- 7.111
	G4- -.778	G3-10.222	G2- 6.889
Y=	1.722	14.472	8.097
s=	1.6732	2.2067	1.5543

SNOW BANK RECESSION

Many species in the alpine environment are often seen to be dependent for their success upon the influence of late-lying snowbanks. Snowbanks work their influence in essentially two different ways. In their persistence, they form a ground cover which can both inhibit plants from germination and growth, and protect them from cold and wind. They also provide a source of moisture late into the growing season upon which many plants can depend. Rates of recession values range between 0.5 to 1.0 = m./day. The measurements show large deviations even within the same measuring period, which would seem to be an effect of local micro-climates coupled to different topographies. Measurements do not show any consistent patterns with aspect as evidenced by the south facing snowbank's lower rate of recession on comparable periods. Rates of recession do not appear to be strictly correlated with average temperature by cursory inspection of the data. As no measurement of snow depth was made at each site, the lack of consistent pattern may be due to differences in snow depth. One interesting observation is the effect that rain had on the rates of recession at least at particular sites within a snowbank. The measurements taken on July 20, correspond to a dry period. Those taken on July 21 were measured after a locally heavy rain had occurred that previous night. Some of the measurements had high values (7.59 and 10.20 m.) compared to a lower range the previous day (3.76 to 4.35 m.). It is emphasized that these measurements were taken on different snowbanks at times not strictly comparable. Even though, they seem to indicate the importance of rainfall in increasing the rate of snowbank depletion.

TABLE XII

SNOWBANK MEASUREMENTS
(METERS/DAY)

DATE AND TEMPERATURE	SNOWBANK 1	SNOWBANK 2	SNOWBANK 3	SNOWBANK 4
JULY 12 T2 = 10.8 C.	Y = 0.7900 S = 0.3559	Y = 1.0970 S = 0.3842	Y = 0.9556 S = 3929	Y = 0.9125 S = 0.4542
JULY 15 T2 = 11.4 C.	Y = 0.4989 S = 0.1440	Y = 0.5587 S = 0.2427	Y = 0.6367 S = 0.2522	Y = 0.5653 S = 0.2729
JULY 20 T2 = 13.9 C.			Y = 0.5456 S = 0.2527	Y = 0.5324 S = 0.1703
JULY 21 T2 = 12.8 C.	Y = 0.9144 S = 0.6412	Y = 0.5450 S = 0.3181		
JULY 28 T2 = 11.4 C.			Y = 1.0698 S = 0.3884	Y = 0.5582 S = 0.1136
JULY 30 T2 = 13.2 C.	Y = 0.7587 S = 0.4896	Y = 0.7031 S = 0.1181		

Y = AVERAGE RECESSION RATE IN METERS/DAY
S = STANDARD DEVIATION OF THE MEAN

CIRQUE VEGETATION

Cover values for the species sampled in the line transects are shown in Table XIII. Taxonomic classification authorities are listed with the total species list (Table XV). Values for the soil temperatures and pH are given in Table XIV. pH values appeared quite similar and due to the fact that they were not measured in the field, were not used in any further analysis of the vegetation stands.

Dominant plants in the shrub communities were *Potentilla fruticosa* and *Salix nivalis*. In transect 14, a different shrub, *Artemisia arbuscula*, is a codominant plant. This stand has 6 species found in no other stand, and 8 species found in no other stand except in stand 13. Both of these stands are located on the lower edges of the cirque walls. Stands 1, 4, 6, and 7 show a temperature inversion at the 3 cm. level. All of these stands have a high cover of grasses. Transects with high soil moisture are indicated by the presence of high cover values of *Carex* spp. and *Caltha leptosepala*, usually associated with the presence of *Salix nivalis* as a dominant species. Of the 57 species sampled in the vegetation transects (mosses and *Helenium hoopsii* were not included, the latter being an endemic species), 42 are known to have distributions in the alpine tundra (Table XV). These 42 species account for 92.5% of the vegetation cover in all the sampled areas, of all the communities in the cirque.

TABLE XIII

SPECIES COVER IN RELATIVE PERCENT
TRANSECT NUMBERS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Achillea millefolium	01.78	00.43	00.28	00.40	00.10	00.87	05.03	-	-	-	-	-	04.10	-
Antennaria alpina	04.12	01.33	-	03.87	00.87	01.70	09.33	00.27	-	-	-	-	-	-
Antennaria umbrinella	-	-	-	-	-	00.17	01.10	-	00.10	-	-	-	01.63	-
Arctostaphylos uva-ursi	-	-	06.38	-	-	-	-	-	-	-	01.87	-	-	-
Arenaria aculeata	-	-	-	-	-	-	00.20	-	-	-	-	-	03.00	-
Arenaria rubella	-	-	-	-	-	-	-	-	-	-	-	-	-	00.80
Arnica mollis	-	-	-	04.50	-	10.47	00.47	-	-	-	-	-	-	-
Arnica longifolia	-	-	-	-	-	01.87	-	-	-	-	-	-	-	-
Artemisia arbuscula	-	-	-	-	-	-	-	-	-	-	-	-	-	13.80
Caltha leptosepala	-	-	-	-	-	-	02.57	-	10.37	00.97	01.83	-	-	-
Carex species	00.25	00.57	01.33	01.70	00.53	00.17	02.27	00.67	24.57	04.70	16.00	13.07	01.73	-
Castilleja miniata	-	-	-	-	-	0.50	-	01.73	02.37	-	-	-	-	-

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Cerastium berringianum	00.18	00.17	-	-	-	-	-	-	-	-	-	-	-	-
Delphinium bicolor	00.06	-	-	-	-	-	-	-	-	-	-	-	-	-
Epilobium alpinum	-	-	-	00.30	-	-	00.10	-	-	-	-	-	-	-
Erigeron peregrinus	00.34	-	-	00.77	-	00.40	03.43	-	-	00.47	-	-	-	-
Eriogonum caespitosum	-	-	-	-	-	-	-	-	-	-	-	-	00.27	-
Erigeron heracleoides	-	-	-	-	-	-	-	-	-	-	-	-	00.27	-
Eriogonum umbellatum	-	-	-	-	-	-	-	-	-	-	-	-	03.07	09.30
Festuca species	13.45	04.90	02.95	02.37	09.83	32.33	05.10	08.93	00.10	-	02.80	00.13	10.17	-
Haplopappus macronema	-	-	-	-	-	-	-	-	-	-	-	-	-	02.37
Helenium hoopsii	08.04	03.33	01.40	04.33	01.80	04.37	04.97	-	-	-	-	-	-	-
Ivesia gordonii	-	-	-	-	-	-	-	-	-	-	-	-	00.83	-
Juniperus communis	-	-	04.28	-	-	-	-	01.30	-	-	-	-	-	-
Kalmia microphylla	02.03	-	-	-	00.60	00.10	00.77	01.90	01.33	00.50	00.50	-	-	-
Linum perenne	-	-	-	-	-	00.80	-	-	-	-	-	-	-	-

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Lomatium dissectum	-	-	-	-	-	25.37	-	-	-	-	-	-	-	-
Lupinus caudatus	-	-	-	-	-	-	-	-	-	-	-	-	-	00.73
Luzula campestris	00.37	-	-	-	-	-	-	-	-	-	-	-	-	-
Luzula spicata	-	-	-	00.10	-	01.27	00.53	01.63	00.67	00.20	-	00.77	-	-
Mimulus primuloides	-	-	-	-	-	-	-	-	-	-	01.23	-	-	-
Moss species	00.55	-	-	-	01.33	00.50	00.13	-	02.97	00.73	00.80	00.27	-	-
Parnassia fimbriata	-	-	-	-	-	-	-	01.10	-	-	-	-	-	-
Pedicularis attollens	03.26	-	-	03.27	-	02.60	04.00	-	00.27	-	-	-	-	-
Penstemon procerus	-	-	-	-	-	-	00.40	-	-	-	-	-	-	-
Phleum alpinum	01.69	-	-	-	-	00.13	02.97	01.30	-	01.90	-	-	-	-
Poa species	10.19	-	00.07	29.10	01.13	-	10.43	00.33	-	-	-	-	-	-
Polygonum bistortoides	-	-	-	01.30	00.27	00.70	-	00.10	-	-	-	-	-	-
Potentilla breweri	02.65	00.17	00.95	07.17	00.30	03.33	04.00	00.83	-	-	-	-	-	-
Potentilla brevifolia	-	-	-	-	-	-	-	-	-	-	-	-	00.40	02.37
Potentilla coccina	-	-	-	00.73	01.83	00.13	06.67	00.33	-	-	-	-	-	-

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Potentilla diversifolia	00.37	02.23	00.51	00.07	01.17	-	00.70	01.93	02.27	02.17	01.03	-	01.57	-
Potentilla fruticosa	11.51	81.00	56.79	02.90	15.13	02.63	05.15	28.57	03.60	08.67	27.53	01.50	32.27	-
Ranunculus eschscholtzii	-	-	-	-	-	-	-	-	-	-	01.50	-	-	-
Ribes montigenum	-	-	-	-	-	-	-	-	-	-	-	-	-	13.57
Salix nivalis	-	-	12.63	-	48.70	00.13	03.03	21.90	32.73	75.80	28.87	82.67	-	-
Saxigraga integrifolia	-	00.63	02.28	00.80	08.30	-	-	02.30	-	-	00.27	-	-	-
Sedum lanceolatum	-	-	-	-	-	-	-	-	-	-	-	-	00.83	-
Senecio crassulus	06.65	-	-	08.60	-	00.20	03.20	00.10	-	-	-	-	-	-
Senecio fremontii	00.62	-	-	-	-	-	-	-	-	-	-	-	-	00.13
Senecio integerrimus	02.92	-	-	-	00.77	-	00.50	-	-	-	00.40	-	03.50	-
Sibbaldia procumbens	-	-	-	-	-	-	01.30	-	00.33	-	-	-	-	-
Sitanion hystrix	-	-	-	-	-	-	-	-	-	-	-	-	-	01.20
Solidago multiradiata	-	-	00.92	-	-	-	-	04.83	-	-	-	-	-	-
Swertia perennis	-	-	-	-	-	-	-	00.37	00.37	-	01.03	-	-	-
Trifolium multipedunculatum	02.65	00.13	00.13	01.73	01.30	02.53	00.90	00.37	01.07	-	-	-	00.43	-

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Vaccinium caespitosum	02.16	00.53	-	00.60	00.83	01.50	02.77	01.60	-	-	-	-	-	-
Zygadenus elegans	00.34	-	-	-	-	00.30	-	-	00.13	-	01.70	-	-	-
Herbs (unidentified)	00.25	-	00.86	-	00.20	00.30	-	-	00.70	-	-	-	-	03.27
Bare Ground	21.95	03.53	04.50	19.10	02.17	04.00	05.33	09.10	-	-	02.40	01.40	14.00	39.3-
Rock	01.60	-	03.33	06.23	-	00.63	12.67	01.40	-	-	01.50	-	18.93	06.77
Water (running)	-	-	00.48	-	-	-	-	07.10	02.53	-	02.30	-	-	-
Water (standing)	-	-	-	-	02.83	-	-	-	14.23	03.20	06.43	00.20	-	-

TABLE XIV

SOIL MOISTURE, TEMPERATURE, AND pH

TRANSECT 1					TRANSECT 2					
SM	pH	T3	T10	Ts	SM	pH	T3	T10	Ts	
15.6	5.6	20.1	13.0	18.7	13.0	6.0	9.9	6.1	14.4	
		20.8	10.1	17.8			10.5	6.5	15.0	
19.0	6.3	20.1	14.7	18.7	7.6	6.6	9.3	6.5	15.3	
		18.5	13.3	14.6			10.2	5.3	14.8	
14.9	6.7	18.4	11.6	16.9	11.0	6.4	8.6	5.7	13.4	
		17.6	11.7	15.3			8.7	7.3	13.4	
12.3	6.7	16.9	11.9	14.7	12.3	6.8	14.7	8.8	14.6	
		18.0	12.9	16.8			11.6	8.6	14.7	
17.6	6.0	19.2	10.7	15.5	17.6	5.9	12.1	9.1	14.7	
		17.2	12.0	16.3			11.5	8.5	14.0	
15.8	6.3	17.7	12.2	16.5	12.3	6.3	10.7	7.2	14.4	= Y
2.58	.47	3.25	1.33	1.52	3.62	.38	1.85	1.41	.64	= S

TRANSECT 3					TRANSECT 4					
SM	pH	T3	T10	Ts	SM	pH	T3	T10	Ts	
21.9	6.2	10.4	6.9	14.9	16.3	5.8	14.0	9.9	15.6	
		10.8	6.5	13.9			18.6	10.0	16.6	
21.9	6.3	10.7	7.0	14.9	20.4	5.9	20.3	11.7	16.0	
		13.1	7.8	15.7			17.6	11.7	15.8	
23.4	6.4	10.4	7.7	14.4	17.6	5.9	18.0	13.0	16.6	
		9.9	7.4	14.9			13.5	9.8	15.2	
23.4	6.5	9.2	5.8	16.9	14.9	6.1	17.5	7.9	16.5	
		11.4	7.6	14.1			14.6	12.4	17.2	
19.0	6.3	9.0	6.3	14.9	19.0	5.5	20.9	15.7	18.8	
		9.1	6.3	13.6			17.8	11.4	15.2	
21.5	6.3	10.4	6.9	14.8	17.6	5.8	17.3	11.4	16.4	= Y
1.84	.11	1.24	.69	.95	2.16	.22	2.52	2.14	1.08	= S

TRANSECT 5

SM	pH	T3	T10	Ts
9.8	5.8	14.3	8.7	18.2
		12.9	8.1	17.4
8.7	6.1	11.6	7.6	15.9
		13.0	8.2	16.5
12.3	6.2	12.8	7.5	14.6
		11.9	7.4	14.0
11.0	5.9	17.0	7.6	16.2
		15.6	7.7	15.4
11.0	6.1	10.0	6.6	13.3
		9.5	6.6	14.1
10.6	6.0	12.9	7.6	15.6
1.36	.16	2.33	.66	1.58

TRANSECT 6

SM	pH	T3	T10	Ts
9.8	5.9	17.0	10.6	16.3
		16.3	10.4	15.1
12.3	6.1	10.9	7.2	16.3
		16.7	9.8	16.2
21.9	6.1	19.3	8.7	16.7
		14.4	8.6	15.6
20.4	6.5	18.2	9.5	15.4
		13.2	9.3	14.1
20.4	6.2	16.3	9.3	14.7
		21.2	11.1	14.4
17.0	6.2	16.4	9.4	15.5 = Y
5.50	.22	2.97	1.13	.89 = S

TRANSECT 7

SM	pH	T3	T10	Ts
16.3	6.2	18.0	11.9	14.9
		22.6	12.8	16.4
21.9	5.9	21.9	12.4	14.0
		18.7	13.6	15.6
21.2	6.0	18.5	13.9	14.9
		19.2	14.8	15.3
17.6	5.7	17.0	10.6	13.2
		22.0	11.3	16.6
20.4	5.6	18.4	10.6	14.2
		16.8	9.2	16.3
19.5	5.9	19.3	12.1	15.1
2.40	.24	2.12	1.73	1.12

TRANSECT 8

SM	pH	T3	T10	Ts
17.6	5.8	15.4	8.5	15.6
		12.0	8.2	15.2
23.4	6.1	13.4	7.5	18.8
		11.5	8.5	14.6
28.2	6.1	9.2	7.6	13.5
		15.6	9.4	13.4
24.2	6.3	9.8	6.8	13.2
		17.4	11.0	15.0
20.4	6.3	13.9	7.6	16.0
		11.1	6.8	17.0
22.8	6.1	12.9	8.2	15.2 = Y
4.00	.20	2.67	1.27	1.75 = S

TRANSECT 9					TRANSECT 10					
SM	pH	T3	T10	Ts	SM	pH	T3	T10	Ts	
19.0	6.4	11.4	5.9	20.2	33.3	6.4	7.8	5.1	16.0	
		9.6	6.8	16.2			7.2	5.3	12.4	
31.5	6.6	8.4	5.4	13.8	28.2	5.4	10.1	6.0	17.2	
		10.6	6.8	14.7			9.7	5.1	14.8	
38.8	6.8	7.4	6.6	13.8	26.5	5.2	7.5	3.8	14.3	
		11.2	7.2	11.9			7.0	4.7	15.0	
29.8	6.4	7.9	7.1	13.5	29.8	6.6	7.6	5.4	14.4	
		7.1	6.7	11.8			7.9	4.9	15.3	
33.3	6.8	9.0	7.0	15.0	33.3	6.9	7.0	5.5	14.8	
		11.3	6.6	18.0			8.6	6.0	17.4	
30.5	6.6	9.4	6.6	14.9	30.2	6.1	8.0	5.2	15.2	= Y
7.25	.20	1.67	.56	2.63	3.04	.75	1.09	.64	1.46	= S

TRANSECT 11					TRANSECT 12					
SM	pH	T3	T10	Ts	SM	pH	T3	T10	Ts	
25.0	6.3	16.2	7.3	15.8	26.5	6.9	8.7	5.5	17.3	
		18.2	8.8	14.6			10.9	5.3	16.8	
28.2	6.7	13.5	7.1	14.6	26.5	6.8	8.5	5.5	15.9	
		8.6	7.6	17.0			5.3	5.0	17.4	
28.2	6.6	14.4	7.5	13.5	26.5	6.8	7.8	5.5	17.6	
		10.6	7.2	17.7			7.9	4.9	19.4	
25.0	6.6	16.1	9.9	13.5	29.8	6.8	8.4	4.8	18.8	
		16.8	9.8	15.4			7.4	4.8	15.7	
25.0	6.7	11.2	7.5	16.4	31.5	6.7	7.9	5.6	14.1	
		16.0	10.0	17.9			8.6	5.6	14.8	
26.3	6.6	14.2	8.3	15.6	28.2	6.8	8.1	5.3	16.8	= Y
1.75	.16	3.12	1.22	1.61	2.35	.07	1.38	.34	1.68	= S

TRANSECT 13					TRANSECT 14					
SM	pH	T3	T10	Ts	SM	pH	T3	T10	Ts	
7.6	6.4	15.6		19.8	2.1	6.7	30.0		31.4	
		11.6		19.7			21.6		27.8	
11.8	6.8	19.1		18.4	4.3	6.5	23.4		21.6	
		12.2		16.9			32.9		28.8	
7.6	6.5	22.6		18.5	11.0	6.5	17.6		24.8	
		17.3		18.9			25.3		20.6	
5.4	6.2	21.2		20.1	2.1	6.7	22.6		23.6	
		18.8		18.9			23.9		24.3	
5.4	6.2	16.3		18.0	2.1	6.6	23.2		24.3	
		22.2		21.4			26.2		27.2	
7.4	6.4	17.7		19.1	4.4	6.6	24.7		25.4	= Y
2.29	.25	3.85		1.25	3.85	.10	4.31		3.33	= S

SM - SOIL MOISTURE PERCENT OF DRY WEIGHT
T3 = SOIL TEMPERATURE AT 3 cm. DEPTH
T10 = SOIL TEMPERATURE AT 10 cm. DEPTH
Ts = SOIL TEMPERATURE AT SOIL SURFACE
Y = MEAN
S = STANDARD DEVIATION OF THE MEAN

TABLE XV

SAMPLED SPECIES
(ALPINE OCCURRENCES, IF ANY, LISTED)

SPECIES SAMPLED	1	2	3	4	5	6	7
Achillea millefolium	X	X	X			X	
Antennaria alpina	X	X		X	X	X	X
Antennaria umbrinella						X	
Arctostaphylos uva-ursi		X	X		X	X	
Arenaria aculeata	X						
Arenaria rubella	X					X	
Arnica mollis							
Arnica longifolia							
Artemisia arbuscula				X			
Caltha leptosepala	X					X	X
Carex spp.		X			X		
Castilleja miniata					X		
Cerastium berringianum	X			X		X	
Delphinium bicolor							
Epilobium alpinum	X						
Erigeron peregrinus		X					
Erigeron caespitosum							
Eriogonum heracleoides							
Eriogonum umbellatum	X						
Festuca spp.		X			X	X	X
Frasera speciosa							X
Haplopappus macronema				X			X
Helenium hoopsii							
Ivesia gordonii							X
Juniperus communis	X						
Kalmia microphylla	X		X				
Linum perenne	X						
Lomatium dissectum							
Lupinus caudatus							
Luzula campestris							
Luzula spicata		X	X		X	X	
Mimulus primuloides							
Moss spp.							
Parnassia finbriata	X	X			X		
Pedicularis attollens				X			
Penstemon procerus					X	X	
Phleum alpinum	X	X			X		X

SPECIES SAMPLED	1	2	3	4	5	6	7
Poa spp.			X			X	
Polygonum bistortoides	X		X			X	X
Potentilla breweri	X						
Potentilla brevifolia							
Potentilla coccina	X						
Potentilla diversifolia	X	X	X			X	X
Potentilla fruticosa		X				X	
Ranunculus eschscholtzii		X		X		X	X
Ribes nontigenum	X						
Salix nivalis		X				X	
Saxifraga integrifolia							
Sedum lanceolatum							
Senecio crassulus						X	
Senecio fremontii			X				
Sibbaldia procumbens	X	X	X		X	X	X
Sitanion hystrix	X			X			
Solidago multiradiata		X		X		X	
Swertia perennis							
Trifolium multipedunculatum							
Vaccinium caespitosum	X		X				X
Zygadenus elegans	X	X	X			X	

SOURCES

1. Hitchcock and Cronquist 1973
2. Choate and Habeck 1967
3. Hayward 1952
4. Mitchell et al 1966
5. Brink 1959
6. Johnson and Billings 1962
7. Cronquist 1972

CLUSTERING ROUTINE

Results of the clustering routine using standard distance and the unweighted pair-group method are shown in Table XVI. Values were plotted using the transect number across the horizontal axis and the level of similarity at which the stands were joined along the Y axis. The resulting dendrogram is shown in Figure 4. Results using the standard distance and the weighted pair-group method are shown in Table XVII, and the corresponding dendrogram is given in Figure 5.

All clusters are named for the lowest transect number in each of the clusters formed, with the individual stands in that cluster given after the name, in parenthesis. Visual inspection of the two dendrograms, using the standard distance as the similarity measure, show almost identical groupings. The only differences are at the 5 group level where cluster 2 (2, 3, 13) is joined with cluster 1 (1, 7, 4) in the weighted pair-group method and is joined with cluster 5 (10, 12, 5, 9, 8, 11) in the unweighted pair-group method, and at the 8 group level where cluster 9 (9) is joined with 5 (10, 12, 5) in the unweighted pair-group method and with cluster 5 (10, 12, 5, 8, 11) in the weighted pair-group method.

Results of the clustering using the product-moment correlation coefficient as the similarity measure and the unweighted pair-group method are shown in Table XVII, and the dendrogram of this analysis is shown in Figure 6. Product-moment correlation coefficient with weighted pair-group method results are given in Table XIX, and its corresponding dendrogram is shown in Figure 7. Inspection of these two dendrograms again shows a marked similarity between the methods, with the clustering differing only in the same way as it did with the use of the standard distance as the similarity measure. Overall the routines produce similar results, particularly so as the number of groups becomes smaller. This is in accordance with the results of Goldstein and Grigal (1972), who found that the various routines produced highly similar groupings.

A problem with the similarity measures used may be evident with inspection of the third fusion level. This fusion joined stand 13 with stand 2 (2. 3). The joining was due to the large _P. fruticosa_ and _Festuca_ sp. covers in stand 13. The stands were joined due to their having the same dominant cover but this ignores the unique species added because their cover values were low. These unique species seem to be indicative of changes in the community, which should separate it out from the other two stands. This idea is reinforced by looking at the environmental variables, which show a distinct difference from the other two stands.

While there is no absolute determination of community groupings, made with the dendrograms, they seem to strongly suggest that the best classification is at the 5 group level.

TABLE XVI

DENDROGRAM ONE
STANDARD DISTANCE/UNWEIGHTED PAIR-GROUP

(MAXIMUM VALUE OF SIMILARITY COEFFICIENT = 0.)

No. GROUPS	FUSION LEVEL	GROUPS FUSED	STANDS INCLUDED
13	0.1408	10 and 12	10.12
12	0.2588	2 and 3	2,3
11	0.3152	2 and 13	2,3,13
10	0.3384	5 and 10	5,10,12
9	0.4634	8 and 11	8,11
8	0.6296	5 and 9	5,9,10,12
7	0.6629	5 and 8	5,8,9,10,11,12
6	0.7020	1 and 7	1,7
5	0.7603	1 and 4	1,4,7
4	1.0184	2 and 5	2,3,5,8,9,10,11 12,13
3	1.2022	1 and 6	1,4,6,7
2	1.2309	1 and 2	1,2,3,4,5,6,7,8,9 10,11,12,13
1	1.4076	ALL ONE GROUP	

FIGURE 4

DENDROGRAM ONE
STANDARD DISTANCE/UNWEIGHTED PAIR-GROUP

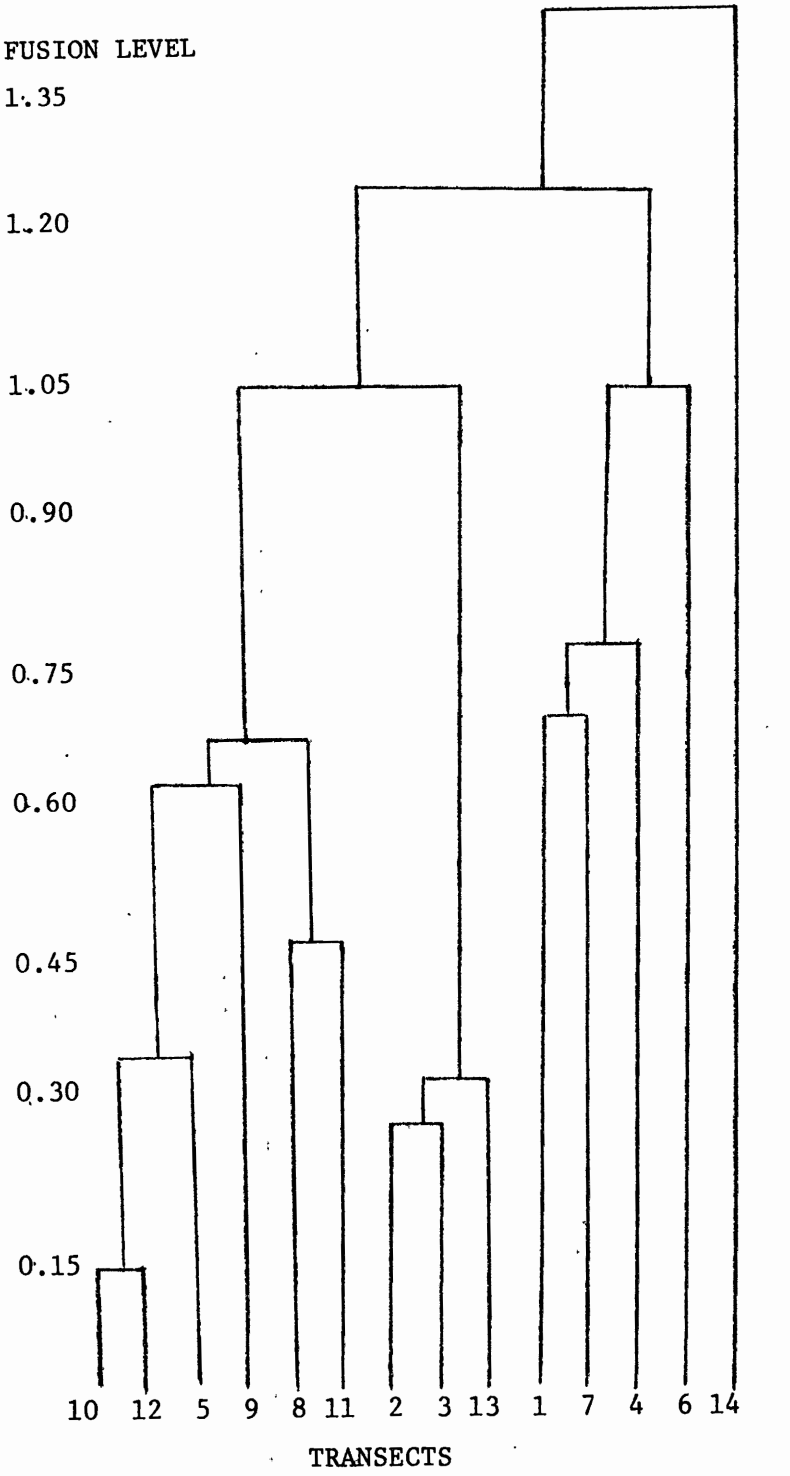


TABLE XVII

DENDROGRAM TWO
STANDARD DISTANCE/WEIGHTED PAIR-GROUP

(MAXIMUM VALUE OF SIMILARITY COEFFICIENT = 0.)

No.GROUPS	FUSION LEVEL	GROUPS FUSED	STANDS INCLUDED
13	0.1408	10 and 12	10.12
12	0.2588	2 and 3	2,3
11	0.2957	2 and 13	2,3,13
10	0.3196	5 and 10	5,10,12
9	0.4624	8 and 11	8,11
8	0.6169	5 and 8	5,8,10,11,12
8	0.7020	1 and 7	1,7
6	0.7169	5 and 9	5,8,9,10,11,12
5	0.8495	1 and 4	1,4,7
4	0.9769	1 and 2	1,2,3,4,7,13
3	0.9873	1 and 6	1,2,3,4,6,7,13
2	1.2081	1 and 5	1,2,3,4,5,6,7,8,9 10,11,12,13
1	1.4141	ALL ONE GROUP	

FIGURE 5

DENDROGRAM TWO
STANDARD DISTANCE/WEIGHTED PAIR-GROUP

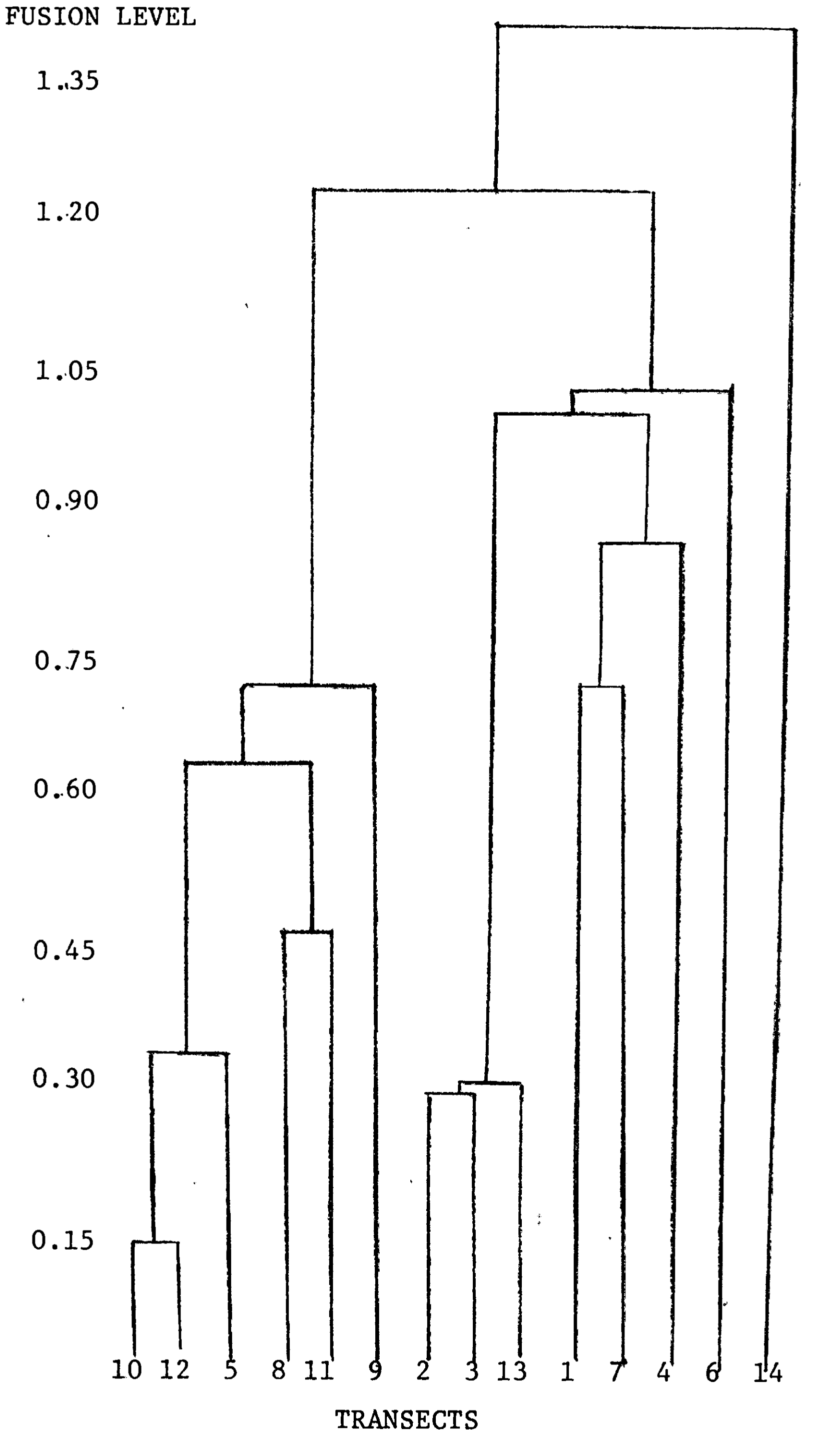


TABLE XVIII

DENDROGRAM THREE
CORRELATION COEFFICIENT/UNWEIGHTED PAIR-GROUP

(MAXIMUM VALUE OF SIMILARITY COEFFICIENT = 1+)

No.GROUPS	FUSION LEVEL	GROUPS FUSED	STANDS INCLUDED
13	0.9899	10 and 12	10,12
12	0.9666	2 and 3	2,3
11	0.9499	2 and 13	2,3,13
10	0.9432	5 and 10	5,10,12
9	0.8843	8 and 11	8,11
8	0.7933	5 and 9	5,9,10,12
7	0.7667	5 and 8	5,8,9,10,11,12
6	0.6960	1 and 7	1,7
5	0.6791	1 and 4	1,4,7
4	0.4543	2 and 5	2,3,4,8,9,10,11 12,13
3	0.1868	1 and 6	1,4,6,7
2	0.1554	1 and 2	1,2,3,4,5,6,7,8,9, 10,11,12,13
1	-.1196	ALL ONE GROUP	

FIGURE 6

DENDROGRAM THREE
CORRELATION COEFFICIENT/UNWEIGHTED PAIR-GROUP

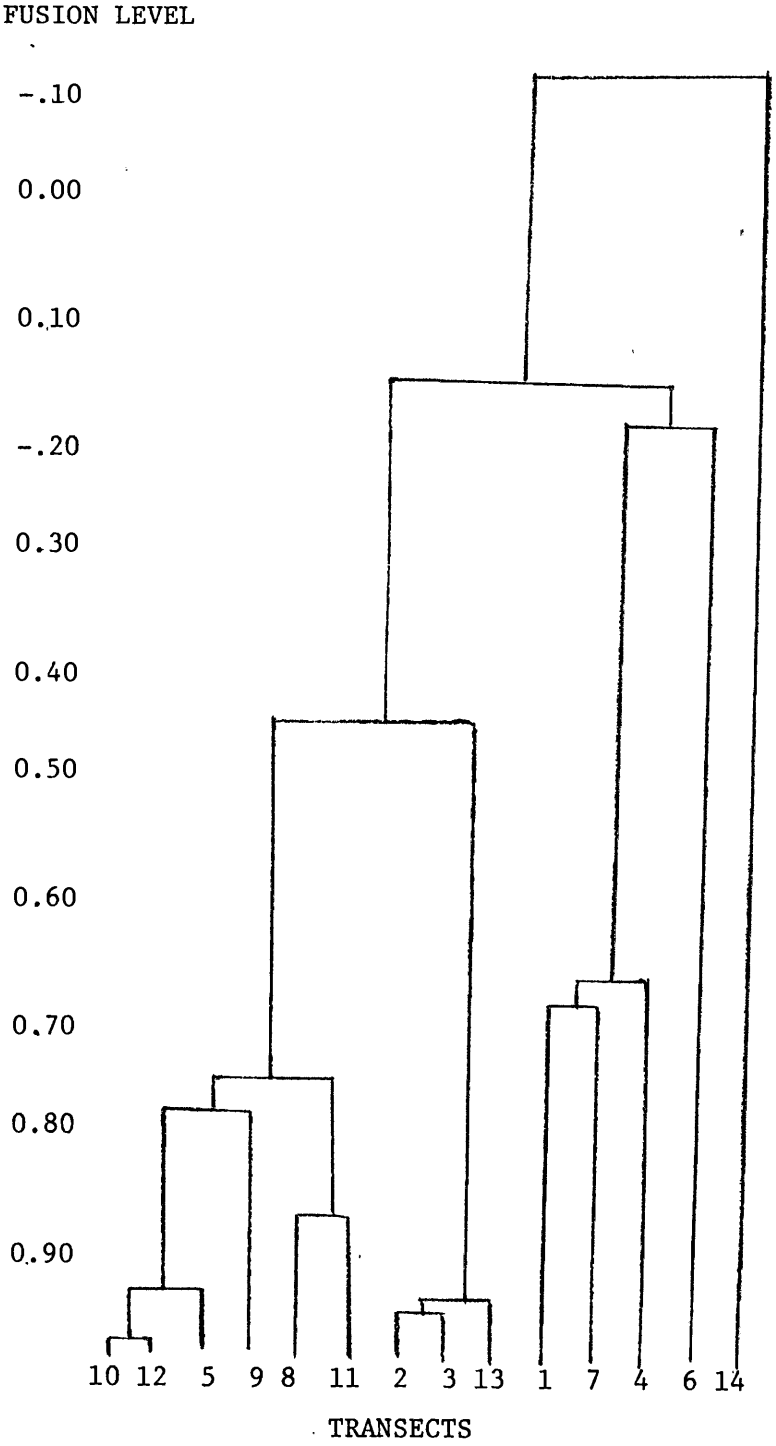


TABLE XIX

DENDROGRAM FOUR
CORRELATION COEFFICIENT/WEIGHTED PAIR-GROUP

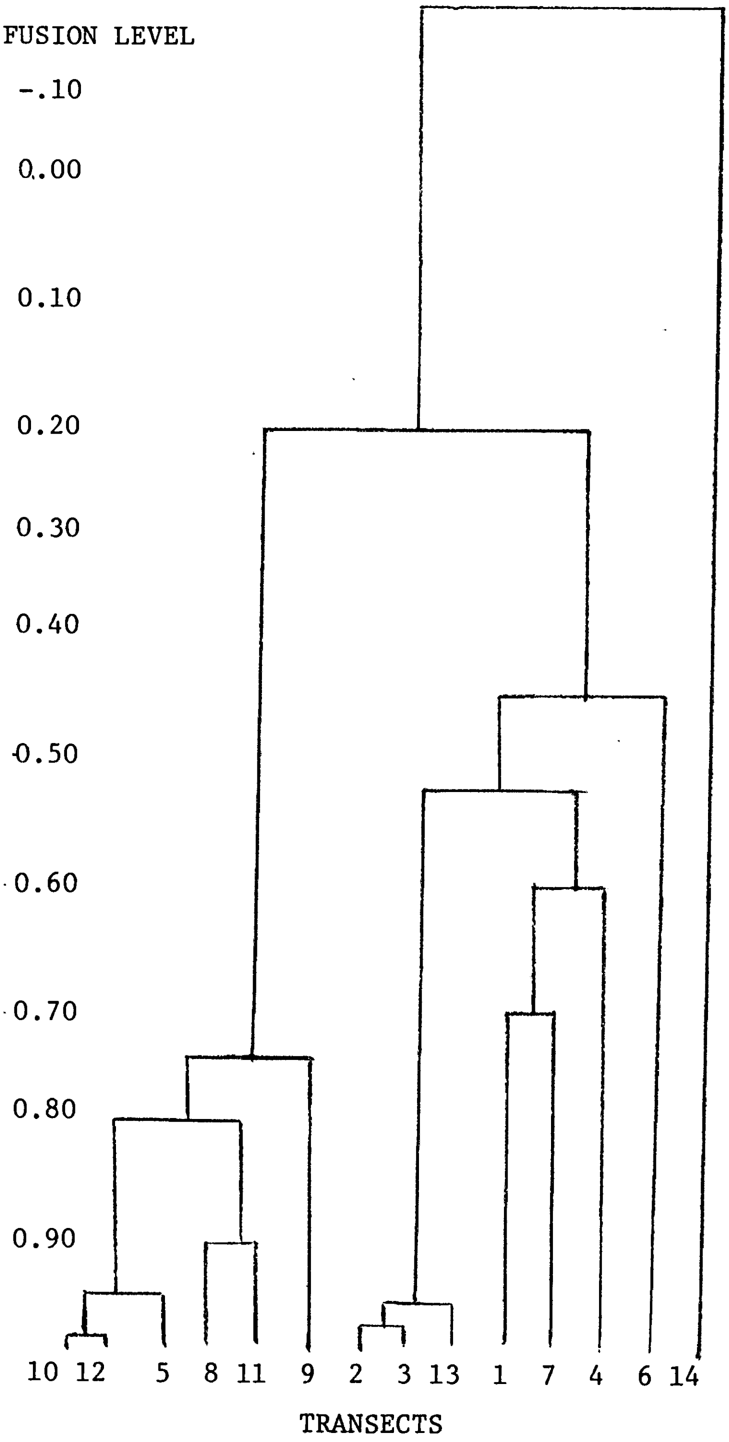
(MAXIMUM VALUE OF SIMILARITY COEFFICIENT = 1+)

No. GROUPS	FUSION LEVEL	GROUPS FUSED	STANDS INCLUDED
13	0.9899	10 and 12	10,12
12	0.9666	2 and 3	2,3
11	0.9578	2 and 13	2,3,13
10	0.9494	5 and 10	5,10,12
9	0.8843	8 and 11	8,11
8	0.7975	5 and 8	5,8,10,11,12
7	0.7272	5 and 9	5,8,9,10,11,12
6	0.6960	1 and 7	1,7
5	0.5947	1 and 4	1,4,7
4	0.5099	1 and 2	1,2,3,4,7,13
3	0.4535	1 and 6	1,2,3,4,6,7,13
2	0.1984	1 and 5	1,2,3,4,5,6,7,8,9, 10,11,12,13
1	-.1322	ALL ONE GROUP	

FIGURE 7

DENDROGRAM FOUR
CORRELATION COEFFICIENT/WEIGHTED PAIR-GROUP

(MAXIMUM VALUE OF SIMILARITY COEFFICIENT = 1+)



STEPWISE MULTIPLE DISCRIMINANT ANALYSIS

Results of the SMDA analysis for the U statistic from 2 to 10 communities are given in Table XX. The stands (Middle columns) were determined by the cluster routine at the group level indicated in the extreme left-hand column. The U statistic relates the fit of these groupings to the measured environmental variables taken in the field. By subtracting the U statistic value from one, the amount of variance accounted for with the different groupings can be determined. Variance accounted for ranges from 61% in the 2 group classification up to 93% in the 10 group classification. On the 3 and 4 group level, where there was a difference in the groupings according to whether the weighted pair-group method or the unweighted pair-group method was used, the unweighted pair-group method accounted for a larger percentage of the variance. At the 7 group level there was a difference between the standard distance/weighted pair-group method and the other three routines. The classification done by the other three routines accounted for more of the variance by a small margin.

As more groups are formed, there is a proportional increase in the variance accounted for. There is an apparent jump in the U statistic at the 5 group level, where 87.02% of the variance is accounted for. At the 6 group level there is little appreciable gain with 87.43% of the variance accounted for with the addition of an additional community type. There is a sizable loss in variance accounted for by going back to the 4 group level where 81.13% of the variance is accounted for. This loss of 5.89% by reducing group size by one, approximates the gain in significance in moving from the 5 group level to the 10 group level, where a gain in variance of 5.99% is obtained at the cost of creating five more community types. The gain in variance accounted for in moving from the 4 group level to the 5 group level is the largest gain in a one level transition at any level except the first transition.

Using the 5 group level as the classification within the cirque basin, the matrix of F values (Table XXI) can be used to show the distinctness of the groups based upon their environmental variables. Two groups can be compared from the matrix by choosing the first group from the column of groups and the second group from the row of groups. The F value listed at the intersection of the two groups indicates if the two groups are different, based on measured environmental parameters at the level listed. The F values show an interesting situation with stand 6, which is not significantly different from stand 1 (1, 7, 4) or stand 2 (2, 3, 13), though the F value for 2 falls just below the significance level. This indicates that for the variables measured, there is no significant difference in these communities. This is reaffirmed by the table of classification (Table XXI). The table of classifications indicates whether the individual measured sites within the groups are representative of that group or of other groups. Misclassifications can be found by finding the group in the column on the left-hand side and moving to the right and noting the number of sites classified into the other groups listed in the row of groups across the top of the table. None of the sites in stand 6 were correctly placed within the stand. On the basis of the variables measured, the groups should not be separated. On the basis of species composition (Figure 6), stand 6 appears as a unique vegetation type. A solution to this apparent paradox may be that stand 6 has an environment between that of stand 1 (1, 7, 4) and stand 2 (2, 3, 13), and is a transition community with unique species. Alternative explanations could be that the presence of certain species in stand 6 are an accident of time, or that an important variable that the vegetation is responding to, has not been measured.

All other community types at the 5 group level show different environments from each other. This is not seen at classification levels greater than 5.

TABLE XX

U STATISTIC FROM SMDA

No. GROUPS	STAND DIVISION	U STATISTIC
2	(14) (2,3,13,1,7,4,6,10,12,5,8,11,9)	0.3870
3	(14) (2,3,13,1,7,4,6) (10,12,5,8,11,9)	0.2084
3	(14) (1,7,4,6) (10,12,5,8,11,9,2,3,13)	0.1957
4	(14) (6) (2,3,13,1,7,4) (10,12,5,8,11,9)	0.2069
4	(14) (6) (1,7,4) (2,3,13,10,12,5,9,8,11)	0.1887
5	(14) (6) (1,7,4) (2,3,13) (10,12,5,9,8,11)	0.1298
6	(14) (6) (4) (1,7) (2,3,13) (10,12,5,8,11,9)	0.1257
7	(14) (6) (4) (1) (7) (2,3,13) (10,12,5,8,11,9)	0.1143
7	(14) (6) (4) (1,7) (2,3,13) (10,12,5,8,11) (9)	0.1177
8	(14) (6) (4) (1) (7) (2,3,13) (10,12,5,8,11) (9)	0.1070
9	(14) (6) (4) (1) (7) (2,3,13) (10,12,5) (8,11) (9)	0.0980
10	(14) (6) (4) (1) (7) (2,3,13) (10,12,5) (8) (11) (9)	0.0699

TABLE XXI

F VALUES AND LIST OF CLASSIFICATIONS

TWO GROUP LEVEL (14) (2,3,13,1,7,4,6,10,12,5,8,11,9)

MATRIX OF F VALUES (F at .05 level = 2.76)

	(14)
(1)	34.84

TABLE OF CLASSIFICATIONS

	(14)	(1)
(14)	5	0
(1)	0	65

THREE GROUP LEVEL (14) (2,3,13,1,7,4,6) (10,12,5,8,11,9)

MATRIX OF F VALUES (F at .05 level = 2.76)

	(14)	(1)
(1)	31.12	
(5)	41.95	18.58

TABLE OF CLASSIFICATIONS

	(14)	(1)	(5)
(14)	5	0	0
(1)	0	30	5
(5)	0	7	23

THREE GROUP LEVEL (14) (1,7,4,6) (10,12,5,8,11,9,2,3,13)

MATRIX OF F VALUES (F at .05 level = 2.76)

	(14)	(1)
(1)	29.84	
(2)	35.88	21.18

TABLE OF CLASSIFICATIONS

	(14)	(1)	(2)
(14)	5	0	0
(1)	0	18	2
(2)	0	9	36

FOUR GROUP LEVEL (14) (6) (2,3,13,1,7,4) (10,12,5,8,11,9)

MATRIX OF F VALUES (F at .05 level - 2.76)

	(14)	(6)	(1)
(6)	18.42		
(1)	29.81	0.15	
(5)	41.34	4.82	17.08

TABLE OF CLASSIFICATIONS

	(14)	(6)	(1)	(5)
(14)	5	0	0	0
(6)	0	3	2	0
(1)	0	12	13	5
(5)	0	3	5	22

FOUR GROUP LEVEL (14) (6) (1,7,4) (2,3,13,10,12,5,9,8,11)

MATRIX OF F VALUES (F at .05 level = 2.76)

	(14)	(6)	(1)
(6)	17.81		
(1)	28.06	0.80	
(2)	35.40	3.80	20.80

TABLE OF CLASSIFICATIONS

	(14)	(6)	(1)	(2)
(14)	5	0	0	0
(6)	0	1	3	1
(1)	0	4	11	0
(2)	0	5	4	36

FIVE GROUP LEVEL (14) (6) (1,7,4) (2,3,13) (10,12,5,9,8,11)

MATRIX OF F VALUES (F at .05 level = 2.76)

	(14)	(6)	(1)	(2)
(6)	18.36			
(1)	28.76	0.79		
(2)	25.95	2.70	12.49	
(5)	40.79	5.60	23.34	9.53

TABLE OF CLASSIFICATIONS

	(14)	(6)	(1)	(2)	(5)
(14)	5	0	0	0	0
(6)	0	0	3	2	0
(1)	0	4	11	0	0
(2)	0	1	1	8	5
(5)	0	2	3	4	21

SIX GROUP LEVEL (14) (6) (4) (1,7) (2,3,13) (10,12,5,8,11,9)

MATRIX OF F VALUES (F at .05 level = 2.76)

	(14)	(6)	(4)	(1)	(2)
(6)	18.36				
(4)	16.19	0.34			
(1)	27.93	1.03	0.66		
(2)	25.78	2.68	4.85	11.43	
(5)	40.35	5.58	7.92	19.72	9.39

TABLE OF CLASSIFICATIONS

	(14)	(6)	(4)	(1)	(2)	(5)
(14)	5	0	0	0	0	0
(6)	0	0	1	2	2	0
(4)	0	2	2	1	0	0
(1)	0	1	3	6	0	0
(2)	0	0	3	0	7	5
(5)	0	2	1	2	4	21

SEVEN GROUP LEVEL (14) (6) (4) (1) (7) (2,3,13) (10,12,5,8,11,9)

MATRIX OF F VALUES (F at .05 level = 2.76)

	(14)	(6)	(4)	(1)	(7)	(2)
(6)	19.58					
(4)	17.36	0.34				
(1)	16.46	0.51	0.08			
(7)	29.69	2.09	1.99	2.04		
(2)	26.85	2.73	4.83	5.16	10.92	
(5)	41.73	5.52	7.81	9.60	14.65	9.28

TABLE OF CLASSIFICATIONS

	(14)	(6)	(4)	(1)	(7)	(2)	(5)
(14)	5	0	0	0	0	0	0
(6)	0	1	1	0	1	2	0
(4)	0	2	2	0	1	0	0
(1)	0	1	1	2	1	0	0
(7)	0	0	0	0	5	0	0
(2)	0	0	0	3	0	7	5
(5)	0	2	1	0	2	4	21

SEVEL GROUP LEVEL (14) (6) (4) (1,7) (2,3,13) (10,12,5,8,11) (9)

MATRIX OF F VALUES (F at .05 level = 2.76)

	(14)	(6)	(4)	(1)	(2)	(5)
(6)	18.20					
(4)	16.08	0.34				
(1)	27.65	1.02	0.65			
(2)	25.47	2.66	4.79	11.27		
(5)	38.04	4.94	7.20	17.78	7.56	
(9)	28.12	5.58	6.78	11.88	8.12	1.38

TABLE OF CLASSIFICATIONS

	(14)	(6)	(4)	(1)	(2)	(5)	(9)
(14)	5	0	0	0	0	0	0
(6)	0	0	1	2	2	0	0
(4)	0	2	2	1	0	0	0
(1)	0	1	3	6	0	0	0
(2)	0	0	3	0	7	5	0
(5)	0	2	1	2	4	6	10
(9)	0	0	0	0	0	1	4

EIGHT GROUP LEVEL (14) (6) (4) (1) (7) (2,3,13) (10,12,5,8,11) (9)

MATRIX OF F VALUES (F at .05 level = 2.76)

	(14)	(6)	(4)	(1)	(7)	(2)	(5)
(6)	27.95						
(4)	23.53	0.37					
(1)	22.81	0.75	0.08				
(7)	41.12	2.73	2.92	2.83			
(2)	40.41	2.24	3.93	5.35	11.81		
(5)	55.59	7.26	10.83	13.28	20.69	3.36	
(9)	37.21	6.56	9.23	10.96	15.55	3.09	0.40

TABLE OF CLASSIFICATIONS

	(14)	(6)	(4)	(1)	(7)	(2)	(5)	(9)
(14)	5	0	0	0	0	0	0	0
(6)	0	1	1	0	1	2	0	0
(4)	0	2	2	0	1	0	0	0
(1)	0	1	1	2	1	0	0	0
(7)	0	0	0	0	5	0	0	0
(2)	0	0	0	3	0	7	5	0
(5)	0	2	1	0	2	4	6	10
(9)	0	0	0	0	0	0	1	4

NINE GROUP LEVEL (14) (6) (4) (1) (7) (2,3,13) (10,12,5) (8.11) (9)

MATRIX OF F VALUES (F at .05 level - 2.77)

	(14)	(6)	(4)	(1)	(7)	(2)	(10)	(8)
(6)	28.10							
(4)	23.79	0.36						
(1)	23.14	0.74	0.08					
(7)	41.90	2.86	3.04	2.91				
(2)	40.12	2.33	4.00	5.43	12.36			
(7)	48.00	8.70	11.96	14.34	23.22	4.25		
(8)	46.48	3.91	6.64	8.39	12.72	1.47	1.97	
(9)	36.69	6.70	9.33	11.08	16.12	3.11	0.24	1.14

TABLE OF CLASSIFICATIONS

	(14)	(6)	(4)	(1)	(7)	(2)	(5)	(8)	(9)
(14)	5	0	0	0	0	0	0	0	0
(6)	0	1	1	0	1	2	0	0	0
(4)	0	2	2	0	1	0	0	0	0
(1)	0	1	1	2	1	0	0	0	0
(7)	0	0	0	0	5	0	0	0	0
(2)	0	0	0	3	0	7	2	3	0
(5)	0	1	0	0	0	4	2	0	8
(8)	0	0	1	0	2	0	4	2	1
(9)	0	0	0	0	0	0	1	0	4

TEN GROUP LEVEL (14) (6) (4) (1) (7) (2,3,13) (10,12,5)
(8) (11) (9)

MATRIX OF F VALUES (F at .05 level = 2.77)

	(14)	(6)	(4)	(1)	(7)	(2)	(10)	(8)	(11)
(6)	20.09								
(4)	18.55	0.38							
(1)	17.74	0.57	0.08						
(7)	32.71	2.88	2.39	2.39					
(2)	25.92	3.90	6.67	7.11	15.67				
(5)	33.07	7.20	10.21	11.82	20.65	5.71			
(8)	25.55	7.06	9.70	10.94	17.08	4.19	0.44		
(11)	28.82	1.65	1.83	2.67	2.85	9.36	8.39	7.77	
(9)	28.32	5.93	7.51	9.01	13.16	7.79	1.72	1.62	4.03

TABLE OF CLASSIFICATIONS

	(14)	(6)	(4)	(1)	(7)	(2)	(5)	(8)	(11)	(9)
(14)	5	0	0	0	0	0	0	0	0	0
(6)	0	1	1	0	1	1	0	0	1	0
(4)	0	2	2	0	1	0	0	0	0	0
(1)	0	1	1	2	1	0	0	0	0	0
(7)	0	0	0	0	5	0	0	0	0	0
(2)	0	1	0	3	0	6	4	1	0	0
(5)	0	1	0	0	0	4	2	2	0	6
(8)	0	0	0	0	0	0	1	3	0	1
(11)	0	0	0	0	1	0	0	0	3	1
(9)	0	0	0	0	0	0	1	0	0	4

CHAPTER V

DISCUSSION

THE ALPINE NATURE OF THE HIGH STEENS

While there is extensive data on the alpine environment, most sites have been located well into the alpine tundra, which is a more severe environment than would occur within the transition zone of the forest-tundra ecotone. An additional complicating factor is that the sites studied have been predominantly in the more well known ranges; either the Rocky Mountains or the ranges in California. Detailed environmental studies of the northern Great Basin have apparently not been done.

Marr (1973) accumulated data for the Front Range in Colorado. One station was positioned at the upper edge of the forest and another was placed just above the ecotone. For the forest edge, they found the mean temperature for the warmest month (July) to be 12 C. in 1964 and 9 C. in 1965. Just above the ecotone, the mean temperature for July was 11 C. in 1964 and 9 C. in 1965. From all data, they concluded that the mean temperature for July within the ecotone was between 8.8 C. and 11 C. Temperature was found to drop 2-4 C. across the ecotone.

Daubenmire (1954) reports temperature data from several timberline and alpine areas. He was defining timberline as the area midway between the forest line and the well developed alpine tundra. From his table of data, several interesting variations on the mean temperature of the warmest month are seen. At Old Glory Mountain, B.C., a station right at timberline, had a mean temperature of 9.1 C. for July. At Alma, Colorado, a station 300 m. above timberline had a mean temperature of 10.2 C. In the San Francisco Peaks of Arizona a station had a mean July temperature of 10.3 C. at 200 m. below timberline.

Mooney et al. (1962) reports temperature data from the White Mountains of California for a station in the subalpine region and one in the alpine region. For the warmest month (July), the mean temperature for the subalpine station was 11.9 C. and for the alpine station 7.3 C. Without knowing the exact location of the stations in relation to the timberline, the mean temperature at timberline is difficult to determine.

In the alpine tundra of the Beartooth Plateau of Wyoming, Johnson and Billings (1962) found the weekly mean temperature for July to be 4.7, 10.0, 11.9, and 10.0 C. for a monthly mean temperature of 9.2 C. Again the exact location of this station to the timberline is not known.

It is apparent from these data that timberline does have a correspondence to a 10 C. mean July isotherm. It is also apparent that there is variation around this figure, and the correspondence is not exact. Factors such as topography, aspect, wind, moisture regimes and edaphic factors can shift the timberline up or down from exact placement by the 10 C. mean July isotherm.

Temperature values from tripid I (T1) show the mean July temperature at this point to be 11.3 C. This station is located on the west slope of the summit ridge. This area shows a transition in vegetation as noted by Faegri (1966) and Mairs (1977). The slope is an open area marked by snow deflation, and strong winds in the winter and extreme aridity in the summer. Faegri found it interesting that the dominant grass in this community, Festuca ovina, was the same as in corresponding communities in the Scandinavian alpine region. This area is approximately 300 m. above the highest growing tree, Populus tremuloides, which exists in a krummholz form at 2590 m. on the west slope (Price 1978). The existence of krummholz P. tremuloides is extremely rare on Steens Mountain, this being the only known occurrence. While no vegetation analysis was done in this area in this study, the dominant species, Erigeron compositus and Festuca ovina, are listed by Cronquist (1972) as major alpine plants in the Great Basin Region. At the summit, the only temperature station is a recording thermograph which has a mean July temperature of 12.6 C. The differential between ground and shelter level is unknown. This station was placed between a stone house and a steel fuel tank and thus was protected from direct winds, which would prevent mixing of the air layers. It this is true, the differential could have been as high as 4.25 C., the same as T3 in July. This would make the temperature at the summit well into alpine range.

The conclusion that an alpine region exists on Steens Mountain can be further justified using Troll's definition of high mountain areas. His first criterion of an area above treeline is easily met. The only tree species with major distributions, P. tremuloides and Jumiperus occidentalis, occur well below the summit ridge. A Limber Pine-Bristlecone Pine community which might be expected to have distributions reaching the summit based on elevational considerations, does not occur on the mountain. Critchfield and Allenbaugh (1969) report that the Limber Pine (*Pinus flexilis*) is absent from the western part of the Great Basin, but widespread in the eastern part. Its westernmost extension is apparently in the Santa Rosa Range of eastern Humboldt County, Nevada, which is 130 Km. southeast of Steens Mountain. Bristlecone Pine (*Pinus aristata*) the other characteristic tree of the Great Basin Ranges, reaches its northwesternmost extension in the Ruby Mountains which are 340 Km. southeast of the Steens. The nearest known range of *Pinus albicaulus*, a typical timberline species in the western United States, is in the Pine Forest Range, some 130 Km. south of the Steens.

Billings (1974) addressed the situation of areas with the lack of sufficiently hardy tree species, which results in an unusually low timberline. He observed that such areas result in luxuriant growths of grasses, shrubs and rosette plants which make the distinction between alpine and subalpine conditions difficult to determine. He considered such areas to be alpine and defined alpine environments as open treeless areas on the upper slopes and summits of mountains, where conditions are usually windy and snowy and temperatures are low throughout the day.

Why there are no typical timberline species on Steens Mountain seems to be an effect of climate which has limited their distribution into this part of the northern Great Basin. Whether or not these species ever extended across this part of the Great Basin is a controversial question (Critchfield and Allenbaugh, 1969). If any of these species existed on the Steens in the past they would have been subject to the glacial ice sheet which covered the top of the Steens in the Fish Lake phase of glaciation (Bentley 1970) and could well have been scoured off the face of the mountain. The possibility also exists that a warming period may have forced these species up to higher elevations where they could have possibly been eliminated from the summit of the Steens. Since these trees do not appear on the mountain now, they are not considered as timberline species for the Steens.

Troll's second criterion for high mountain belts is that they be above the Pleistocene snowline, which is best approximated by the lowest occurrence of cirques formed during the last glaciation. As noted by Bentley (1970), the last glaciation on the Steens produced a series of high cirques along the summit ridge. Troll's second criterion is met on the Steens.

The third criterion is that an area of solifluction exist. These are the specific degradational processes which occur in the cold climate of high mountains. Bentley (1970) concludes that it is freeze-thaw and nivation which are the active degradational forces at the summit of the Steens.

THE VEGETATION OF BIG ALVORD CIRQUE

In discussing the Sierran series of ranges in the western Great Basin, Billings (1951) observed that the tundra vegetation often occurred below timberline in rocky cirque basins. Analysis of the vegetation in the Big Alvord Cirque, both on a community basis and on a species basis, indicates the presence of an alpine tundra vegetation.

The community classification produced by the cluster routine and further analysis of environmental factors using the Stepwise Multiple Discriminant Analysis gives strong justification for the presence of 5 communities within Big Alvord Cirque. These communities are a Salix-Carex community, a Potentilla community, a grass-herb community, and a transition shrub-cushion plant community.

Billings and Mooney (1968) identified one of the most common community gradients found in tundra vegetation as being a cushion plant community, usually found on dry exposed ridges, down into a dry meadow community at midslope, and then into dense bogs and wet meadows under the influence of meltwater. This community gradient is well represented in the vegetation pattern within Big Alvord Cirque. The best developed cushion plant communities are along the ridgetops of the cirque. Though these areas were unmeasured in this study, they extend down the cirque walls where they pick up shrub vegetation (Artemisia arbuscula and Ribes montigenum) at the lower edge. This community (transect 14) is on the south facing slope and the shrubs appear to be taking advantage of the protection from ridge winds and the warmer prevailing conditions.

The dry meadow communities are represented by transects 1, 4, 7 which are aligned around the base of the cirque walls. This area is dominated by the grasses, Poa sp. and Festuca sp., and by small herbs. The bog and meadow community in the Big Alvord Cirque is represented by the Salix-Carex community. Salix dominates the areas where there is running water, with Carex and other bog species around the periphery, where standing water and extremely moist conditions prevail. Though the dry meadow communities are adjacent to late-lying snowbanks on the slopes, meltwater is predominantly channeled around these communities and empties into the communities at the lower edge of the cirque basin.

There are two additional community types in the cirque. The *Potentilla* community is best defined along the low ridges which dissect the cirque. Soil depths were observed to be shallower here than in the adjacent grass community, and the *Potentilla* was observed to have its roots in the crevices along the ridge. This may reflect the inability of *Potentilla fruticosa* to compete with the grasses in the deeper soil areas. Snow depth may also play a role here as winter accumulation should be less right on the ridge than in back in the bowl-shaped basin of the grass community.

The fifth community type, the transition grass-herb community, is difficult to interpret. The largest ground cover is by *Festuca*, typical of the other grass-herb communities, but there are large occurrences of 2 species, *Lomatium dissectum* and *Arnica mollis*, found almost nowhere else. Both of these species have no known recorded alpine occurrences, as far as they can be determined. If their occurrence is due to warmer temperatures, it is not reflected in the soil temperatures, which are comparable to those in the grass-herb community, even to the point of showing the same inversion at the 3 cm. level. The cause of this temperature inversion is unknown, but its consistency within the transects of similar species, makes the possibility of it being an experimental error unlikely.

The nature of the vegetation on a species basis, reinforces the conclusion of a well developed alpine area within Big Alvord Cirque. This conclusion is based on the large percentage of cover of species with known alpine occurrences.

DISTRIBUTION LIMITATIONS OF *OXYRIA DIGYNA*

There have been several experiments and many theories as to what limits the downward distribution of high mountain plants. Daubenmire (1943), working with trees in the Rocky Mountains, stressed the importance of drought resistance. Griggs (1940) thought competition was a major factor. Mooney et al (1974) noted the importance of transpiration characteristics in determining species patterns in alpine communities. This work was in the Sierra Nevada Mountains, where summers are extremely arid. Mooney found that moist site plants transpired more than dry site plants, under similar conditions, and that the moist site plants would wilt at higher soil moisture conditions. Many of the alpine plants would show a shutdown in transpiration at times corresponding to maximum temperature and radiation. On the other hand, *Oxyria digyna* showed increasing transpiration rates with increasing temperature and radiation, with no rate reduction in transpiration during stress periods. In transplant studies with other alpine plants, they found an increase in transpiration with a decrease in altitude. They speculated that this increasing transpiration could be a limiting factor in the downward distribution of alpine plants. Maximum transpiration rates measured for *Oxyria* were 3.00 $g/dm^2/hr$ at a temperature of 26.1 C. Billings (1970) explained the lack of a reduction in transpiration at peak stress periods by the inability of *Oxyria* to control its stomatal openings. Thus, there appears to be a trade off between increased CO_2 assimilation and increasing water loss due to increasing transpiration rates. These traits make Oxyria an obligate snowbank or moist site species throughout most of its southern distribution.

Mooney and Billings (1961) emphasized temperature related photosynthetic efficiencies. In their work with arctic and alpine populations of Oxyria, they found that the southern (alpine) populations were more tolerant of high temperatures. The rate of respiration increase was less at increasing temperatures and lower at all temperatures. They related this higher temperature tolerance to the higher temperature compensation points of plants in the alpine populations. By extrapolation of their curves, they found upper temperature compensation points for the alpine populations to be 35 C. (Temperature compensation point was the temperature at some known light intensity where the apparent photosynthetic rate is equal to the dark respiration rate.) Chabot et al. (1972) in a later work, found maximum net photosynthesis in Oxyria to decrease above leaf temperatures of 20-25 C. Billings et al. (1966), in related work on alpine plants, observed that on a bright sunny day, with an air temperature of 25 C., the leaf temperatures were about 40 C. This high leaf temperature allowed the respiration rate to exceed photosynthetic rate at that time.

All four ground max-min thermometers used in this study were out of direct insolation, which would have the level of illumination lower than that used by Mooney et al. (1961) and Chabot et al. (1972). The effect of this would be to have air temperature close to leaf temperature and gross photosynthesis at lower levels, with a reduction of net photosynthesis.

At none of the sites for any of the three months, does the temperature reach or exceed 35 C., which is the temperature compensation point for alpine populations of Oxyria, at the higher light levels used in the experimental studies. For July, G1 reached the 20-25 C. level 70% of the days, G2 50%, G3 10%, and G4 100%. In August, the values are G1-5%, G2-0%, G3-5%, and G4-25%. For September, the values are G1-30%, G2-0%, G3-0%, and G4-0%. The 20-25 C. range is the temperature at which maximum net photosynthesis in Oxyria is seen to decrease.

The assumption with this data is that the Oxyria on Steens Mountain respond similar to those southern populations which have been tested and reported in the literature. If this is true, then the Oxyria plants, at the various sites, experienced a reduction from maximum net photosynthesis on those days when they reached or exceeded the 20-25 C. range. This would have the effect of reducing the amount of photosynthate that would be available for storage over the next winter. This stored material is the key to survival for Oxyria, as it needs this material to allow for rapid growth and reproduction in the extremely short growing seasons of the alpine environment.

The data also provide an explanation for the presence of plants in areas which were shaded from insolation during peak temperature periods. Leaf temperatures may exceed air temperatures by 10 to 20 C. on a clear day (Billings 1970). This would have the effect of having the plants reach the temperature compensation point too often to allow for minimal net production, and thus the plants are limited to specific microhabitats.

Eilif Dahl (1951), in a pioneering work on the distribution of alpine plants, proposed that high summer temperatures limit downward distribution of alpine plants. For his calculations, Dahl used the maximum summer temperature occurring in a given region. He justified his use of extreme summer temperature on three grounds. The first was an adverse effect of high temperature on the protoplasm of the plant. The second was that increased temperature would raise the respiration rate, which could have the effect of lowering assimilation and cause conditions where the plant would be starved. The third reason was based on experimental studies, which showed that plants required a certain day temperature which was different from the temperature required at night. This phenomenom has been termed thermoperiodism. His extensive list for the extreme temperature in which alpine plants could be found, have for *Oxyria digyna*, a maximum summer temperature of 26 + C. The summer maximums for the three sites where *Oxyria* was growing, all have temperatures below this maximum. Mooney et al (1961) agrees with the premises of Dahl, by concluding that the primary restrictive factor which limits the distribution of *Oxyria* is a relatively high summer temperature. Their explanation for this is that high temperature causes a depletion of carbohydrate reserves and a malfunctioning of enzyme substrate systems, which results in the death of the plant.

Inspection of the data on the *Oxyria* sites in Steens Mountain indicates a trade-off in various processes to meet the requirements for successful growth and reproduction. G1 and G2 have higher maximum temperatures which may well be limiting their net photosynthetic rates at peak temperature periods. This loss of carbon assimilation during the day, would apparently be compensated for by their lower night minimum temperatures, which should have the effect of lower dark respiration rates. G3 is seen to have lower maximum temperatures, which should lower their light respiration rates. This apparent gain for Oxyria is matched against the higher minimum temperatures, which would increase its dark respiration rates. Coupled with this is the apparent, but unmeasured lower illumination, which would reduce the level of maximum gross photosynthesis. Plants at G4 would not experience problems with high levels of dark respiration, but would be inhibited by the extreme daytime temperatures with resultant effects upon carbon assimilation and storage. The range of daily temperature extremes at the Jackman Park site clearly shows the greater range of fluctuations in temperature at G4 in comparison to the site at G3.

CHAPTER VI

CONCLUSIONS

This study shows that the top of Steens Mountain is an alpine area and that the Big Alvord Cirque has extensive tundra vegetation cover. This is based on the temperature data, the flora present at the top of the mountain and in the cirque, the position of the cirques, and the active freeze-thaw processes on the high Steens. Secondly, the absence of trees on the high Steens may be the result of one or more factors related to climate and glacial history. Finally, the presence of isolated patches of *Oxyria digyna* at lower elevations is due to local suitable alpine-like conditions within a microhabitat.

TABLE XXII

COMPLETE SPECIES LIST

FAMILY	GENUS
Boraginaceae	*Mertensia oblongifolia* G. Den
Caryophyllaceae	*Arenaria aculeata* Wats.
	A. rubella J.E. Smith
	Cerastium berringianum Cham + Schlecht
Compositae	*Achillea millefolium* L.
	Antennaria alpina Gaertn.
	A. microphylla Rydb.
	A. umbrinella Rydb.
	Arnica longifolia D.C. Gast.
	A. mollis Hook.
	Artemisia arbuscula Nutt.
	A. vulgaris L.
	Erigeron compositum Dougl.
	Haplopappus macronema Gray
	Senecio canus Hook.
	S. crassulus Gray
	S. fremontii T+G
	S. intergerrimus Nitt.
	S. pseudareus Rydb.
	S. triangularis Hook.
	Solidago multiradiata Greene
Crassulaceae	*Sedum lanceolata* Torr.
Cruciferae	*Arabis lemonii* Wats.
	Draba sphaeroides C.L. Hitch.
Cyperaceae	*Carex* spp.
Ericaceae	*Arcostaphylos uva-ursi* Spreng
	Kalmia microphylla (Hook) Heller
	Vaccinium caespitosum Mich.
Gentianaceae	*Gentiana prostrata* Haenke
	Swertia perennis L.

Gramineae	*Deschampsia caespitosa* Beaur.
	Festuca ovina L.
	Phlenum alpinum L.
	Poa cusickii Vasey
	P. nervosa Vasey
	Sitanion hystrix Smith
Grossulariaceae	*Ribes cereum* Dougl.
	Ribes montigenum McClatchie
Hydrophyllaceae	*Phacelia hastata* Dougl.
Iridaceae	*Sisyrinchium angustifolium* Mill.
Juncaceae	*Luzula campestris* L.
	L. parvifolia Desv.
	L. spicata D.C.
Labiatae	*Monardella purpurea* Urban
Leguminosae	*Lupinus caudatus* Kell.
	Trifolium multipeduculatum Kennedy
Liliaceae	*Lloydia serotina* Sweet
	Zygadenus elegans Pursh.
Linaceae	*Linum perenne* L.
Onagraceae	*Epilobium alpinum* L.
	E. obcordatum Gray
Polemoniaceae	*Leptodactylon pungens* Torr.
Polygonaceae	*Eriogonum heracleoides* Nutt.
	E. ovalifolium Nutt.
	E. umbellatum Torr.
	Polygonum bistortoides Pursh
	Oxyria digyna Hill.
Polypodiaceae	*Cystopteris fragilis* (L.) Beruh.
	Polystichum scopulinum Maxon
Portulacaceae	*Claytonia megarhiza* Parry
	Lewisia pygmaea Robins
Primulaceae	*Dodecathon pulchellum* Merril

Ranunculaceae	*Caltha leptosepala* D.C.
	Delphinium bicolor Nutt.
	Ranunculus eschscholtzii Schlecht
Rosaceae	*Geum triflorum* Pursch
	Ivesia gordonii T + G
	Potentilla brevifolia Nutt.
	P. breweri Wats.
	P. concinna Richards
	P. diversifolia Lehm.
	P. fruticosa L.
	P. glandulosa Lindl.
	Sibbaldia procumbens L.
Salicaceae	*Salix arctica* Pall.
	S. nivalis Hook.
Scrophulariaceae	*Castilleja miniata* Dougl.
	Mimulus namus H+A
	Mimulus primuloides Benth.
	Pedicularis attolens Gray
	Penstemon davidsonii Greene
	P. procerus Dougl.
	Veronica serpyllifolia L.
	V. wormskoldii Roem. + Schult.
Saxifragaceae	*Parnassia fimbriata* Konig.
	Saxifraga integrifolia Hook
Umbelliferae	*Lomatium dissectum* Math + Const.
	Cymopteris petraeus M.E. Jones
	C. nivalis Wats.
Valerianaceae	*Valeriana acutiloba* Rydb.

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