AN ABSTRACT OF THE THESIS OF

Jan Alan Henderson for the Doctor of Philosophy

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Title: Composition, Distribution and Succession of Subalpine Meadows in Mount Rainier National Park

Abstract approved: W W Chilcote
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In 1970 a phytosociological reconnaissance consisting of 135 plots in the Subalpine Meadow Zone was made. These samples were sorted using an association table and several Alpine Zone and very early seral communities were set aside. An additional hundred plots taken by M. J. Hamann were incorporated with these and compiled in another association table and combined in a two-dimensional ordination. This analysis yielded 18 major and 16 minor described community types which were clustered into five vegetation types. A key to the vegetation and community types is also presented.

Soil moisture and temperature data were taken during 1971 and 1972 and are used to help characterize selected important communities. Soil moistures did not drop much during either season, although differences between communities are apparent. The difference in temperatures (of the top 2 cm of soil) of the same selected communities were more striking. The Festuca dominated communities experienced soil temperatures over 35^{o} C, while maximum

temperatures in other communities rarely ranged over 20° C. Low nighttime temperatures were relatively similar from community to community, ranging from near freezing to about $+5^{\circ}$ C.

Several successional patterns were uncovered. In general the communities in the Low-Herbaceous Vegetation Type are early seral and are replaced by members of the Wet-Sedge, Lush-Herbaceous and the Dry-Grass Vegetation Types.

Trees appear to be invading all vegetation types, with considerable variation in pattern and frequency. This variation is attributed to differences in soil moisture and temperature and depth and duration of winter snowpack. Analysis of the ages of invading trees indicates that there was an intensive invasion in the early 1930's and several other minor invasion periods. Several factors are discussed which must be favorable for the successful invasion of meadows by trees.

The Subalpine Meadow Zone, using vegetation types as map units, is mapped at a scale of about 1:50,000. The total area of the meadow vegetation in the zone is 14,650 acres (6,000 hectares). The entire zone including open subalpine woods covers 24,650 acres (10,000 hectares).

Composition, Distribution and Succession of Subalpine Meadows in Mount Rainier National Park

by

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COMPOSITION, DISTRIBUTION AND SUCCESSION OF SUBALPINE MEADOWS IN MOUNT RAINIER NATIONAL PARK

I. INTRODUCTION

Mount Rainier was established as the Nation's 5th National Park in 1899. Since then the number of visitors has increased from about 700 in 1894 (Haines, 1962) to about 2 million in 1971. The spectacular features of the mountain, however, were recognized in the mid-nineteenth century. Tolmie made his famous collecting trip to Mt. Rainier in 1833. Attempts to climb it finally succeeded in 1870. From 1870 to 1916 it was already a popular place for summer outings, particularly in Paradise Park, although another popular trail led to Mowich Lake and Spray Park. In 1911 the first automobile reached Paradise Park. General automobile traffic, however, was not permitted until 1915.

By 1893 it was already noted that people were damaging the vegetation significantly (Haines, 1962). Trees and limbs were cut for firewood and bedding. Cattle, horses and people ate and trampled the vegetation heavily and individual trees and clumps were set afire to provide spectacular conflagrations (Haines, 1962). A few farsighted people persuaded Congress to include Mt. Rainier among America's National Parks but management of the Park's features and visitors evolved slowly.

The need was seen early to preserve the mountain and its surrounding terrain. The subalpine meadows rank with the grandeur of the mountain and its glacier system as the most significant features which merit preservation.

Taylor (1922) noted that the meadows ". . . are among the most famous natural flower gardens in the world."

It is disturbing that an area which is so heavily used, the value of which was recognized so early, and contains so many socially and scientifically valuable plant communities has received so little attention from botanists.

To date two major compilations of the Park's Flora have been published (Jones, 1938; Brockman, 1947). Several preliminary lists of species preceded Jones' work. These included work by Piper (1916). Later, Flett (1922) discussed some of the more conspicuous flowering plants and St. John and Warren (1937) published a list of the flowering plants of Mt. Rainier National Park. Brockman (1933 and 1949) prepared publications on the forests and trees of Mt. Rainier. He also initiated the first study on the impact of people on the subalpine meadows (Unpublished). Earlier, ecological work was begun by Taylor (1922) who published a brief discussion of the vegetation of the Park. More recently Higinbotham and Higinbotham (1954) related the mosses in the Park to forest types. Franklin et al. (1971) reported on the invasion of subalpine meadows by trees. Recently, Singer (unpublished) did a study on the impact of foot trampling on Burroughs Mountain and Hamann (1971) submitted her unpublished report on the impact of elk on the vegetation of the Park and finished her study of the Alpine and Subalpine vegetation in the northeast part of the Park (1972).

In 1970, when this study was begun, it was readily apparent that studies of the ecology of the subalpine meadows in Mt. Rainier National Park were sorely lacking despite early recognition of the social, recreational and ecological significance and later recognition of the need for proper management. Thus working with J. F. Franklin, M. J. Hamann, and N. A. Bishop in 1970, it was decided that the phytosociology and dynamics of the meadows had been neglected long enough.

The objectives of this study therefore, were to delimit and describe the subalpine meadow communities in Mt. Rainier National Park in terms of composition, structure, distribution and habitat and to begin work on the successional relationships and animal and human impact on the meadows.

II. DESCRIPTION OF THE AREA

Location

Mount Rainier National Park lies in the Cascade Range of Washington approximately 47° north latitude and 122° west longitude, and about 50 miles (80 km) southeast of Seattle, 100 miles (160 km) northeast of Portland and 50 miles (80 km) west of Yakima. Its lowest elevation is 1600 feet (488 meters) and its highest is the summit, 14,410 feet (4395 meters). It covers 378 square miles (98560 ha) of rugged, glacier-carved terrain of which about 9% is subalpine meadow.

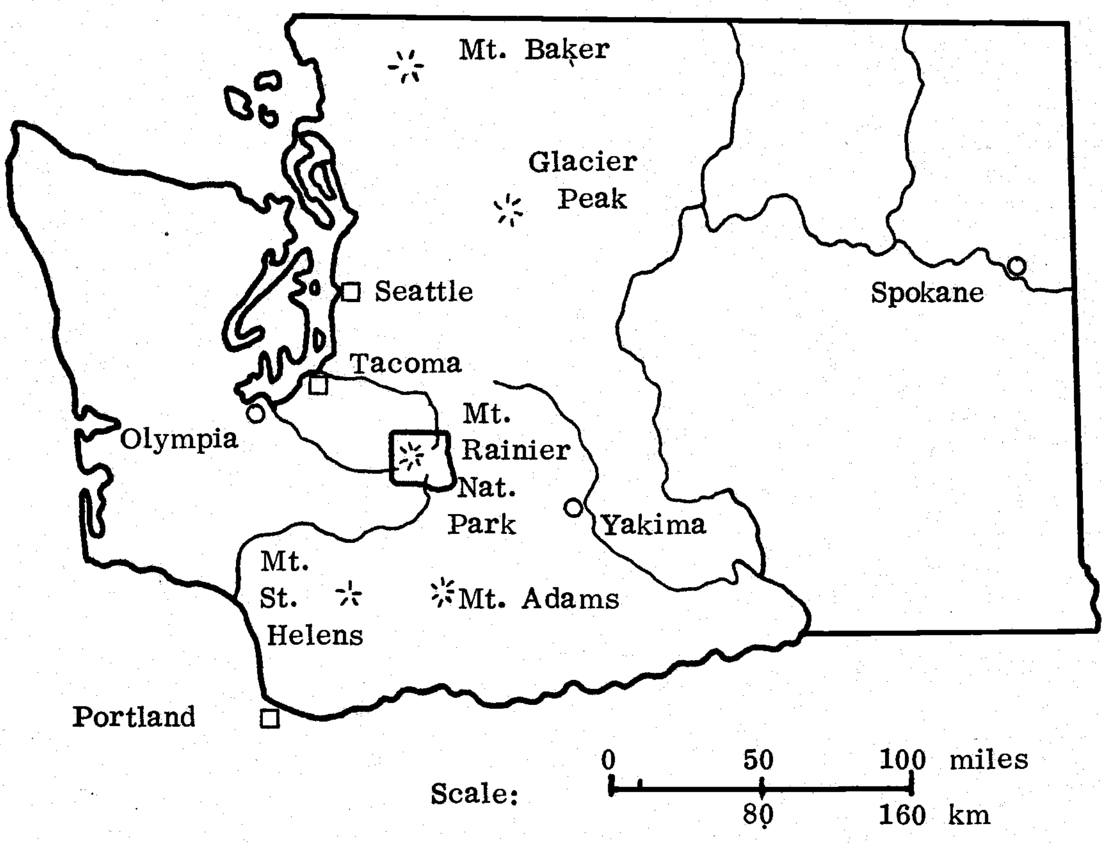


Figure 1. Location of Mt. Rainier National Park, Washington.

Climate

The climate of the Subalpine Meadow Zone on Mt. Rainier is generally cool and moist, although quite variable with habitat and elevation. A weather station has been maintained at Paradise Park, elevation 5,550 feet (1680 meters), since 1920, somewhat intermittently, although regularly since 1955. Another station has been maintained at Longmire, elevation 2,761 feet (825 meters), since 1930. The Paradise weather station is located in a small opening in the forest near forest-line in an area of mostly heath-shrub and lush-herbaceous vegetation. All climatological data cited are from U.S. Dept. of Commerce (n.d. and 1920 to date).

Temperatures at the Paradise weather station have not changed greatly since records began. The annual average temperature prior to 1931 was 38.3° F (3.50° C); for the period from 1956 to 1968 it was 38.4° F (3.55° C); while in the intervening period from 1931 to 1942 (data are missing for 1932, 1933, 1934, 1937 and 1939) it was half a degree higher at 38.9° F (3.83° C). Average temperatures during the summer months (July, August and September) were warmest during the 1940's, coolest during the 1950's and intermediate for both the 1930's and 1960's (Table 1). (See Figures 2 and 3.)

Total annual precipitation has varied more than temperature. Prior to 1931 the average annual precipitation at the Paradise weather station was 102.4 inches (260 cm); during the period from 1930 to 1943 (minus 1933, 1934 and 1939) the average was 95.8 inches (244 cm) and for the period from

Table 1. Average July, August and September temperatures.

Years	Temperatures	
1930 - 1939	51.73° F	(10.96° C)
1940 - 1949	51.80° F	(11.00° C)
1950 - 1959	51.42° F	(10.79° C)
1960 - 1969	51.77° F	(10.98° C)

1955 to 1968 it was 118.5 inches (301 cm). This was 23.3 inches above the average for the drought period of the late 1930's (Figure 5).

During the snow-free period of the summer (July, August, and September) the precipitation averaged 6.91 inches (17.6 cm) in the 1930's, 9.18 inches (23.3 cm) in the 1940's, 9.84 inches (25.0 cm) in the 1950's and was greatest at 10.00 inches (25.4 cm) during the 1960's. This represents a distinctly increasing precipitation pattern during the past 40 years.

Summer precipitation had increased 45% from the 1930's to the 1960's while changes in summer temperatures for the same period were less than 1%. Thus the "warmer-drier" period of the late 1930's may have been only a drier period. The variation in the precipitation has probably had much more of an effect than the almost obscure change in temperature (Figure 7).

The highest temperature of the summer usually comes about the third week in July and ranges in the middle 80's (° F). Sometimes the maxima occur in late August or September. Such late maxima are usually lower than average which probably indicates a somewhat cool summer. These late maxima occur every 3 to 4 years and often occur in the years following conifer cone crops.

Total snowfall at the weather station averages about 500 inches (1270 cm) annually but in 1970-71 and 1971-72 the total was more than twice as much. Minima are about 325 inches (825 cm) (Figure 6). The maximum snowpack varies from about 100 inches (254 cm) to over 300 inches (762 cm) (Figure 8).

The maximum winter snowpack occurs during March or April and snow usually remains on the ground until late June or July, although on different habitats it may melt off sooner (e.g. dry-grass communities) or later (e.g. wet-sedge communities). The dates the snowpack has melted off at the weather station site at Paradise are given in Figure 9. The snowpack starts building from mid-October to mid-November, although snow may fall intermittently beginning in September or earlier. In an average year the snow depth record at Paradise reaches zero about July 1.

Geologic History of Mt. Rainier

Mt. Rainier, as a volcano, can be traced backwards in time for about one million years. It was in the Pleistocene epoch that andesite flows began exuding from the site which is now marked by the great cone.

At first these flows filled deep valleys. Gradually the mountain was built of andesite magma, pyroclastic materials, lahar and pumice. Its maximum height was reached about 2000 years ago when its maximum elevation was

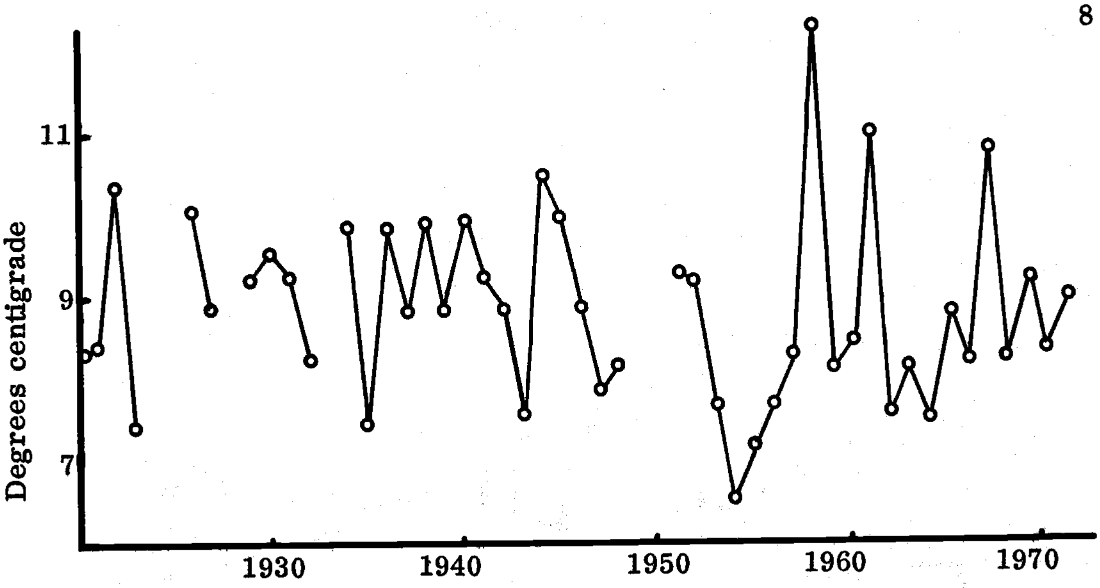


Figure 2. Average May, June, July and August temperatures - Paradise.

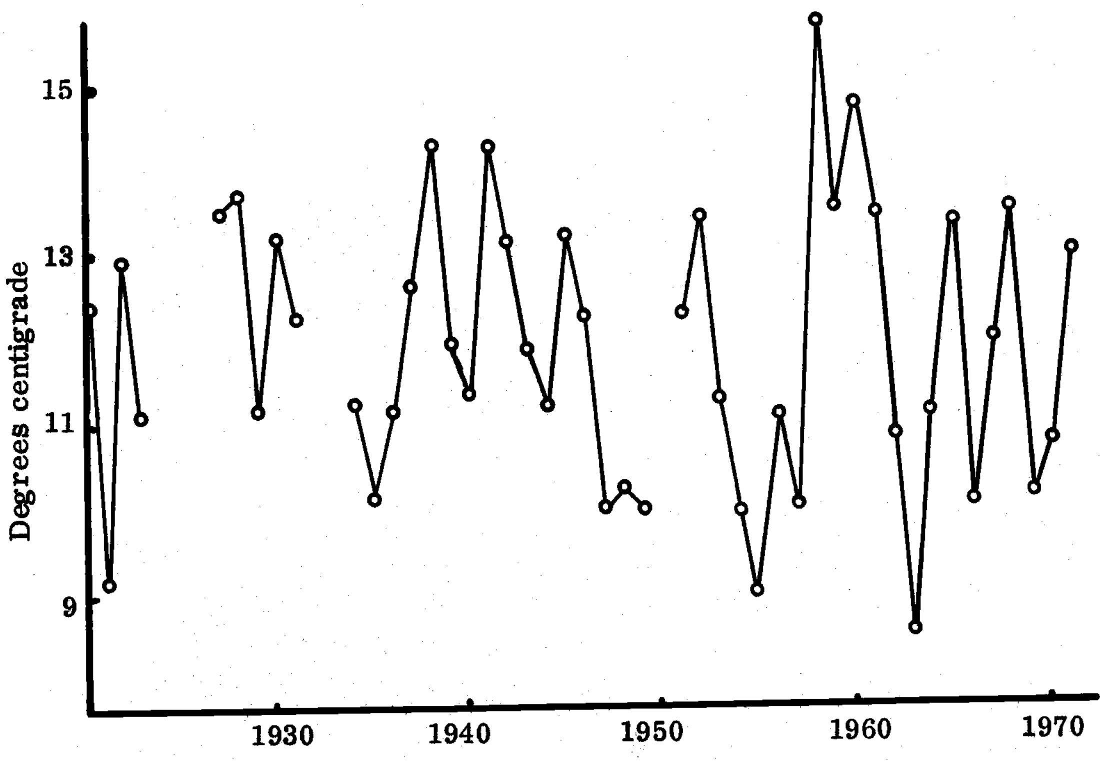
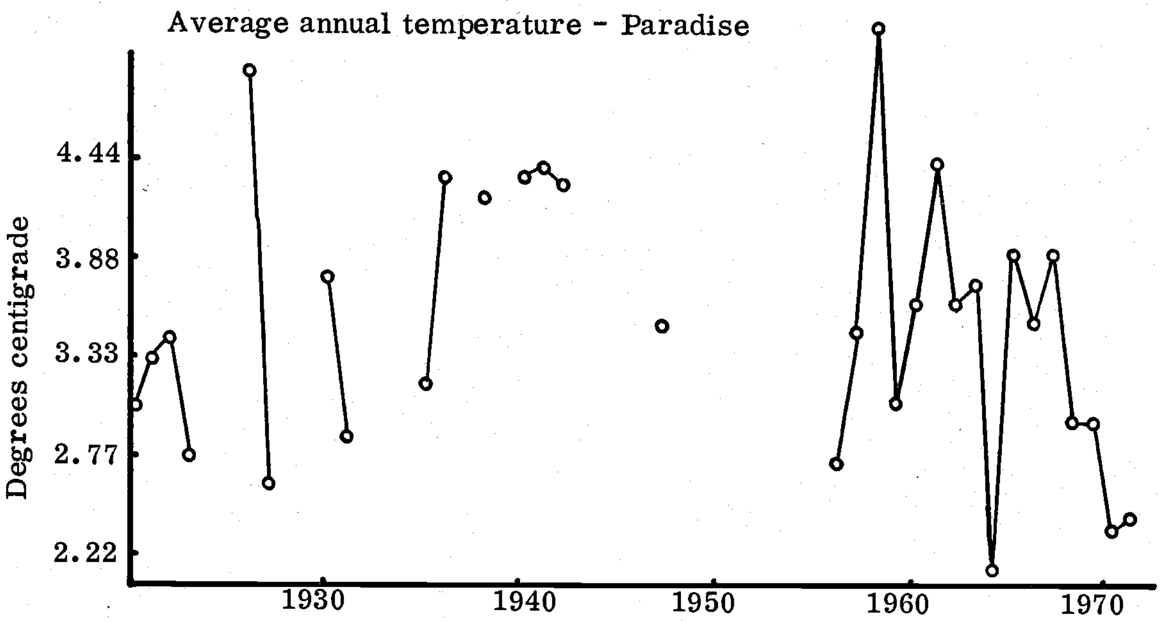


Figure 3. Average July temperature - Paradise.



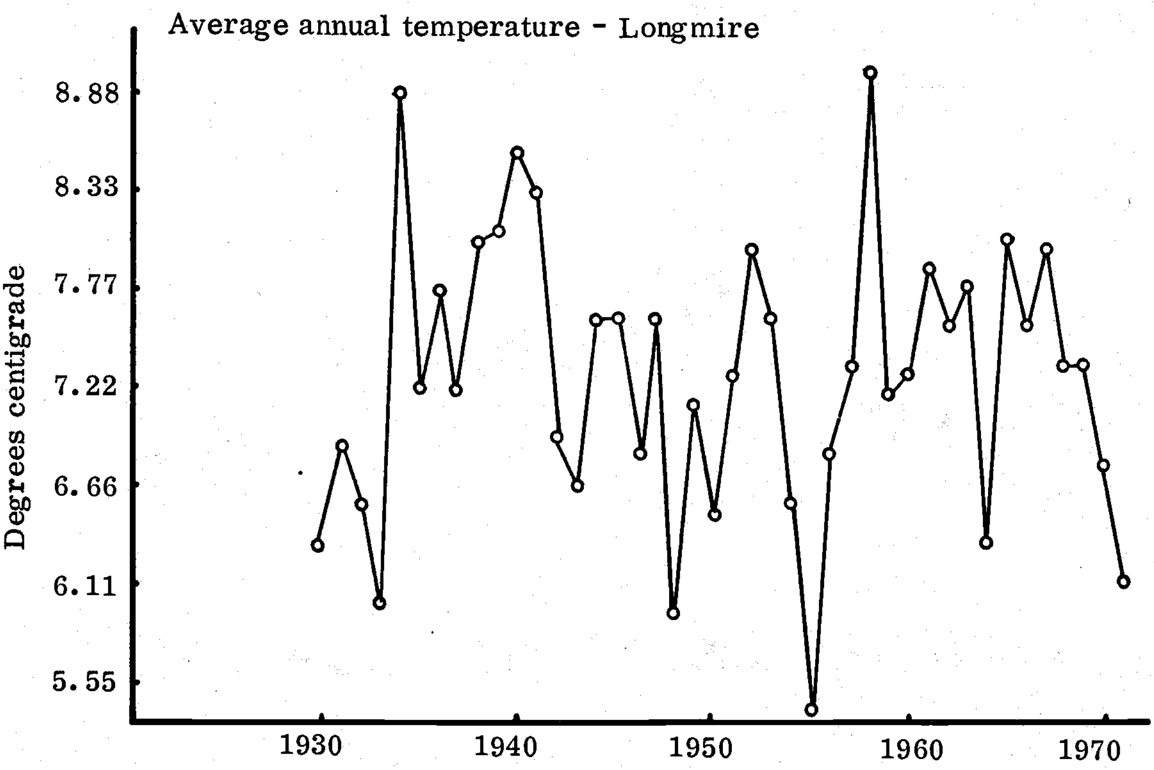


Figure 4. Average annual temperatures for two weather stations on Mt. Rainier.

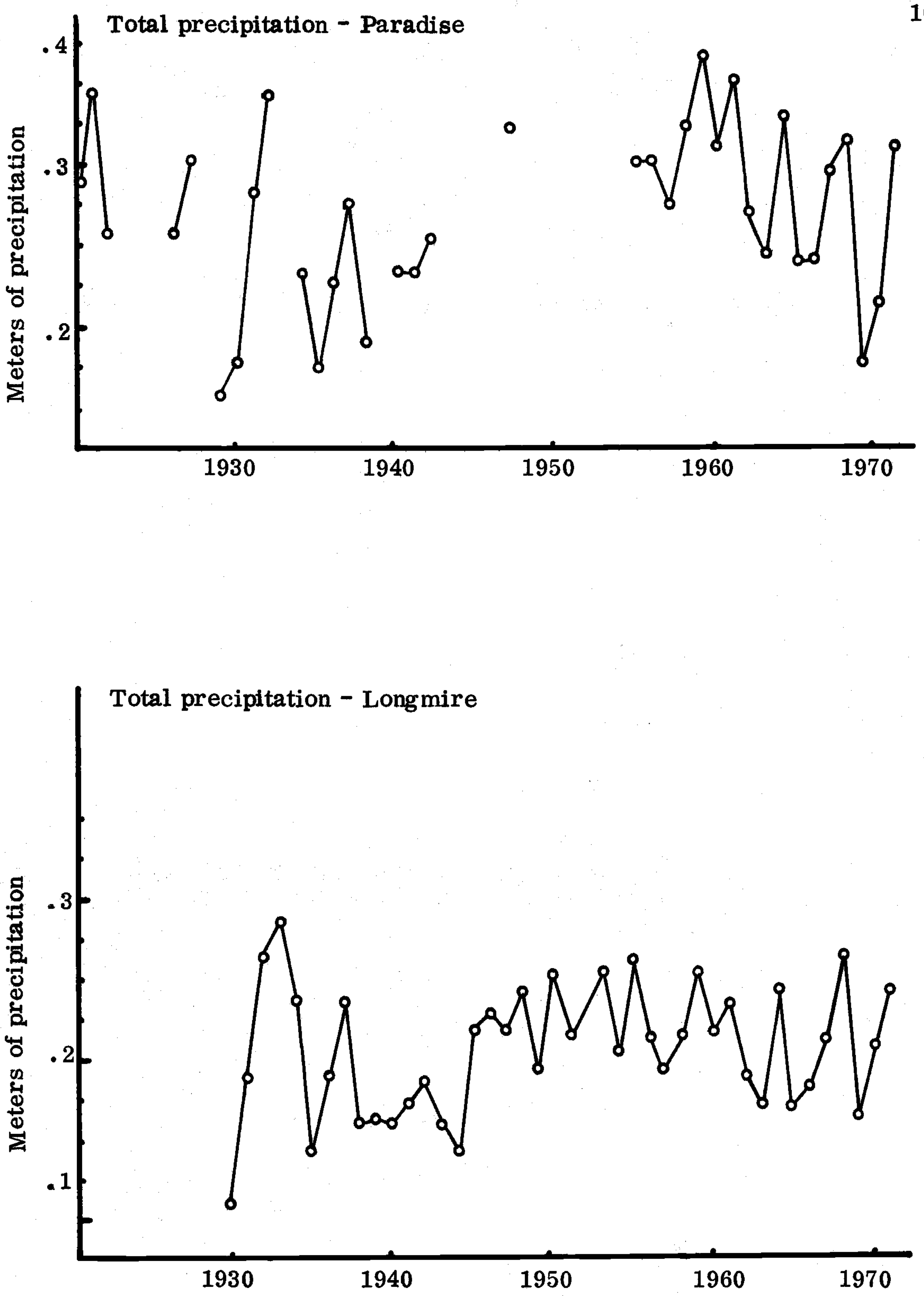


Figure 5. Total annual precipitation for two weather stations of Mt. Rainier.

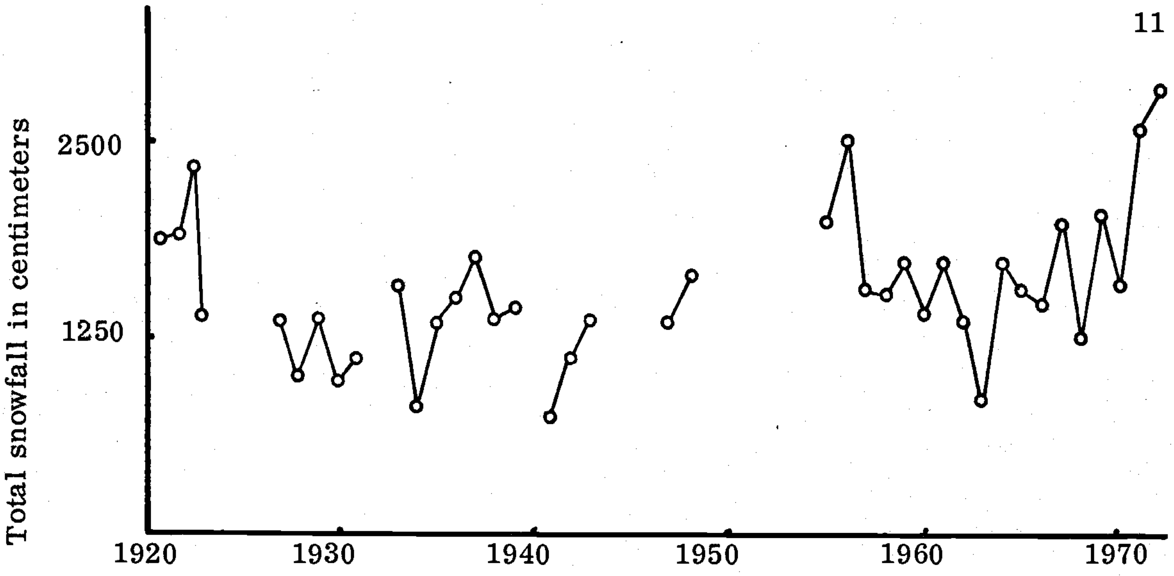


Figure 6. Total seasonal snowfall - Paradise.

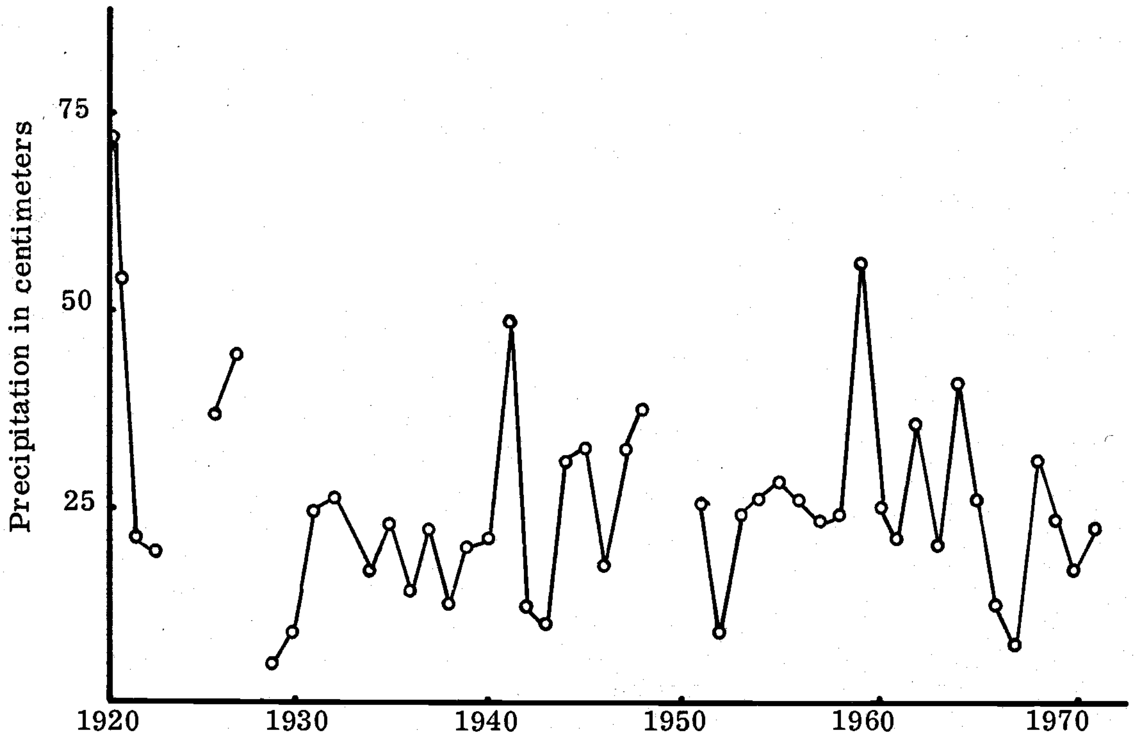


Figure 7. Precipitation during July, August, September, in Paradise.

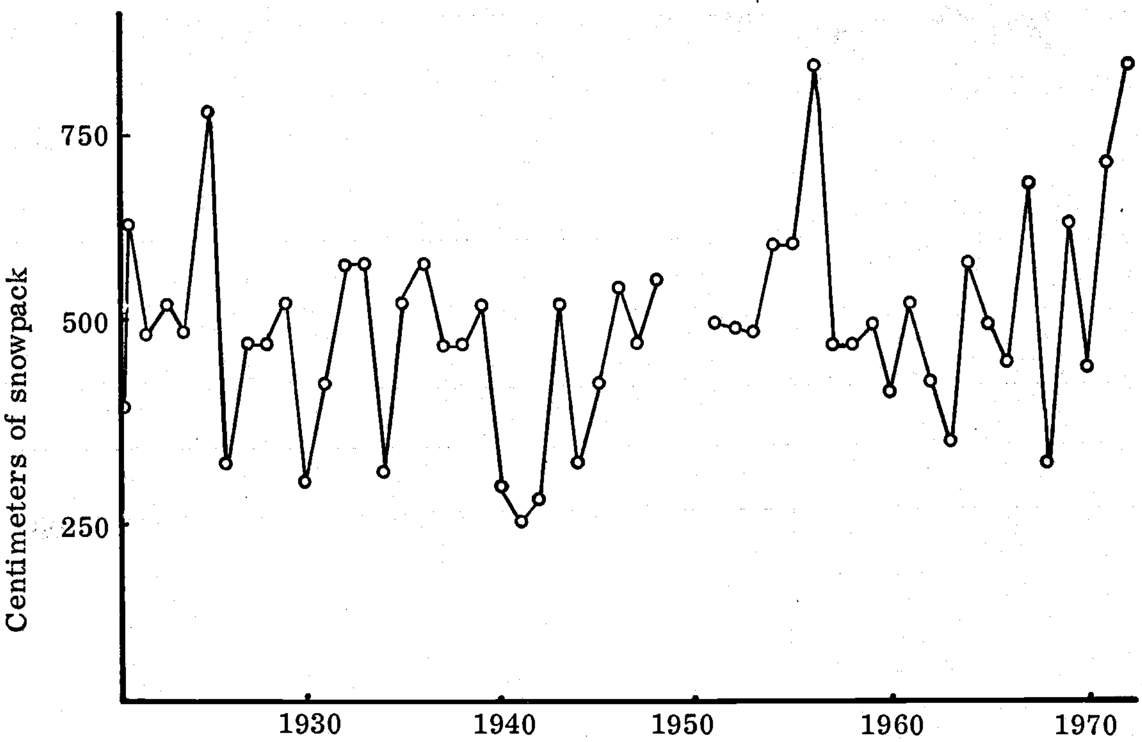


Figure 8. The maximum snowpack depth for the Paradise Weather Station, 1920-1972. Maximum depths are recorded through the winter season e.g. 1971-72 but are plotted in the year of attainment e.g. 1972. In all cases maximum snowpeak came after January 1.

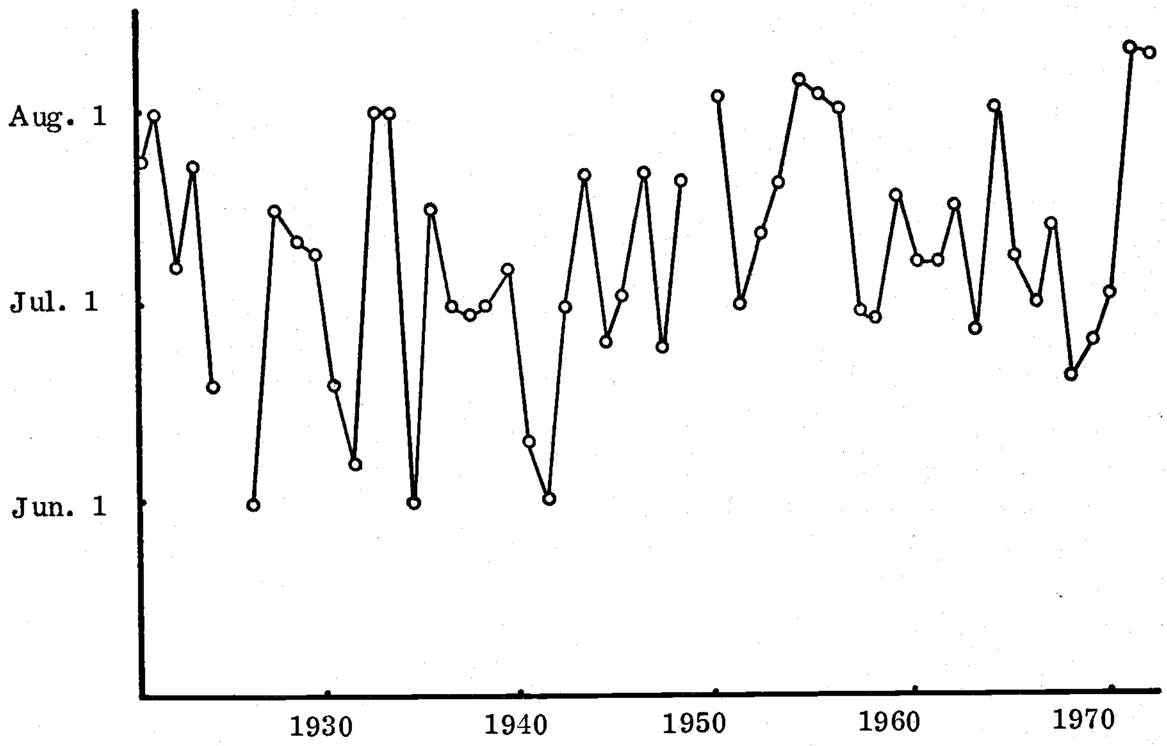


Figure 9. Last day of spring snowpack - Paradise. The date the snowpack melts off at the weather station at Paradise. Data missing for 1925 and 1949. Other late years are recorded. Fisher (1918) indicated that 1916 and 1917 were heavy snowpack years which melted off during the first week in August. Haines (1962) indicated that 1884, 1892, 1893 were late years.

15,000 feet (4,600 meters). Subsequently, however, gigantic debris flows and the ever-active force of glaciation have reduced both the height and the bulk of the mountain.

The foundation on which Mt. Rainier rests is much older than the mountain itself. The history of the underlying strata can be traced back nearly 60 million years to the Eocene when the area now known as western Washington was a broad lowland of swamps, deltas, and inlets that bordered the Pacific Ocean (Fiske et al., 1963; Crandell, 1969a). Clay and sand were being deposited by rivers draining the lands to the east, and organic matter was being deposited in place. The result was 10,000 feet (3,000 meters) of beds of sandstone, shale and coal called the Puget Group.

On top of the Puget Group lies the Ohanapecosh formation, another 10,000 feet of material laid down about 40 million years ago. This volcanic material, however, was extruded under water and formed into beds of breccia.

During the Oligocene, about 30 million years ago, volcanic eruptions poured great amounts of hot pumice on top of the Ohanapecosh formation. This material consolidated and cooled to form the Stevens Ridge Formation.

During the Oligocene or Miocene the Fifes Peak Formation was deposited to a depth of 760 meters. It was again volcanic and was composed of basalt and andesite flows.

Following a period of uplifting and folding a plutonic intrusion pushed upward through the Puget Group and younger rocks. This occurred about 12 million years ago.

About the time of the formation of the pluton, the Cascade Range, as we know it, began to rise. As the land rose, rivers carved deep valleys from the uplifted rocks, into which the first outflows of Mt. Rainier andesite would be spilled.

Today most of the foundation of Mt. Rainier is the Pliocene granodiorite pluton. The lateral ridges, however, are formed from the Ohanapecosh, Stevens Ridge, and Fifes Peak formations and from the Pleistocene andesite flows from Mt. Rainier itself (Crandall, 1969a).

Surficial Geology

Secondary rock, ash and lahar deposits upon the bedrock parent material have been important factors in soil and plant community development. The study of such deposits, or surficial geology, yields much information about the ecology of these meadows. The following discussion is based on a review of the surficial geology of Mt. Rainier by Crandall (1969b).

Pumice and ash layers form an important part of the soil in most of the Subalpine Zone. Of these the Mount St. Helens Y is the most important throughout the Park, and is most conspicuous in the western part. It is dated about 3300 to 4000 years and is composed of coarse yellow sand. Its depth of accumulation varies from 2 cm in the east side of the Park to 45 cm at places in the west. Only two other layers are recognized in the west, the St. Helens W, a white sand about 450 years old and the Mt. Mazama O, a yellowish-orange silt about 6600 years old. All layers are found in the east side of the Park but mostly they are less than 4 cm deep, each.

The older, finer textured layers are usually well preserved in the soil profile and mark the rate of soil accumulation. They have aided in community development by adding fine textured material to the soil. They probably had devastating effects on the plant communities when they fell, however. The coarser textured pumice layers, more conspicuous on the eastern ridges, might be a factor in inhibiting community development by increasing the amount of bare mineral soil and increasing the porosity and drainage of the soil.

In many places, such as road cuts along Sunrise Ridge or in Paradise Park several layers can be found exposed at once. See the photograph of the cut near Sluiskin Falls on page 8 of Crandall (1969b).

The St. Helens Y was encountered at 105 cm in a pollen profile taken from Frog Heaven near Paradise. The St. Helens W, 450 years, was encountered at about 30 cm.

Other surficial deposits are locally more important as substrate for subalpine communities. These are mudflows and depositions of till or drift.

Mudflows and lahars have occurred in most parts of the Park, although most commonly in the southwest. The oldest of these is the Van Trump Mudflow, 11,000 to 15,000 years old. It swept down Mt. Rainier's south flank and spread over Van Trump Park. It is a mixture of unsorted clay, sand and rock debris which accumulated to about 2 meters. Only about 40 hectares of this deposit remain today upon which mostly lush-herbaceous communities have developed.

The Osceola Mudflow (ca 5700 years b. p.) is the largest mudflow to have originated on Mt. Rainier. It originally covered an area of more than 160 square kilometers and is an unsorted mixture of clay, sand and rock debris. Remnants occur more than 125 m above the valley of the White River and on ridgetops above Glacier Basin and on Steamboat Prow where it is unvegetated or supports stands of Valeriana/Veratrum or a Heath-shrub.

Another mudflow covers part of Indian Henry's Hunting Ground. The age is not given by Crandall but is included in a class of mudflows occurring in the Tahoma Creek and North and South Puyallup River valleys which are all less than 4000 years old. Most, if not all, mudflow material now deposited in the Subalpine Zone supports stands of Lupinus/Valeriana or Valeriana/Veratrum Community Types.

A similar mudflow occurred in the Paradise area between 5800 and 6600 years ago. It was composed of a plastic yellow-orange mixture of unsorted clay, sand and rock fragments a few centimeters to over 5 meters thick. The mudflow lies on top of pumice layer O.

Deposits of drift in the Subalpine Zone include the Evans Creek Drift, 15,000 to 25,000 years b.p.; the McNeeley Drift ca. 11,000 years b.p.; the Burroughs Mountain Drift 2500 to 3000 years b.p. and the Garda Drift mostly deposited from 450 years ago to present.

The Evans Creek Drift occurs on all sides of the Park, mostly above 1375 meters elevation and predominantly in the northeast part of the Park. It is usually stony, loose and well drained and often supports stands of the Festuca/Lupinus community or other Lupinus meadows although some pockets have developed into wet sedge or Antennaria lanata meadows.

The McNeeley Drift is much less abundant and occurs mostly between 1680 and 1980 meters on the ridges. Its texture is undescribed.

Burroughs Mountain Drift is loose and not appreciably weathered. It mostly occurs near the Winthrop Glacier and although it was deposited less than 3500 years ago some deposits have supported several generations of trees. Most drift deposits occur at elevations of about 7000 feet (2150 meters) and are raw piles of rubble where very little apparent succession has occurred.

The Garda Drift is composed of unweathered and unsorted gray pebbles, cobbles and boulders in a silt and sand matrix. These deposits are up to 2500 years old and sometimes support trees up to 750 years old. Most are younger than pumice layer W and therefore are less than 450 years old. This material is largely unvegetated or is being pioneered by Saxifraga tolmieie communities and occurs above about 6000 feet (1830 meters) on the ridge tops and down to 3500 feet (1070 meters) in the valley bottoms. Many high elevation pumice deposits are the same age, being covered by ice fields instead of glaciers during the past 450 years.

Glacial History

Five major periods of glaciation are recognized on Mt. Rainier for the past 50,000 years. The oldest of these corresponds to the Farmdale stage of the Iowan ice age (Hansen, 1961; Cornwall, 1970). It is marked on Mt. Rainier by the Hayden Creek Drift. This glaciation occurred between 35,000 and 50,000 years ago and attained ice-cap proportions. The entire park was covered by ice during this period (Crandall, 1969a).

The next major glacial period occurred between 25,000 and 15,000 years ago and is marked by extensive accumulations of Evans Creek Drift. This corresponds to the Tazewell or classical Wisconsin glacial period. At this time icefields and glaciers mantled the slopes of Mt. Rainier above about 5000 feet (1525 meters). Each major valley was filled with a glacier 1000 to 1500 feet (300 to 450 meters) thick which extended up to 35 miles (45 kilometers) beyond the Park boundary (Crandall, 1969a).

The next most recent glaciation, occurring about 11,000 years ago, is marked by the McNeeley Drift and corresponds to the Mankato-Valders glacial period (Hansen, 1961). Morraines of the McNeeley drift can be found at elevations between 5500 and 6700 feet (1680 and 2050 meters).

Since this major period of glaciation, marked by Evans Creek and McNeeley Drift, two major ice advances are recognized. One, between 2500 and 3500 years ago, is marked by the Burroughs Mountain Drift. During this advance the glaciers became only slightly larger than they are today. Between the Mankato-Valders period and the Burroughs Mountain advance (11,000 to ca. 3000 years ago) a warm, dry period is recognized (Hansen, 1949; Crandall, 1969). During this time glaciers were smaller than they are today and vegetation zones probably extended higher on the mountain.

Although potential timberline was probably higher during this period, the subalpine vegetation was probably not as well developed as it is now. This would be due to the raw, immature soil conditions which existed then. Beginning with the Mount Mazama eruption 6600 years ago, many ash and pumice layers have accumulated and vegetation and climate have had several thousand years to rework the soil since the Wisconsin glacial period. Subalpine vegetation during this post-glacial dry period was most likely very similar to that which now exists in the central Oregon Cascades.

The last known period of glaciation existed during the past several centuries. Crandall (1969b) claims that this period terminated sometime between the 17th century and 1910. Records from Alaska (Lawrence, 1950) and from British Columbia (Mathews, 1951) indicate that for North America there were at least two advances during this "Little Ice Age." One terminating about 1750 followed by a retreat and then another advance terminating about 1860 followed by ice retreat to current positions.

Harrison (1956a, 1956b), Sigafoos and Hendricks (1961) and Meier and Post (1962) indicated that for the Nisqually Glacier recession began about 1750 and continued slowly until about 1850 when it temporarily advanced then receded slightly and readvanced slightly about 1882 then retreated rapidly until

1900 when it again advanced slightly. About 1906 it began receding rapidly and steadily until 1953 when it again advanced. From 1953 to 1962 it remained relatively stationary.

Minimum dates of Garda moraines taken by Sigafoos and Hendricks and given on the map accompanying Crandall (1969b) indicate both the 1750 and 1860 dates as times of terminal morraine deposition. Their data also indicate that at least one older advance ca. 1650 and perhaps another older still in the 14th century may have also occurred. The regularity of such dates leads one to suspect that ice advances may have been occurring at hundred-year intervals for several centuries. Since the last ice advance occurred sometime in the middle to late 19th century, it would not be too surprising to find another ice advance occurring in this century.

Records show that since the maximum extent of the Garda advance there was a period of warmer, drier climate which terminated about 1940. Since then temperatures have declined and precipitation has increased (Figures 4 and 5).

Retreat of the glaciers has probably not been steady or smooth during this period. Lawrence (1950) has found a series of about 20 small parallel moraines which marked the recession of the Herbert Glacier, about 40 km north of Juneau Alaska. The oldest of these moraines he believed to have been deposited about 1740. He believed that the periods of moraine deposition corresponded with the 11-year sunspot cycle; where deposition was correlated with increased health of the glacier due to periods of low sunspot numbers.

Hansen (1961) indicates more glacial periods for North America than are currently recognized on Mt. Rainier. The Cochrane period ca. 7000 years b.p. is well recognized for North America but no signs of it have been found on Mt. Rainier. For the period since the Cochrane glaciation, Hansen recognizes four glacial periods, two of which are recognized on Mt. Rainier. In addition to the "Little Ice Age" and the Burroughs Mountain advance, Hansen recognizes one period about 1800 years b.p. and another at 4000 years b.p.

III. METHODS

A phytosociological reconnaissance of the Subalpine Meadow Zone was made during the summer of 1970. One hundred and thirty-six unmarked, variable-sized plots were located and sampled in the Park. One hundred of these are shown in the association table (Table 2). Thirty-six were not used in the association table because of unusual environmental features or because the plots were taken too early in the season when only ephemeral species were identifiable or were determined to be Alpine Zone communities. Edge effects and ecotones were avoided when recognized, but the samples were taken without regard for a preconceived notion of what the community classification hierarchy should be. Such a pre-stratification would have probably yielded more uniform field data. However, the object was neither to create an artificial classification out of a continuum nor to express a discrete vegetation mosaic as a continuum. Plot locations were chosen, albeit arbitrarily, so that the vegetation mosaic would have the best chance of expressing itself in the analysis of the data.

Location of subalpine meadows for sampling was not difficult. All major trails lead to the Subalpine Zone sooner or later. Trail access necessarily biased the location of the samples, but numerous trips were taken cross-country to meadows not accessible by trail.

Once the plot location was established, most data were taken by standing in one place and recording all information desired. Sometimes more than one sample per meadow was taken if the meadow was large or if it contained more than one distinguishable community. Then to be sure to include obscure or rare plants a search was made in the vicinity, often on hands and knees for additional species. The area searched varied with the homogeneity of the stand. Care was taken not to include vegetation from a different community when it could be recognized.

These plots were sampled for species dominance using the prominence rating method of Poulton[1] (Poulton et al., 1971); for sociability using the method of Braun-Blanquet as described in Küchler (1967); and for percent ground cover to the nearest percent for values less than or equal to 10% and to the nearest 5% for higher values by a method similar to that described by Franklin and Dyrness (1970). Additional data were taken on aspect, slope, elevation, topographic position, animal and human impact and phenology.

At the same time M. J. Hamann was taking similar data for subalpine and alpine meadows in the northeast portion of the Park (Hamann, 1972). Our data were combined for the SIMORD analysis of the subalpine meadow vegetation and association table but her data are not presented here.

During the short summer of 1971 the results of the SIMORD and association table analyses (done during the previous winter) were field-checked. Additional plots were taken to fill in gaps in the data. Data were taken that would help define successional patterns and field work was begun on a type-map of the subalpine meadow vegetation.

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[1] See Appendix II for description of Poulton's methods.

The analysis of the data taken in 1970 yielded a description of the community and vegetation types in the form of a hierarchy and a two-dimensional ordination. A key to the community and vegetation types was also built.

Field checking in 1971 involved many more miles of reconnaissance, testing the keys and descriptions in field situations and making references on the aerial photos to be used in the preparation of the type map.

Also in 1971 a serious attempt was begun to collect data that would help in the analysis of successional patterns. Plots and photographs were taken in different communities on similar habitats. These stands were selected because it was believed that they belonged to a recognized sere. Phenological data were also taken to guard against calling a phenological progression a succession. Care was also taken to distinguish between an environmental gradient and a succession, although the two are nearly inseparable. Also, numerous trees and seedlings were aged by counting both terminal bud scale scars and growth layers to try to recognize and analyze seedling growth and periods of tree invasion. This follows work begun by Franklin et al. (1971) who first described meadow invasion by trees on Mt. Rainier and indicated that a mass invasion had occurred during the 1930's when "the climate was warmer and drier."

Measurements were taken of soil moisture by burying electrodes imbedded in plaster-of-Paris at depths of two and 20 centimeters and measuring resistance across the gap. Soil moisture has been calibrated to the resistance which is proportional to the amount of free moisture in the soil. These measurements were converted to soil moisture by using the calibration curve of Drew (1968). These blocks were buried in typical Phyllodoce/Vaccinium, Carex nigricans, Lupinus/Valeriana, and Festuca/Aster meadows at Paradise and in a Festuca/Lupinus and Festuca/Aster meadow at Sunrise (Table 5).

The temperature of the surface 2 cm of soil was measured using a 7-day recording thermograph in the Festuca/Aster, Carex nigricans, Phyllodoce/Vaccinium and Lupinus/Valeriana meadows at Paradise and in the Festuca/Lupinus meadow at Sunrise (Figures 14, 15, 16, 17, 18, 19).

During the summer of 1972 similar measurements were taken on soil moisture and temperature. The type map, prepared during the previous winter, was field checked and work was begun on additional ecological and taxonomic problems.

IV. RESULTS

Phytosociological

As a result of field work a stand (association) table was assembled (Table 2). It includes only the major species (or those occurring in more than six stands) and those plots taken personally. An additional hundred plots taken by Hamann (1972) were included in an inclusive stand table and in the SIMORD runs. Her raw data are not shown here. The stands are aggregated by similarity and species are aligned in groups of species often found growing together. Some stands were omitted from the association table which are clearly early seral and have very low ground covers. The inclusive association table was used in compilation of the keys (p. 58) and in building the vegetation hierarchy. It shows, however, upon inspection that many stands do not fit neatly into the classification built from it. This vegetation hierarchy emphasizes differences, whereas the SIMORD ordination, in many ways, emphasizes similarities.

The SIMORD ordination[1] (Dick-Peddie and Moir, 1970) was used to ordinate stands based on computed arithmetical similarities to four reference stands selected from the stand table. Such an ordination uses the plants themselves as indicators of the environmental gradients along which the stands are ordinated. The four reference stands are thus carefully selected to represent the end points of two environmental and/or successional gradients.

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[1]See Appendix I for a discussion of SIMORD.

Three SIMORD runs were made. In two runs, reference stands were selected, in the third the computer was programmed to select the four most dissimilar stands in the table. This third run was then discarded because it showed no meaningful relationships.

After the community types were delimited, two more runs were made but using community types as inputs instead of stands. The results of one of these runs is shown in Figure 10. It shows the relationships between community types and how they can be segregated into vegetation types. In the upper part of this ordination, the Phyllodoce/Vaccinium type stands alone. In the left corner the Carex nigricans and low herb communities are clearly clustered. In the center is a group of non-related successional types which resemble the low-herb group but are succeeding to the lush-herbaceous types. The linear assemblage of types in the lower right corner represents the gradient of dry-grass to lush-herb types.

Table 2. Association Table

Species/ Plot	36	42	93	107	128	78	62	53	91	81	84	24	100	70
Ca ni[1]	80	70	50	70	65	80	80	70	70	60	50	50	30	30
Pe or	1		1	1		1	2	1	1	1			5	
As al		1		1	8	3	1	7	2		20		15	1
An al		1										1		5
Ta st	1													
Va de	1		1			1	1	1	1				1	
Ph em	1	1	1	1	1		2	1			1	1	2	
Ca me		2	1		1		1		2	1			2	
Lu pe	1	2						1				1		
Po fl		2	1	1		2	5	1	3	10	2	1	20	
Ca sp	2	4	1		1		2	1	1	10		25	3	
Po bi								1				1		
An oc														
Ca pa								1	1					2
Er pe														
Ve cu											1	1		2
Hi gr														
De at														
Lu gl														
Lu wa														
Lu di														
Er	1						1			8				
Ge ca						1								
Lu la										10		2		1
Pe ra											1			
Pe co												1		
Va si														
Ve vi	1													
Ar la														
Fe vi												8		
Mi al														
As le														
Pe br														
Li gr	1									1				
Ca mi														
Ph di														
Er ov														
Po ne														
Ac mi														
Pe pr														
Sa to														
Ju pa		1												25
Ar ob														
Xe te														
Tr sp														
Ag au														

[1] See Appendix III for key to these species abbreviations.

Table 2. Association Table (Cont'd.)

Species/ Plot	25	30	94	32	09	126	124	129	97	10	08	127	90	21	22
Ca ni	25	40	20	20	1	8	6	8	6	1				6	1
Pe or			1	1		1							2		
As al				2	10	2		10		30	35	1	1		
An la			1	2		15		20		8	15	8	15	20	
Ta st		50	1	30	45					1			1		
Va de	5		10	15	1	10		4				12	4	7	1
Ph em			20	1									20	35	20
Ca me				1		4							5	5	7
Lu pe	50		1	2				4					15		2
Po fl			1	4	1	3	25	1	12	10	8	8		2	
Ca sp			1		1		25	1	1	1	2			5	1
Po bi				1	8	12	1	3		6	1	15	1		
An oc									1	1		1		2	
Ca pa			1	4	1			3		1		1	2	1	
Er pe						6	1	15					1		
Ve cu			1	1	1		1	4		1		1	1		1
Hi gr						1	3	1							
De at				1	1	1	1			1			1		
Lu gl												8			
Lu wa															
Lu di									1						
Er				3						1	1	1		4	
Ge ca						3		1				1			
Lu la					10	2	10	2	6	1	1	1	2		2
Pe ra				1									1		
Pe co				1		3						1			
Va si												1			1
Ve vi							1		1						
Ar la															
Fe vi					4	5	1	5	25	30	20	8			
Mi al					1		3			1					
As le										5					
Pe br											5				
Li gr						1	1	1	1	1	1	7	1		
Ca mi															
Ph di											15				
Er ov															
Po ne															
Ac mi															
Pe pr															
Sa to			1												
Ju pa															
Xe te														1	
Tr sp								1							
Ag au							1								

Table 2. Association Table (Cont'd.)

Species/ Plot	89	35	75	85	28	79	125	33	30	73	77	109	71	60	51	101
Ca ni								1	1				3			
Pe or		1				3	1		1	1		1	1	2	1	
As al	1	1	1						1	1	1	2	1		2	3
An la	1	1		1		1			1	1		1	3		1	10
Ta st	2	5						5	5							
Va de	55	20	15	45		15	25	10	30	10	10	60	15	10	15	20
Ph em		35	2	40	10	15	25	60	10	30	40	15	25	60	8	
Ca me		10	30			10	15	20	15	30	20	1	15	10	7	
Lu pe	2			4			5	1	1	1	10		1		1	5
Po fl				1		1		1	1		1	1		1	1	2
Ca sp						1	1	1						2	1	
Po bi	1											1			3	3
An oc				1											1	1
Ca pa	1	1	1	1		2		2	1		1		1	1	2	2
Er pe							1				1	1			1	
Ve cu		1		1			1						1		1	
Hi gr	1			1			1			1			1	1	1	2
De at	1						1	1		1	1	1	1	1		
Lu gl				1			1	1				1				
Lu wa		1	1			1					1				1	
Lu di																
Er		3	1			1			2		1					
Ge ca											1	2	1			
Lu la	1	1	2	2					1	5		10	10	8	45	15
Pe ra	1	1				1		2	3				1		1	
Pe co			5										3		1	
Va si	1			1			1									
Ve vi		1														
Ar la																
Fe vi		1													1	5
Mi al				1								1			1	1
As le																
Pe br																
Li gr	1					1				1	1	1		1	1	2
Ca mi																
Ph di																
Er ov																
Po ne																
Ac mi																
Pe pr																
Sa to																
Ju pa		1														
Ar ob																
Xe te			8	1	30	2				1			3			
Tr sp		1														
Ag au	1															

Table 2. Association Table (Cont'd.)

Species/ Plot	68	103	66	69	50	115	65	119	49	56	111	74	118	57	76
Ca ni			5		8	1	2		2	1	1		5		
Pe or	1	1		1		1	2			2	1	5		1	1
As al		1	2		1									1	
An la	1	1	1	2	1							1		8	
Ta st															
Va de	20	8		2	1	1		3			5			5	1
Ph em	5	1		1	15	25	15	25	15	35	25	20	10	20	20
Ca me	25	40	30	30	2	1				20	25	15	10	25	
Lu pe		1	20		6	3	4	1		1	5	1			1
Po fl		1				1		1	3			1		2	2
Ca sp	1				4	15	2	1	5	2	1		1		2
Po bi		6		1	1	2		4	2	1		1		2	8
An oc					1	1		1	1	1					
Ca pa		1		1		2		4	2	2			1	1	1
Er pe	2	1		3	1	1		3	1			1			1
Ve cu		1			2		1	1	1	1				1	1
Hi gr	1	1			1	1		1	1	1	1	1	1		1
De at		1			1			1			1	1		1	1
Lu gl		1						1	1					2	
Lu wa		1		1	1			1	2	1			4	2	
Lu di					1								1	2	
Er						3		1	2			10		1	1
Ge ca	2	1		1								1			1
Lu la	15	20	30	40	45	30	15	25	20	10	20	20	10	15	30
Pe ra		1													1
Pe co				2	1				1						
Va si						1		5	5				1		10
Ve vi									1						
Ar la								1	1						
Fe vi		1													
Mi al		1							1	1		1	1	1	1
As le															
Pe br					1									1	
Li gr		3		1	1	1			2			1		1	1
Ca mi															
Ph di							2								
Er ov															
Po ne													1		
Ac mi															
Pe pr															
Sa to													1		
Ju pa		1			1		15			1			1		
Ar ob															
Xe te															
Tr sp		1	2		2										
Ag au													1		

Table 2. Association Table (Cont'd.)

Species/ Plot	72	12	13	23	80	83	61	37	112	92	98	99	52	82	29	114
Ca ni	1									1			1			1
Pe or																
As al	1					1							2		2	
An la	1				1	1					1		2	1		
Ta st															2	
Va de	1	50			2	2	4									
Ph em	2	1		5	2											
Ca me	20				1											
Lu pe									1		1					
Po fl		1			2	2			1		2	7	1	2	1	2
Ca sp	1	1	5		3	1		2	30	30	20	5	1	1	2	15
Po bi	10	1			10	15	2	2	3	1	15	25	15	15	2	20
An oc		3			5				2		6	8	4			3
Ca pa	1	2		1	15	5	2		1		1	2	2	1	9	
Er pe					1	2	2			2	1					
Ve cu	1			1	1	1			1		1		1	1		
Hi gr	1				1	1			1		2			1		
De at	1				1	1	1		1	1	1					
Lu gl		1					1							1	1	
Lu wa	1								1							
Lu di	4															
Er			25		2	10	15		1			1	1	10	2	
Ge ca	1															
Lu la	55				25	30	40	10	25	50	15	25	40	30	25	25
Pe ra						2							2		4	
Pe co	1				8								6		1	
Va si		8	35	20	15	20	30	25	10		15			15		
Ve vi		1	15	8				2	2	1			1			1
Ar la							1		8							
Fe vi	10				1	1		2					2	12	9	15
Mi al					1	1					1	1		1		
As le		1						8	2							
Pe be								1					1			
Li gr		1			1					1	8	10	1			2
Ca mi								3								
Ph di													1			
Er ov																
Po ne																
Ac mi																
Pe pr																
Sa to																
Ju pa																
Ar ob																
Xe te			1													
Tr sp																
Ag au																

Table 2. Association Table (Cont'd.)

Species/ Plot	27	132	58	47	130	95	46	121	106	14	104	133	102	120
Ca ni						1								
Pe or														
As al								1	3					
An la			1						1	1		1	1	
Ta st														
Va de														
Ph em	1									1				
Ca me														
Lu pe								4						
Po fl	1		2	2	4	6		1	1	1		4		5
Ca sp	1		2	8	1	1		1	5	1		5	4	1
Po bi	20		2	8	1	8			5		1	1	20	1
An oc	1	15	1		15			4		2		3		6
Ca pa			1	1	1			1		1				
Er pe		1	2									10		
Ve cu	1	1	1	1	10		1	1	3	5	1	1	1	3
Hi gr				1	3									1
De at														
Lu gl			1		3			1		1		1		
Lu wa						1		1						
Lu di									1					
Er		1										1	1	
Ge ca														
Lu la	30		4	30	1	30	25	20	15	35	20	25	4	25
Pe ra														
Pe co							2							
Va si		20	25					1		1				
Ve vi						1	1		1					
Ar la								1						1
Fe vi		20	35	35	25	30	30	20	55	45	45	40	45	25
Mi al	1		1	2	1		1		1	1				2
As le	20	20		1			2	1	1				12	5
Pe br	1		3											
Li gr		3	1				10				3	1	1	1
Ca mi	1						2		1		1		1	1
Ph di	1						1	1	1	5	4	1		1
Er ov						1								
Po ne														
Ac mi	1								1		5			1
Pe pr											1			
Sa to														
Ju pa							1			1		1		1
Ar ob				1					1			1		1
Xe te														
Tr sp						1					1			1
Ag au									1					1

Table 2. Association Table (Cont'd.)

Species/ Plot	86	55	59	48	38	96	134	87	131	110
Ca ni										
Pe or										
As al		1	1	1						
An la			1			1				
Ta st										
Va de	15									
Ph em		1			1					
Ca me										
Lu pe		1								
Po fl			1		1	1		1		
Ca sp	1	3	3		1	3		8		8
Po bi	2	2	3			3		10	1	1
An oc	2	1	1		2	2			10	10
Ca pa		1	1						1	
Er pe	5	2	3					5	3	
Ve cu	1	1	1	2	1		1	1	4	3
Hi gr					1		1			1
De at										
Lu gl										
Lu wa										
Lu di									1	
Er						1			1	
Ge ca										
Lu la	1	25	10	10	3		1	1		15
Pe ra										
Pe co	20	1			4		1	2		
Va si		1						1	3	
Ve vi										
Ar la										
Fe vi	20	25	45	25	12	40	30	20	40	45
Mi al			3	3	1					
As le	15	25	8	25	15	30	20	20		6
Pe br			2							
Li gr	1		1	2	1			2		1
Ca mi		2			2	3	1	8		
Ph di	5	1	1	2	1		2			8
Er ov				1	1					
Po ne				1	1		1			
Ac me				1	1		1			
Pe pr		1								
Sa to										
Ju pa					1		3			
Ar ob				1	1		1			
Xe te										
Tr sp										
Ag au										

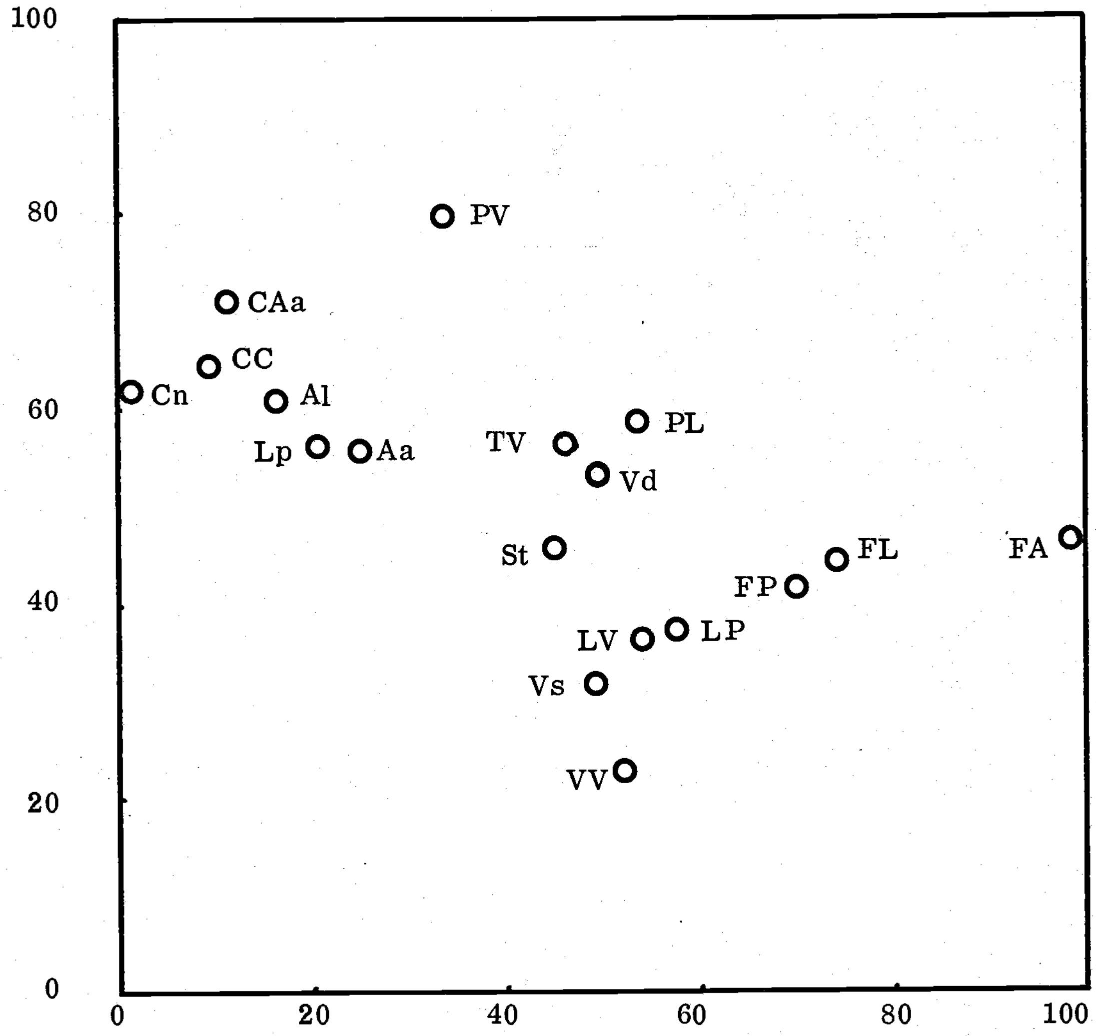

Figure 10. SIMORD Ordination of major Community Types on Mt. Rainier using the Carex nigricans, Festuca/Aster, Valeriana/Veratrum, and Phyllodoce/Vaccinium Community Types as the four reference points on a two-dimensional ordination. Cn represents a cool, wet habitat, FA represents a warm, dry habitat with long potential growing season, VV represents a cool, mesic habitat with deep soils and long growing season, and PV represents a cool, mesic habitat with shallow soils and short growing season. Symbols, e.g. "PV" explained in Appendix V.

Table 3 presents the average dominance ratings for the major species in the major community types. These are averages of several stands and not data for individual stands. The species are abbreviated along the vertical axis and the community types are abbreviated along the horizontal axis.

Table 4 presents the computed similarity coefficients between all major community types. The highest possible coefficient is 100 (%) and the lowest is 00. All coefficients 40% and greater are underlined. These are significantly similar communities. A block of dissimilar stands are outlined in the upper left corner.

Succession

The successional patterns in this vegetation mosaic are still not well understood. Many patterns have become apparent which help explain many of the trends, however.

The life span of most of the subalpine communities does not go back farther than to the Wisconsin ice age when the present area of the Subalpine Zone was under snow and ice. Since then these communities have developed from bare rock or soil as it became exposed by receding glaciers. Recently, newer areas have been exposed by a recent ice retreat, giving another positive reference point in dating the development of these communities.

It can be assumed that the pioneer stages of well developed extant communities were the same as pioneer communities existing today at higher

Table 3. Alliance Table for Mt. Rainier Subalpine Meadow Stands

Species / Com. Type	Cn	CC	CA	Al	Aa	Lp	St	PV	PL	TV	Vd	Vs	VV	LP	LV	FP	FL	FA
Ge ca			+					+	+									
Pe or								1.7	2.4		+							
Ta st	+	+	+		1.0			+		3.6								
Ph em	+	+	1.5	+			+	4.0	3.7									
Ca me	+	+	+	1.2			+	3.9	2.8									
Lu pe	+	+		1.3		3.6		1.6	1.7		1.2							
Ca ni	5.0	4.0	3.5	3.3	+	2.8	+		1.3		+	1.5		+	+			
As al	1.2	1.3	4.3	2.0	4.0			+			1.8			+	1.4			
Va de	1.0	1.2	+	+	+			3.7	+	4.0	3.0			+	2.4			
An la	+	+		4.5	1.0	1.2	+	1.4	1.2	1.8	2.3			1.3	+	1.4	+	+
Ca sp	1.5	3.4	1.5	+	1.9	1.2	1.2	+	1.5		1.2	3.0	1.2	3.3	1.2	1.6	1.7	1.7
Po fl	1.5	1.9	1.3	1.5	2.5			+	+	+	1.8	1.5	+	2.4	2.0	3.5	1.6	+
Po bi	+	+		1.2	2.1				1.6	1.6	2.8	2.0	+	3.8	2.9	2.5	2.3	2.0
Ca pa	+						+	1.2	1.5	1.2	2.2	1.0	1.0	2.3	3.0	1.8	1.0	+
An oc	+						+		+		1.8		1.2	2.3	+	2.4	1.4	1.7
Er pe	+								1.0					+	2.4	+	+	1.5
Ve cu						+		+	1.1		1.5	1.0	+	1.2	1.5	2.2	2.4	1.7
Lu la						+	+	+	4.0	2.0	3.5		1.0	4.5	4.2	1.6	4.0	2.1
Li gr										+	2.0	1.0	+	2.0	2.4	1.6	2.4	2.3
Va si										+	1.8	5.0	4.8	1.1	4.1	1.5		+
Ve vi													3.5	1.1	1.0			
Fe vi										+	2.0	1.5	+	+	1.2	4.2	4.4	4.2
Ery spp.								1.3	+			2.5	1.5	+	1.6			
As le											+			+	+	+	1.4	4.2
Ph di																+	1.2	1.5
Ca mi																	+	1.6
Mi al																+	1.1	+

Table 4. Computed similarity coefficients between all major community types.

	Cn[1]	CC	CA	Al	Aa	LP	St	PV	PL	TV	Vd	Vs	VV	LP	LV	FP	FL	FA
FA	18	9	9	11	18	17	9	13	38	22	34	27	22	43	31	58	70	
FL	24	13	13	15	23	14	11	16	34	23	40	34	23	48	36	70		
FP	22	21	10	16	35	21	11	19	24	36	57	36	29	67	44			
LV	26	24	18	18	22	14	16	25	34	26	53	43	49	60				
LP	31	27	19	19	26	21	11	24	38	34	59	44	43					
VV	18	8	13	14	12	16	20	25	34	22	29	46						
Vs	29	22	27	18	21	18	21	19	32	25	48							
Vd	33	28	29	32	26	24	20	32	47	35								
TV	26	21	25	22	29	13	7	30	22									
PL	34	24	35	29	21	39	25	48										
PV	33	27	37	28	18	24	14											
St	12	10	12	14	10	11												
LP	62	33	34	31	26													
Aa	58	50	44	36														
Al	64	67	43															
CA	72	72																
CC	86																	
Cn																		

[1] See Appendix V for key to the Community Type abbreviations.

altitudes. Since different areas have been exposed at different times and different rates of succession exist, it is possible to piece together most seres in this zone.

These following species are recognized as pioneer or early successional. They are found on disturbed or recently exposed areas and characterize communities obviously at the beginning of the successional gradient.

Luzula wahlenbergii
Saxifraga tolmiei
Eriogonum ovalifolium
Polygonum newberryi
Luetkea pectinata
Juncus parryi
Carex nigricans
Polytrichum spp.

Other species are often, although not necessarily, associated with young or developing communities. They include:

Antennaria lanata
Aster alpigenus
Carex spectabilis
Tauschia stricklandii
Vaccinium deliciosum
Polygonum bistortoides
Phyllodoce empetriformis
Cassiope mertensiana
Lupinus latifolius

<u>Lupinus latifolius</u> and <u>Valeriana sitchensis</u> are characteristic of the best developed and most mature meadow community on moderate habitats, although <u>Lupinus latifolius</u> may occasionally invade deep, fine textured soil recently exposed by retreating snow or ice fields.

By comparing the relative abundance of these species plus invading and established trees, a couple of seres can be distinguished (Figures 11 and 12). The final successional stage in these seres is dominated by trees. Thus the transition from meadow to forest is of considerable interest.

Succession from meadow to forest can be seen in all stages from open subalpine forests to bare deglaciated soil. The distribution of these open subalpine forests is shown on the type map accompanying the thesis. They are dominated mostly by trees 100 to 160 years old which have invaded in clusters or along meadow margins. These trees are nearly as tall as older relicts or forest trees but can be distinguished by their spire-like form. Even more conspicuous is the abundance of smaller trees occurring in meadow communities. These trees have invaded recently and will eventually dominate the meadows and strongly modify the composition of the ground vegetation.

Ages of sampled trees are shown in Figure 13. Some of these ages were determined by repeated whorl and/or ring counts. Repeated counts on the same stem have shown that the accuracy of an age from one measurement is $\pm$ 2 years at best and that repeated measurements can reduce the

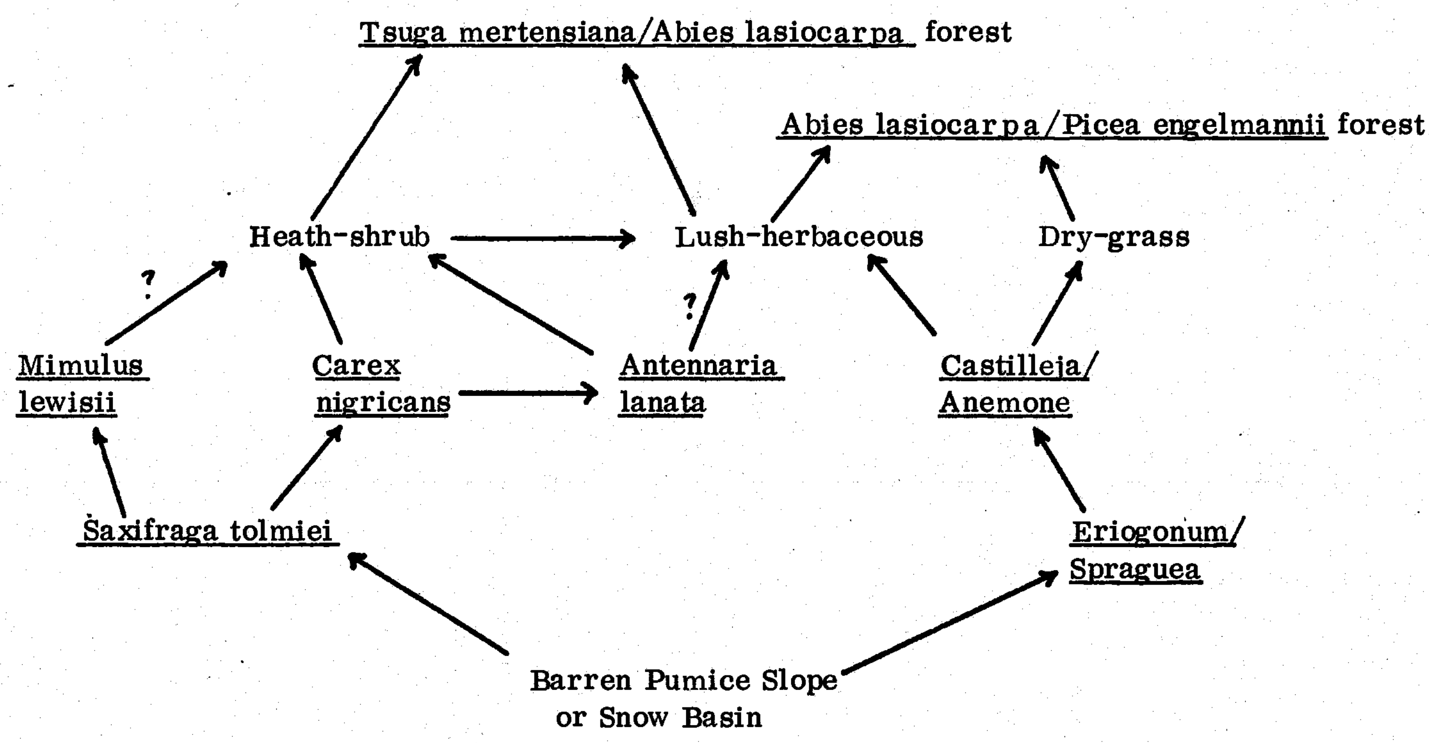

Figure 11. Successional patterns from barren, high elevation Pumice Slopes or snow basins to late seral and forest climax communities.

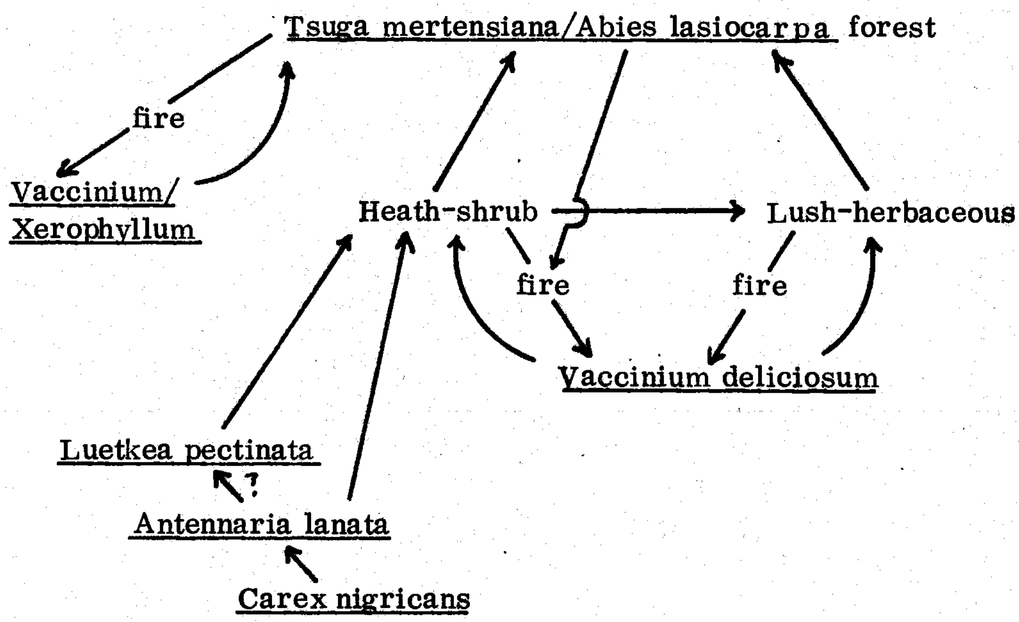

Figure 12. Successional relationships as influenced by fire.

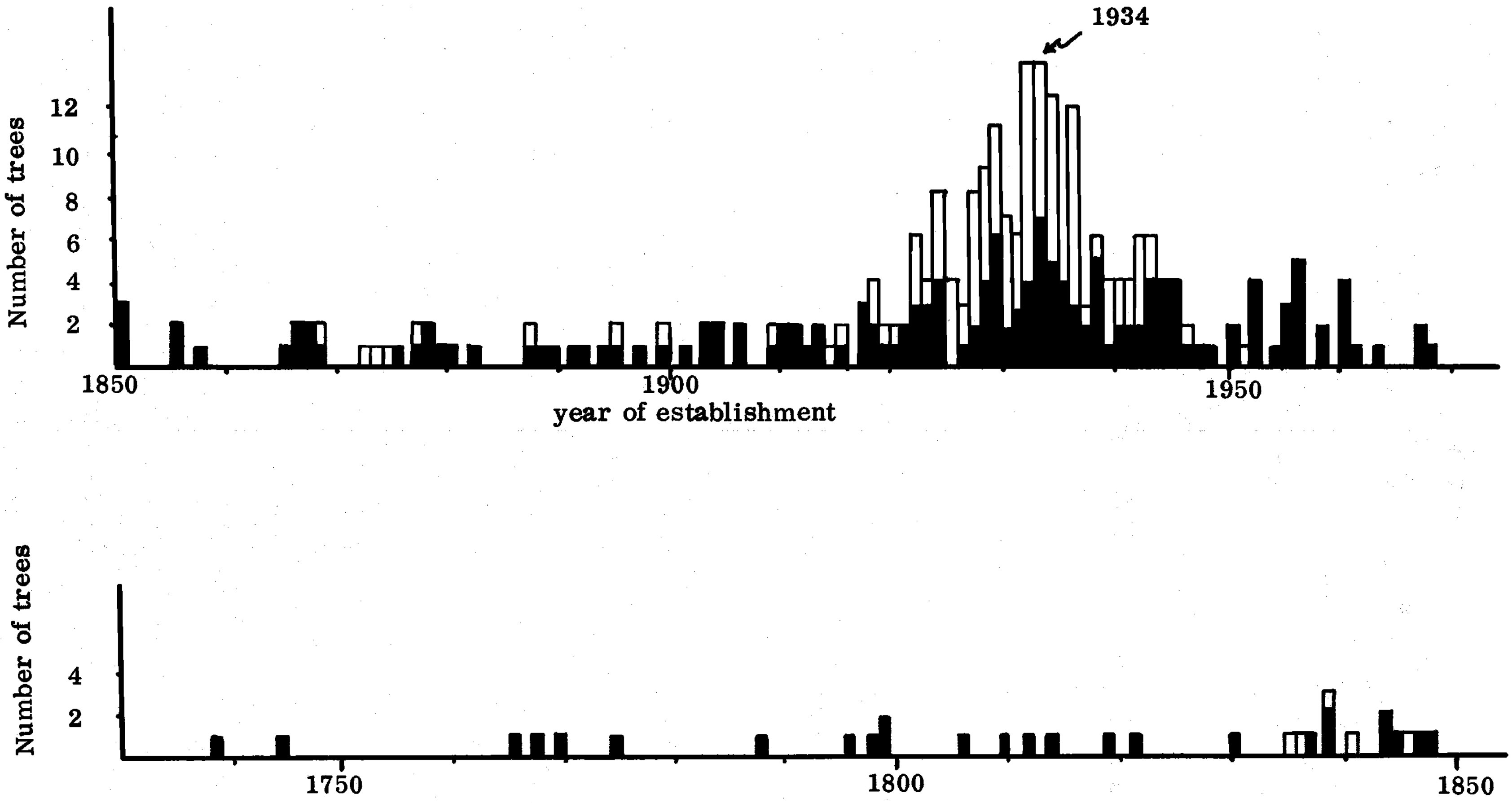

Figure 13. Frequency of seedling establishment, ▯ from Franklin <u>et al</u>. (1971).

reliability to $\pm$ 1 year. Several correlations and implications of this phenomenon will be discussed later.

A peak period of establishment of trees in meadow communities occurred in the early 1930's (Figure 13). Other lesser periods of establishment are evident from the figure. A discussion of this phenomenon will be found under Section V - Discussion.

Distribution

A type map showing the distribution of the subalpine vegetation types in the Park is found at the back of this thesis. It shows the relationships between dry climate and topographic position in the distribution of the *Festuca* dominated types, found mostly in the northeast part of the Park. When found elsewhere they are always on dry, steep, well-drained, southfacing slopes which become free of snow early in the summer. The preponderance of meadows in the eastern part of the Park is also apparent from the map.

Successional relationships can be inferred in general from the relative positions of vegetation types on the map, since higher elevations have been free of permanent snow or ice pack for less time than adjacent areas of similar topographic position lower down. The heather types are always on areas more recently exposed than lupine or valerian dominated types.

Lush-herbaceous communities are often found adjacent to and above open subalpine woods and appear to be in a position to be invaded by trees. "Other Shrub" communities are often the result of fire.

The acreage covered by the five vegetation types as derived from the type map of the subalpine zone is: Heath-Shrub, 8170 acres (3309 ha); Dry-Grass, 3200 acres (1296 ha); Lush-Herbaceous, 2330 acres (944 ha); Low-Herbaceous, 750 acres (304 ha); and Wet-Sedge, 200 acres (81 ha). In addition, the semi-open, forest-meadow areas ("Open subalpine woods" on type map) covers 8000 acres (3240 ha) and the fire or glacial activity created "Other Shrub" areas cover 6100 acres (2470 ha). The Subalpine Meadow Zone, including open subalpine woods, covers a total of 24,650 acres (9983 ha) in Mt. Rainier National Park.

Environmental Data

Since the objectives of this study were to describe the composition, structure and dynamics of these communities, little time was allocated to quantifying environmental and pedological characteristics of the communities. It was decided that soil moisture and soil surface temperature were two important parameters of the environment which could be easily quantified and which would not consume much of the limited time available.

Seven-day recording thermographs were set out in selected communities in 1971 and 1972. Soil moisture blocks were used in an attempt to determine relative differences in soil moisture between communities. The soil temperature data yielded some interesting differences and similarities between communities, but the moisture data only confirm that obviously dry sites are drier than obviously wet ones, without adequately quantifying the differences. One problem is that these blocks were not calibrated for the soil types in which they were implanted and that the summers of the study were very unusual--late snow pack plus summer storms which kept the soils from drying out as they would in a more normal year.

By comparing the record of temperature of the surface 2 cm with perhaps the first thing apparent is that the nighttime temperatures are not very different from community to community, except for the Phyllodoce/Vaccinium community where nighttime temperatures are more moderate than in other communities (Figures 14, 15, 16, 17, 18, and 19). The differences between communities appear in the high temperatures on sunny days, and in the differences between high and low temperatures on the same day. The record of the Carex nigricans, Phyllodoce/Vaccinium and Valeriana/Lupinus communities indicates high temperatures generally in the 60's (degrees F.) and low temperatures generally in the 40's. The Festuca characterized communities on the other hand are characteristically warm with highs often approaching or exceeding 100° F. (38° C.). Because of the steep temperature gradient near the surface of the soil, some of the variation in temperatures may be due to placement of the thermograph probe.

Soil moisture stress as determined by using the calibration curves prepared by Drew (1968) for western Oregon forest soils, shows considerable drying in the Festuca characterized communities but little for the others (Table 5). During a longer summer than those of this study the differences in soil moisture should be more apparent.

Table 5. Water stress in the soil (in atmospheres) of selected communities.

Community	8-16-71		9-6-71		
	2 cm	20 cm	2 cm	20 cm	
Carex nigricans	.3	.3	.3	.3	
Phyllodoce/Vaccinium	.3	.4	.3	.3	
Lupinus/Valeriana	-	.4	.4	.4	
Festuca/Aster/Lupinus	8	5	.4	.4	
Festuca/Lupinus	12	1.5	12	1.5	(8-29-71)
Festuca/Aster	12	10	.4	.4	

	8-10-72		8-25-72		9-8-72	
	2 cm	20 cm	2 cm	20 cm	2 cm	20 cm
Phyllodoce/Vaccinium	.3	.4	.4	.4	Raining,	
Lupinus/Valeriana			.4		Soil saturated	
Festuca/Aster	20+	1.0	.5	.5		

Habitats free of spring snowpack: 8-1-72, Phyllodoce/Vaccinium; 8-4-72, Lupinus/Valeriana; and ca. 6-20-72, Festuca/Aster.

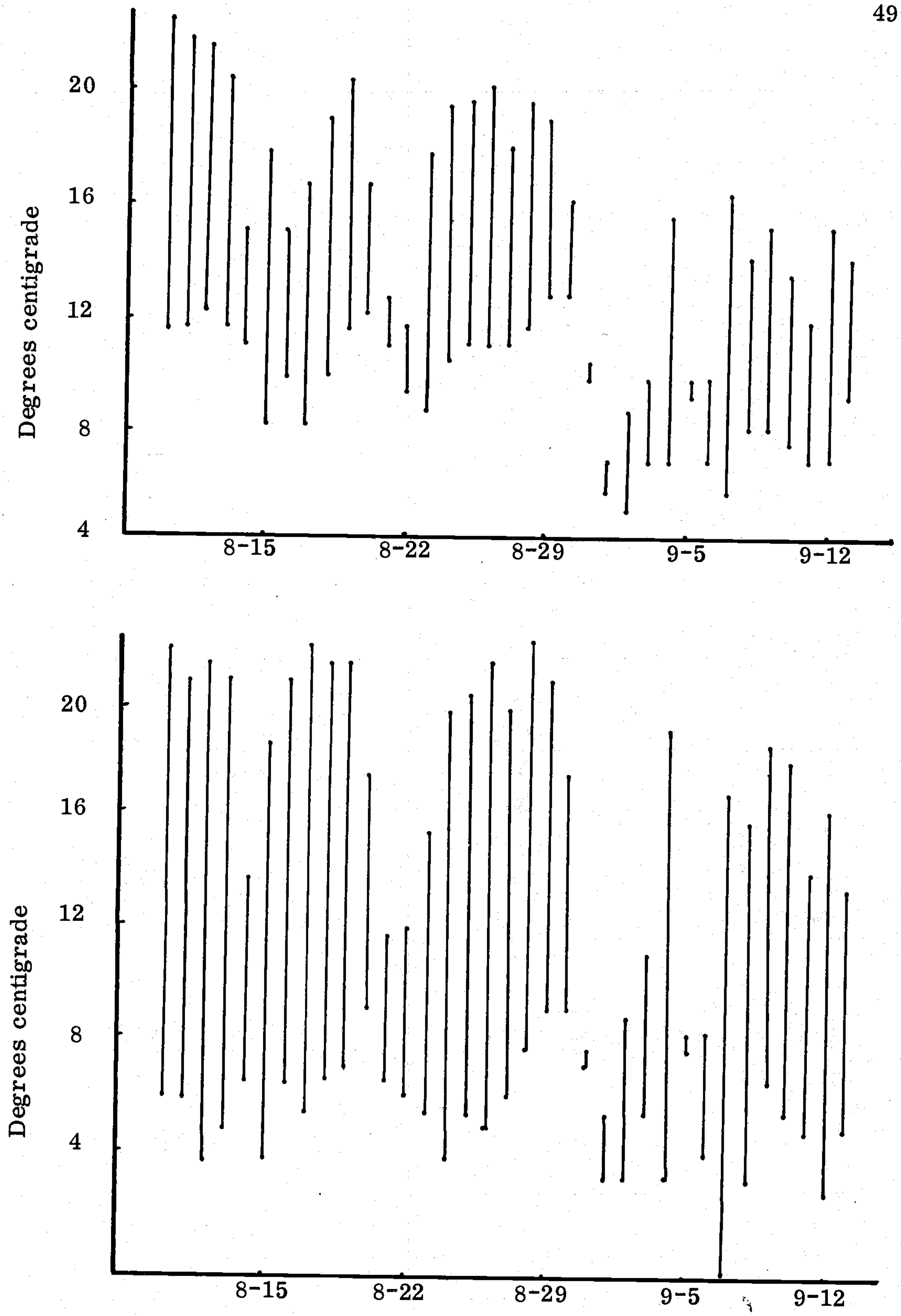

Figure 14. Ranges in daily temperature of the surface 2 cm of soil in Phyllodoce/Vaccinium community above and Carex nigricans community below - Paradise 1971.

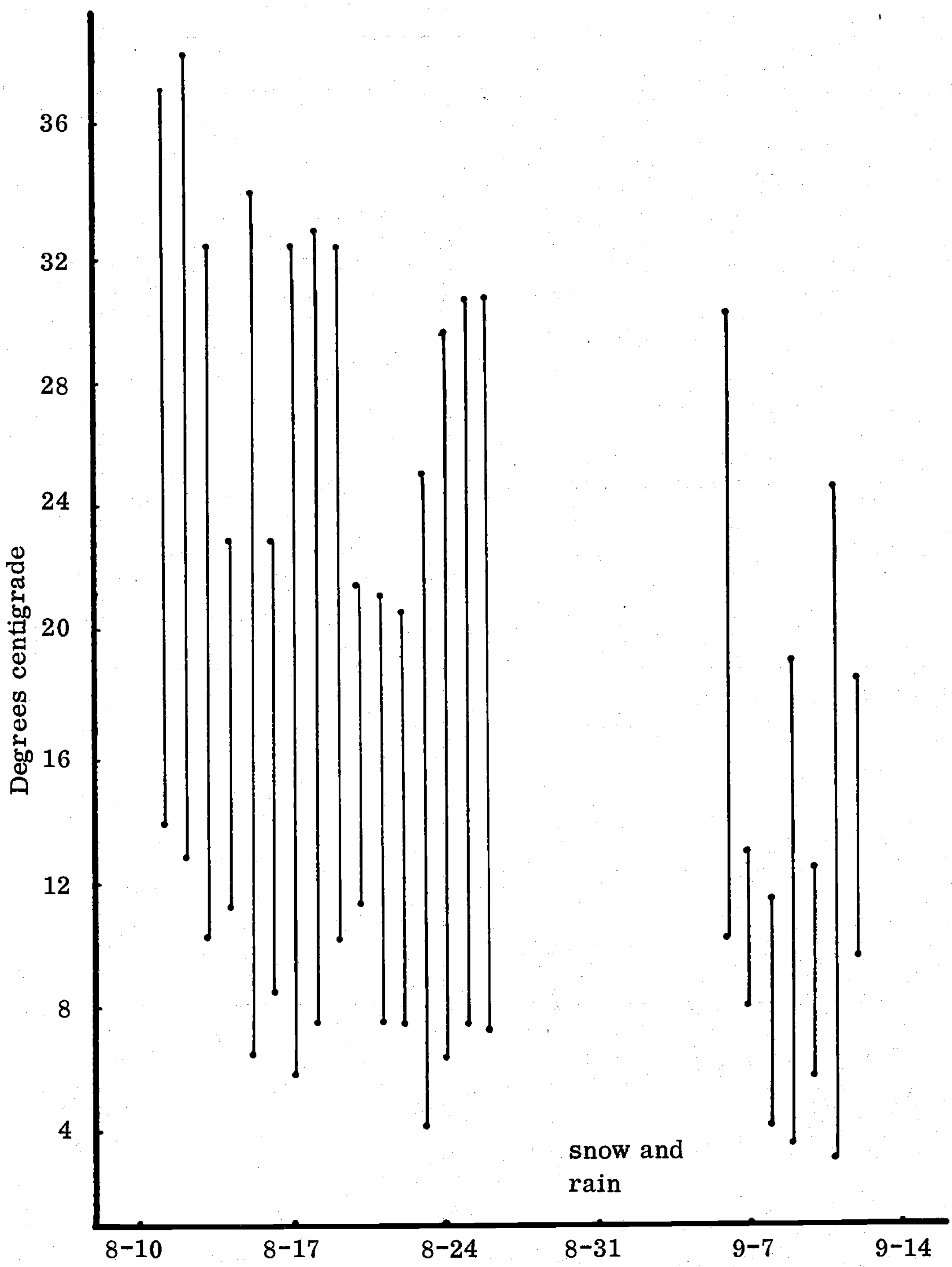

Figure 15. Ranges in daily temperature of surface 2 cm of soil in Festuca/Lupinus community - Sunrise area, 1971.

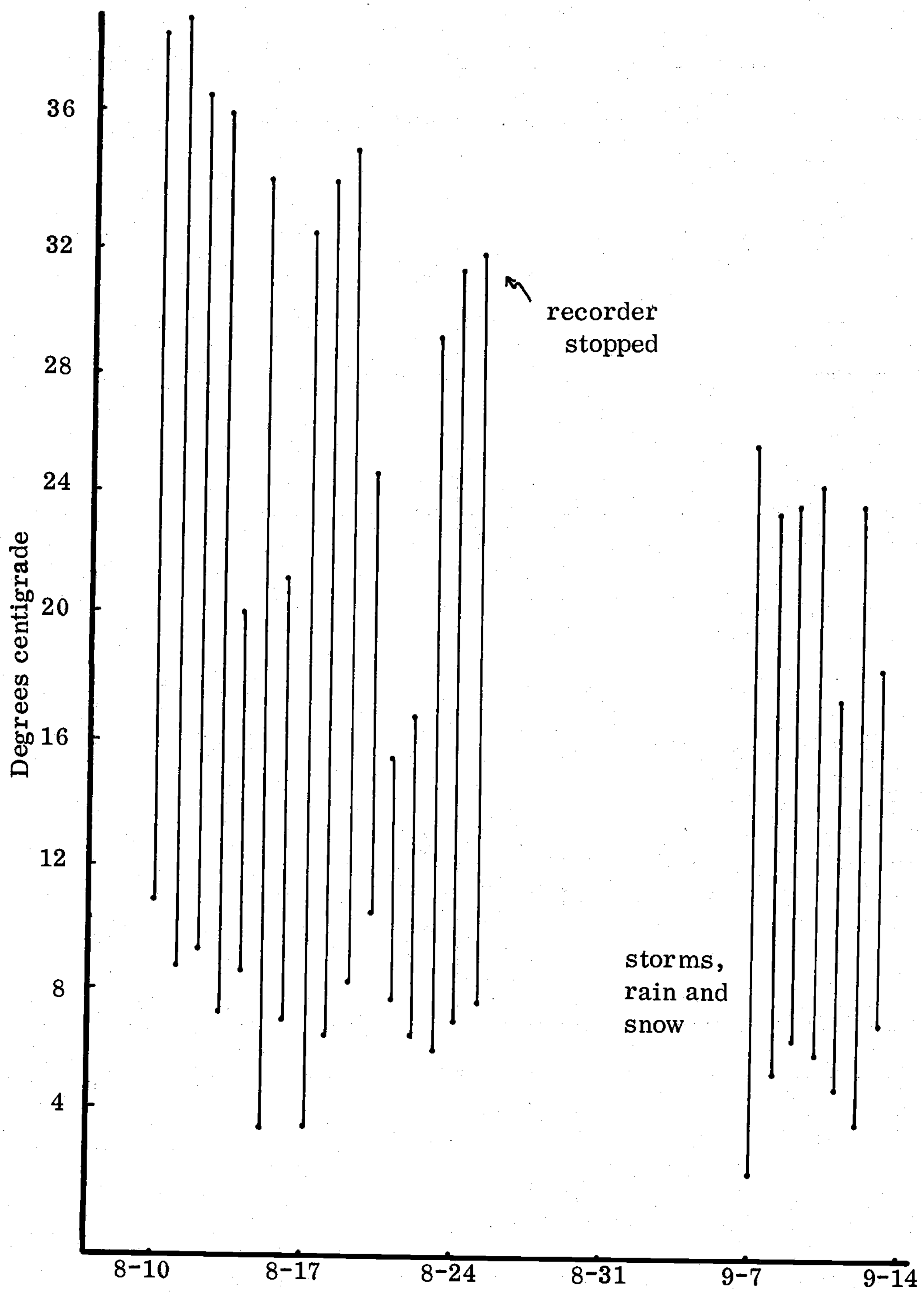

Figure 16. Ranges in daily temperature of surface 2 cm of soil in Festuca/Aster community - Paradise, 1971.

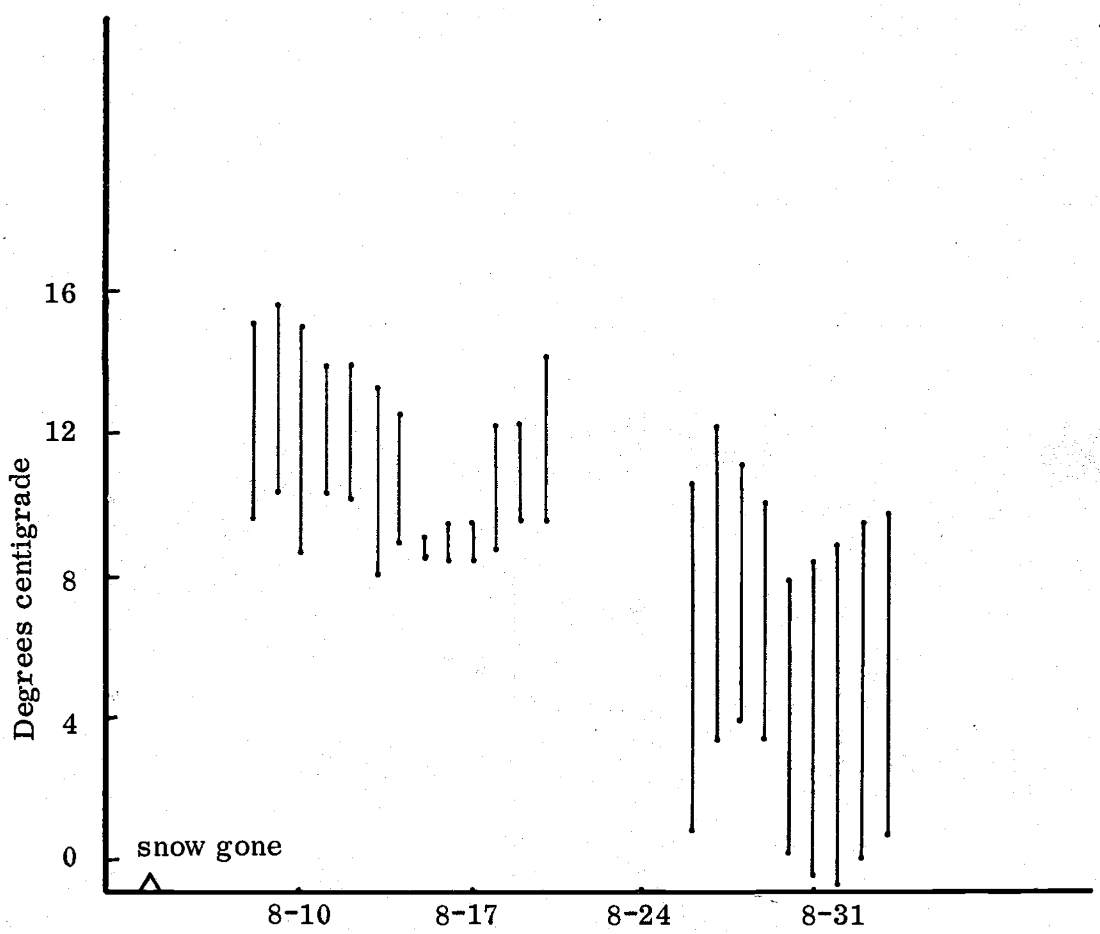

Figure 17. Ranges in daily temperature of the surface 2 cm of soil in a Phyllodoce/Vaccinium community - Paradise, 1972.

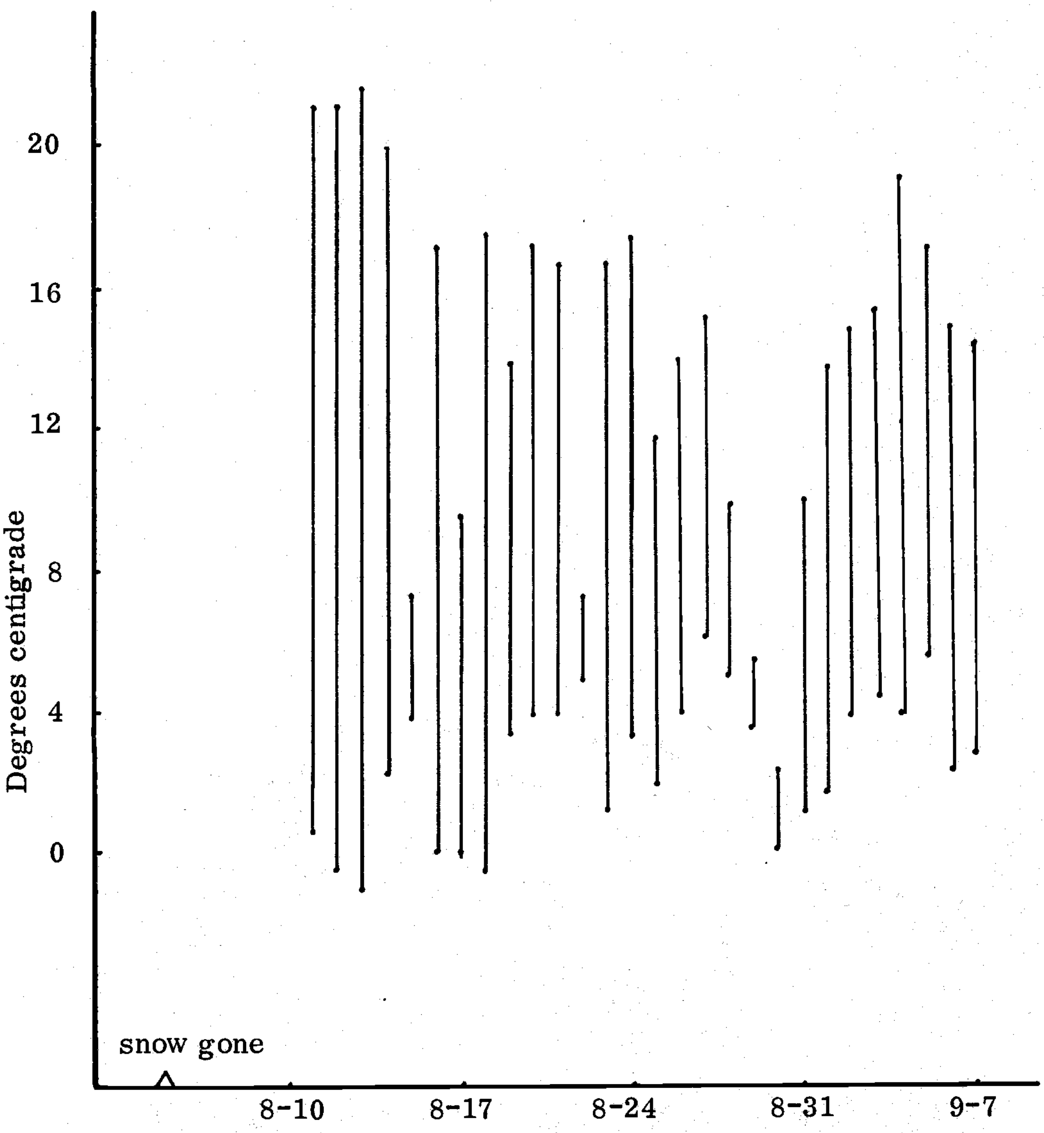

Figure 18. Ranges in daily temperature of the surface 2 cm of soil in a Lupinus/Valeriana community - Paradise, 1972.

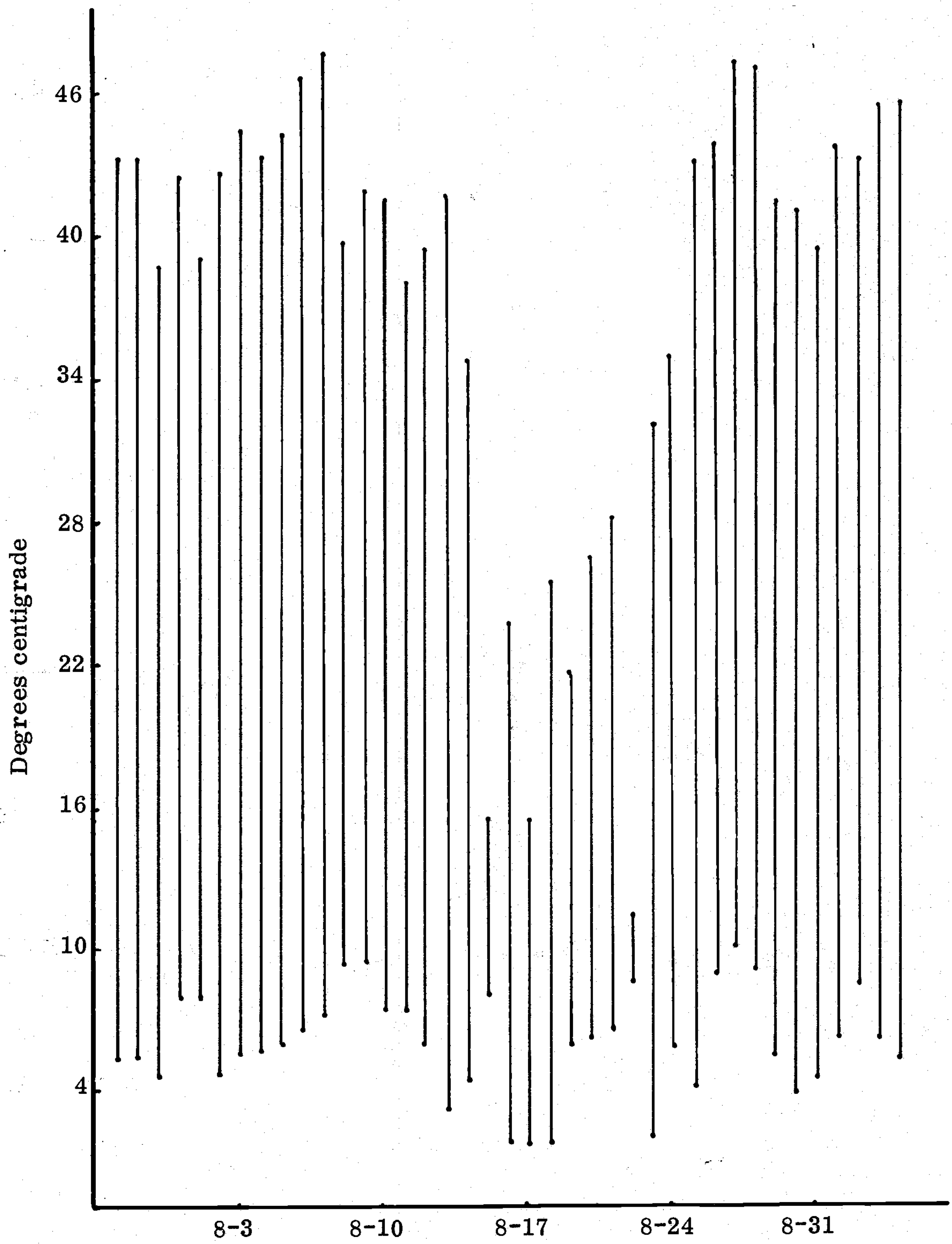

Figure 19. Ranges in daily temperature of the surface 2 cm of soil in a <u>Festuca/Aster</u> community - Paradise, 1972.

V. DESCRIPTIONS AND KEYS TO THE SUBALPINE MEADOW AND COMMUNITY TYPES

Analysis of the data by association tables and SIMORD ordination yielded five vegetation types which are subdivided into 18 major and an additional 16 minor community types. These are presented as components of a typal hierarchy and as nodes along a vegetation gradient. These 34 community types comprise the five vegetation types and the five vegetation types along with scattered tree-dominated copses and open subalpine woods comprise the Subalpine Meadow Zone. The Subalpine Meadow Zone is that area above the continuous forestline and below the treeline (i.e. below alpine). It corresponds to the Parkland Subzone of the Tsuga mertensiana Zone (Franklin and Dyrness, 1969), the Upper Mountain Hemlock Zone (Krajina, 1965) or the Upper Hudsonian Life Zone (Barrett, 1962). On Mt. Rainier the forestline is about 5300 feet (1620 meters) in the west and south parts of the Park and up to about 5700 feet (1240 meters) in the northeast. The treeline occurs at about 6600 feet (2000 meters) in the south and west and about 6900 feet (2100 meters) in the northeast. These boundaries are higher on southerly facing slopes than northerly slopes on the same ridge.

Each community type is an abstraction of two to several concrete stands which were visited and sampled during the course of the study. As such there may not be a stand which exactly fits all of the parameters assigned to the

Figure 20. The Subalpine Meadow Zone on the southwest side of Mount Rainier as seen from Pinnacle Peak. Center of the photo is the Paradise Park area, to the left is the Nisqually Glacier and Cushman Crest.

type. For the more important and extensive community types a reference stand was selected which will serve as the type stand and may be revisited and used as a standard.

The vegetation and community types may be identified using the accompanying keys which were derived after considerable analysis, trial and error and field testing. The key characteristics are those which have the most diagnostic value.

Key to Subalpine Meadow Vegetation Types

A. Community dominated by ericaceous shrubs. HEATH-SHRUB VEGETATION TYPE.

A. Community not dominated by ericaceous shrubs.

- B. Community more than 20 cm tall at maturity.
  - C. Community dominated or characterized by _Festuca viridula_. DRY-GRASS VEGETATION TYPE.
  - C. Community dominated or characterized by perennial herbs. LUSH-HERBACEOUS VEGETATION TYPE.
- B. Community less than 20 cm tall.
  - C. Community dominated or characterized by _Carex_ spp. WET-SEDGE VEGETATION TYPE.
  - C. Community not dominated by sedges, although sometimes present. Drier than wet-sedge types. LOW-HERBACEOUS VEGETATION TYPE.

Key to Subalpine Meadow Community Types

Heath-Shrub Vegetation Type

A. Community dominated or characterized by Vaccinium spp.

B. Community dominated or characterized by V. membranaceum, plus Xerophyllum tenax, Epilobium angustifolium. VACCINIUM MEMBRANACEUM/XEROPHYLLUM C.T.

B. Community dominated or characterized by V. deliciosum.

C. Tauschia stricklandii codominant. VACCINIUM DELICIOSUM/TAUSCHIA C.T.

C. Vaccinium deliciosum sole dominant. VACCINIUM DELICIOSUM C.T.

C. V. deliciosum codominant with Phyllodoce empetriformis and/or Cassiope mertensiana. PHYLLODOCE/VACCINIUM C.T.

A. Community dominated by heath-type shrubs, although Vaccinium deliciosum sometimes present.

B. Community dominated by Phyllodoce empetriformis and/or Cassiope mertensiana.

C. Vaccinium deliciosum more conspicuous than Lupinus latifolius. PHYLLODOCE/VACCINIUM C.T.

C. Lupinus latifolium more conspicuous than Vaccinium deliciosum. PHYLLODOCE/LUPINUS C.T.

B. Community characterized by Phyllodoce glanduliflora or Empetrum nigrum, although Cassiope mertensiana and Phyllodoce empetriformis may be present.

C. Phyllodoce glanduliflora dominant. PHYLLODOCE GLANDULIFLORA C.T.

C. Empetrum nigrum dominant. (This is an alpine community often found near Phyllodoce glanduliflora C.T. but is not

considered to fall within the bounds of the study area.)
EMPETRUM NIGRUM C.T.

The Phyllodoce empetriformis, Cassiope mertensiana, Vaccinium deliciosum, and Lupinus latifolius dominated communities represent nodes along a multidimensional continuum within the Heath-Shrub Vegetation Type. The Vaccinium membranaceum/Xerophyllum tenax, Empetrum nigrum and to some extent, the Phyllodoce glanduliflora types represent more discrete and well defined plant community types.

Dry-Grass Vegetation Type

A. Lupinus and/or Aster ledophyllus conspicuous, Castilleja miniata often present.

B. Lupinus latifolius more conspicuous than Aster.
FESTUCA/LUPINUS C.T.

B. Aster more conspicuous than Lupinus.
FESTUCA/ASTER C.T.

A. Lupinus and Aster mostly absent, Potentilla flabellifolia or Castilleja parviflora present and usually conspicuous.

B. Potentilla codominant or conspicuous.
FESTUCA/POTENTILLA C.T.

B. Anemone occidentalis and Castilleja parviflora codominant Festuca sometimes absent.
ANEMONE/CASTILLEJA C.T.

The Festuca/Lupinus, Festuca/Aster and Festuca/Potentilla Community Types represent nodes along a gradient on the SIMORD ordination, however, parent material and habitat often distinguish these communities in the field.

Lush-Herbaceous Vegetation Type

A. Valeriana sitchensis dominant.

B. Veratrum viride absent or nearly so.
VALERIANA SITCHENSIS C.T.

B. V. viride present and usually conspicuous.
VALERIANA/VERATRUM C.T.

B. Lupinus latifolius conspicuous or codominant.
VALERIANA/LUPINUS C.T.

A. Valeriana sitchensis inconspicuous or absent.

B. Lupinus latifolius conspicuous or dominant.

C. Polygonum bistortoides conspicuous or codominant.
LUPINUS/POLYGONUM C.T.

C. Carex spectabilis conspicuous or codominant.
LUPINUS/CAREX SPECTABILIS C.T.

B. Lupinus latifolius inconspicuous or absent.

C. Carex spectabilis and Polygonum bistortoides codominant
POLYGONUM/CAREX SPECTABILIS C.T.

C. Mimulus lewisii dominant or at least conspicuous.
MIMULUS LEWISII C.T.

Wet-Sedge Vegetation Type

A. Carex nigricans dominant or codominant.

B. Carex nigricans clearly dominant.
CAREX NIGRICANS C.T.

B. Carex nigricans codominant

C. Aster alpigenus codominant or at least conspicuous.
CAREX NIGRICANS/ASTER C.T.

C. Carex spectabilis codominant.
CAREX NIGRICANS/CAREX SPECTABILIS C.T.

C. Pedicularis groenlandicum conspicuous.
CAREX NIGRICANS/PEDICULARIS GROEN-
LANDICUM C.T.

C. Caltha spp. conspicuous.
CAREX/CALTHA C.T.

C. Kalmia polifolia conspicuous.
CAREX/KALMIA C.T.

A. Carex nigricans not dominant and usually not conspicuous.

B. Carex spectabilis conspicuous or codominant.

C. Carex nigricans present and often conspicuous.
CAREX NIGRICANS/CAREX SPECTABILIS

C. Potentilla flabellifolia present and usually conspicuous.
CAREX SPECTABILIS/POTENTILLA C.T.

B. Eriophorum present.
ERIOPHORUM POLYSTACHION C.T.

Low-Herbaceous Vegetation Type

A. Anemone occidentalis and Castilleja parviflora codominant.
ANEMONE/CASTILLEJA C.T.

A. Aster Alpigenus and/or Antennaria lanata dominant or conspicuous.

B. Aster dominant, Carex nigricans often present.
CAREX NIGRICANS/ASTER ALPIGENUS C.T.

B. Aster and Antennaria codominant.
ASTER/ANTENNARIA C.T.

B. Antennaria dominant, Carex nigricans sometimes present.
ANTENNARIA LANATA C.T.

A. Trisetum spicatum dominant.
TRISETUM SPICATUM C.T.

A. Tauschia stricklandii codominant to conspicuous.

B. Vaccinium deliciosum conspicuous.
VACCINIUM/TAUSCHIA C.T.

B. Vaccinium deliciosum absent.
TAUSCHIA STRICKLANDII C.T.

A. Saxifraga tolmiei dominant, Luzula wahlenbergii usually present.
SAXIFRAGA TOLMIEI C.T.

A. Eriogonum and Spraguea present, ground cover less than 15%.
ERIOGONUM/SPRAGUEA C.T.

A. Luetkea pectinata dominant.
LUETKEA PECTINATA C.T.

The Vegetation Types

The five major vegetation types are 1) the Heath-Shrub, 2) the Dry-Grass, 3) the Lush-Herbaceous, 4) the Wet-Sedge, and 5) the Low-Herbaceous Vegetation types. To distinguish between vegetation types and community types in further discussion, the vegetation types will be referred to by their common name (e.g. the Wet-Sedge V.T.) and the more specific community types by the scientific name of the most important dominants (e.g. the Carex nigricans C.T.).

The Heath-Shrub Vegetation Type is common throughout the Park and throughout the Cascades as well. It is characteristically found developing on moist, cool but often shallow soil. It develops on all slopes and aspects, although it is most common on gentle northerly slopes. The dominants in this type include *Phyllodoce empetriformis*, *Cassiope mertensiana*, *Vaccinium deliciosum*, *Lupinus latifolius* and *Phyllodoce glanduliflora*.

Use of this type by small mammals is not well known. Small mammal runways and scat piles are not uncommon and seedlings of invading trees may be found stripped of bark and twigs by some of these mammals, principally the heather vole (*Phenacomys intermedius*).

The elevational range of this vegetation type is from near the forest-line at about 5200 feet (1590 meters) to alpine about 7000 feet (2150 meters) elevation. There is a clear change in species composition along this altitudinal gradient. Red heather is common and most dominant at lower elevations i.e. 5200 to 6000 feet (1590 to 1830 meters); while the white heather is most common from 5800 to 6500 feet and the yellow heather is found from 6400 to 7200 feet (1730 to 2210 meters).

This is an important type in the Park because of the acreage it covers. Its successional status, however, is unclear. It is believed that most members of this type represent early seral stages in succession while others represent later stages of the same or different seres.

Some stands of Heath-Shrub are found replacing stands of *Luetkea pectinata* or even pioneering bare ground. In others where the stand structure has become well developed, there are often significant numbers of conifer seedlings invading.

Human impact in this type is not great as yet, but it is readily susceptible to trampling damage.

The Dry-Grass Vegetation Type is characterized by fescue (*Festuca viridula*). The community types in this vegetation type may occur on glacial deposits e.g. the *Festuca/Lupinus* meadows over the Evan's Creek Drift in Yakima Park, or on rather steep residual, stony soil or over talus. These sites are well to excessively well drained and are often some of the first meadows to be free of snow in the spring (especially the *Festuca/Aster* type); thus many of the plants are usually subjected to summer drought. In exceptional years, such as 1971, the soil moisture may never reach drought conditions. At the height of flowering, these types are rather attractive, although through most of the season only the vegetative parts of the plants are conspicuous.

The pocket gopher is the most conspicuous animal in these types and keeps the surface of the soil in a constant state of disturbance. In spring the trailings which mark its winter tunnels through the snow are conspicuous and in summer when the gophers retreat into their underground residences, the earth-filled openings to their tunnels are common. On Sunrise Ridge a conspicuous feature of the hillside is the greener, more lush micro-mounds scattered throughout the meadow which are believed to be centers of pocket gopher activity. Tunnels are more common in these spots and the activity creates a slight mound and this causes that area to melt off slightly sooner than adjacent areas. The tilth and probably the fertility of the soil is improved in these gopher mounds also.

The Lush-Herbaceous Vegetation Type includes many distinguishable community types and is characterized by its tall, lush vegetation and complete ground cover. It is dominated by plants often growing to more than 50 centimeters and is the most colorful vegetation type in the Park. Important species include *Lupinus latifolius*, *Valeriana sitchensis*, *Polygonum bistortoides*, *Carex spectabilis*, and *Castilleja parviflora*. Deer, elk and mountain goats may do conspicuous damage to stands of this type locally, although such damage is not common.

Within this vegetation type are many community types which develop on different habitats. The lupine dominated types are best developed on the deep soils of the Paradise and Indian Henry's mudflows. The valerian dominated types occur on shady, moist sites throughout the Park. These are low elevation subalpine types which are often associated with forest openings or northerly slopes.

The Wet-Sedge Vegetation Type does not cover significant acreage, although it is widespread and easily recognized. It is important, however, as a relatively permanent successional type where the water table is near or at the surface most or all of the year. Under drier conditions it may be a seral stage in the development of some of the heath-shrub or low-herbaceous types. Human impact is lowest in this type of any of those found in the Park.

It is very resistant to trampling damage. Only extra heavy camping or hiking use can bare ground now covered by a wet-sedge community.

Animal use of this type is limited by the high water table. Pocket gopher signs have been found in a few drier wet-sedge meadows. In these cases it is believed that the pocket gopher uses the wet-sedge basin in the winter and then retreats to the drier margin of the meadow for the summer.

The most common plant in these types is the black sedge (Carex nigricans), others include Carex spectabilis, Aster alpigenus, Antennaria lanata, Pedicularis groenlandicum, Dodecatheon jeffreyi, Caltha spp., Eriophorum polystachion, and Kalmia polifolia.

The Low-Herbaceous Vegetation Type is found scattered throughout the Park and ground cover is often incomplete. The height of the vegetation canopy is less than the Lush-Herbaceous V.T. and the plants are less succulent. Most of these types range from 10 to 20 centimeters tall and the habitat is often wet in the spring as the snow melts but becomes dry as the summer drought begins.

These community types are mostly seral. The Aster alpigenus and Antennaria lanata types fall in this category plus the Anemone/Castilleja type which is found on an intermediate habitat between the Lupinus/Valeriana and the Festuca/Lupinus types but is believed to be a seral stage in the development of a lush-herbaceous community.

Human impact is usually low on these types because of their relative inaccessibility, especially at the higher elevations, and because of the sparse ground cover characteristic of many of these communities. Animal impact is relatively unknown.

The habitats of these types are usually characterized by gentle, variable slopes. Soil development is practically non-existent. The surface litter of the present year will be completely gone by the end of the next season. Soil texture is sandy to gravelly due to the high occurrence of pumice and ash.

These five vegetation types described above are broken down into more explicit community types for the purpose of further study and more elaborate descriptions and are used as map-units on the type map of the Subalpine Zone (Appendix VI).

The Community Types

The Heath-Shrub Vegetation Type

The Heath-Shrub Vegetation Type is comprised of four major community types: the *Phyllodoce/Vaccinium*, the *Vaccinium deliciosum*, the *Phyllodoce/Lupinus*, and the *Phyllodoce glanduliflora*.

Phyllodoce/Vaccinium Community Type. This is one of the most common subalpine meadow communities in the Park. Moreover, it is the major subalpine meadow type in the Washington Cascades from Mt. Rainier northward. It is dominated by three species: *Phyllodoce empetriformis*, *Cassiope mertensiana*, and *Vaccinium deliciosum*, which usually account for 70 to 90 percent of the plant cover.

This type occurs most commonly on gentle slopes and on residual, moist but moderately well drained soils where danger of avalanche or severe snow creep is not present. Slopes usually are from 10 to 40% although it may be found on nearly flat to steep (80%) slopes. Season-long moisture during most summers and good root anchorage appear to be necessary for this community to develop. It may be found on any aspect, although northeast is the most common. Within the Park this community type may be found at elevations from 5400 feet to 6800 feet (1650 to 2075 meters). Red heather is more dominant than white heather at elevations from 5400 to 6000 feet (1650 to 1830 meters) and from 6000 feet to 6800 feet (1830 to 2075 meters) white heather assumes dominance, while above 6800 feet (2075 meters) *Vaccinium* drops out and the red and white heathers are gradually replaced by *Phyllodoce glanduliflora*.

The heather vole (*Phenacomys intermedius*) is the most conspicuous mammal in this community. Its scat piles are easily recognized. Subalpine fir (*Abies lasiocarpa*) seedlings can sometimes be found (often near the scat piles) which have been nearly or completely stripped of tender twigs and bark during the winter. Under cover of snow the winter-active voles burrow around the seedlings in the snow, eating the bark and cutting the twigs into 5 to 6 cm lengths for storage. Several saplings over 3 meters tall were found during the summer of 1971 from which large patches of bark and smaller twigs had been removed as from the smaller trees. Teeth marks indicated that only an animal the size of the heather vole could have been responsible.

Besides the damage to subalpine fir, the heather vole also clips considerable quantities of huckleberry (V. deliciosum) twigs 5 to 6 cm long for winter food. This has severe impact over a small area, for patches several square meters in area have been found in which every huckleberry has been clipped back almost to the ground. This huckleberry may be a major food source for many other animals as well. Richardson's water vole probably cuts quantities of huckleberry twigs where it is growing along streams. Deer and marmots eat the young leaves and many mammals use the berries and flowers.

The heathers are rarely used for food, however. Some evidence of clipping by the heather vole has been found but only rarely. A marmot was seen pulling red heather out of the ground by its teeth, but this may have been for bedding rather than food. The immature capsules of the heathers are eaten by ptarmigan and probably by grouse and small mammals as well.

Animal pressure appears to favor the heathers and inhibit the huckleberry. This may help explain an apparent succession from huckleberry to heather on several potentially forested but disturbed subalpine areas (Figure 13).

Successional relations of this type are not completely understood. The heathers may invade the pumice soil near a receding snow bank along with Juncus parryi, Carex nigricans, and C. spectabilis with huckleberry or lupine appearing later. Or the huckleberry may become established on a disturbed site and be followed by the heathers. In its seral condition the huckleberry may be accompanied by Tauschia stricklandii or Luetkea pectinata. Luetkea pectinata forms a seral community on gentle slopes or on scree and will probably develop into a Phyllodoce/Vaccinium stand after succession proceeds.

The Phyllodoce/Vaccinium type occurs on habitats which are potentially forested. Moreover, evidence is strong that some stands of this type will ultimately be replaced by coniferous forest of subalpine fir and mountain hemlock baring significant climatic shift. Most Phyllodoce/Vaccinium stands, especially at elevations from 5400 to 6000 feet (1650 to 1850 meters), have subalpine fir and/or mountain hemlock seedlings established in them. Most seedlings examined were from 20 to 105 years old; their age distribution indicating a mass invasion about 100 years ago and again about 40 years ago.

When invading seedlings become older than 150 years the forest will close and the ground vegetation will change from Phyllodoce/Vaccinium to some Phyllodoce and Vaccinium membranaceum or in some cases to a Valeriana dominated understory.

In the North Cascades (Douglas, 1970) and British Columbia (Brooke, et al., 1970) a dwarf hemlock-heath community is recognized which is similar to some stands of Phyllodoce/Vaccinium on Mt. Rainier. In the North Cascades, then, Tsuga mertensiana is the principal invader, while on Mt. Rainier it is Abies lasiocarpa. Both Douglas and Brooke noted the ages of invading hemlocks at about 25 to 45 years.

Thirty stands were sampled during the summer of 1970 which are considered to be members of Phyllodoce/Vaccinium Community Type. (See

Table 6.) The type locality is stand number 30, elevation 5600 feet (1700 meters), 20% west slope near lookout tower in Sunset Park.

Vaccinium deliciosum Community Type. This is not a common type in the park and is usually found in small patches on convex surfaces. It is considered to be seral to other types and is considered to be mainly a product of disturbance and is replaced by Phyllodoce/Vaccinium, a Lupinus/Polygonum or a Lupinus/Valeriana community.

The physiographic location of stands of this type indicates that the site is potentially or was at one time occupied by trees. Trees invading this type are not uncommon, although the growth rate of such seedlings is retarded.

Vaccinium deliciosum is quite susceptible to animal damage as was discussed earlier. This is thought to be a major reason for its seral status. Where animal damage is not present this species can attain a height of 20 centimeters and appears able to compete successfully with its associates. Where animal damage is obvious it usually only reaches a height of a decimeter. Vaccinium deliciosum is also a major component of the Tauschia/Vaccinium and the Phyllodoce/Vaccinium types.

Six stands of the Vaccinium deliciosum Community Type were sampled. The type locality is stand number 101, 30% west slope, 5900 feet (1840 meters) elevation above Paradise Park. (See Table 7.)

Phyllodoce/Lupinus Community Type. The Phyllodoce/Lupinus Community Type is characterized by moist, stony soil, incomplete ground cover and dominance by red and white heather and subalpine lupine. Cascades

Table 6. Phyllodoce/Vaccinium Community Type.

Species	Dominance[1]		
	Type	Average	Constancy[2]
Phyllodoce empetriformis	4	4.0	93
Cassiope mertensiana	4	3.9	93
Vaccinium deliciosum	4	3.7	100
Pedicularis ornithorhyncha	2	1.7	70
Luetkea pectinata	1	1.6	60
Antennaria lanata	2	1.4	60
Erythronium montanum	3	1.3	50
Castilleja parviflora	2	1.2	50
Aster alpigenus	1	0.9	30
Carex spectabilis	2	0.8	33
Tauschia stricklandii	3	0.8	25
Potentilla flabellifolia	2	0.7	40
Pedicularis rainierensis	3	0.7	25
Lupinus latifolius	2	0.7	33
Veronica cusickii	-	0.7	30

[1]Dominance (prominence) ratings for the community designated as the type stand and the average of all stands of this type sampled.

[2]Constancy given is percent occurrence in all stands of this type.

Figure 21. Klapatche Park. The upper left center is Tauschia/Vaccinium community, and the lower left corner is Phyllodoce/Vaccinium. The trees, subalpine fir and mountain hemlock are following the invasion of the Tauschia/Vaccinium by the Phyllodoce/Vaccinium community.

Figure 22. Indian Henry's Hunting Ground. Center is a Carex nigricans community replacing the pioneer moss community dominated by Polytrichum and Marsupella in a filled-in pond. Around the edge are heath-shrub communities.

Table 7. Vaccinium deliciosum Community Type.

Species	Dominance		Constancy
	Type	Average	
Vaccinium deliciosum	4	3.0	100
Lupinus latifolius	4	2.8	100
Polygonum bistortoides	3	2.8	83
Antennaria lanata	-	2.3	83
Castilleja parviflora	-	2.2	83
Ligusticum grayi	2	2.0	100
Festuca viridula	2	2.0	67
Aster alpigenus	3	1.8	83
Potentilla flabellifolia	2	1.8	83
Anemone occidentalis	2	1.8	67
Valeriana sitchensis	-	1.8	67
Veronica cusickii	-	1.5	67
Carex spectabilis	2	1.2	50
Luetkea pectinata	2	1.2	50
Erythronium spp.	-	1.0	50
Luzula glabrata	-	1.0	33
Carex nigricans	-	0.8	33
Hieracium gracile	2	0.7	50

huckleberry may be present in small amounts but is often absent. Slopes and aspects are variable, the community appearing able to develop wherever a moderately cool, moist soil is available. Average slope is 26 percent. Soils appear to be deeper than those under heather or Phyllodoce/Vaccinium stands and slopes tend toward being more southerly; otherwise the distinction may be one of successional status only.

Mountain goats have been noted feeding on flowers and herbage in this type, and numerous tracks and scats were found in this type, indicating that it is one that is favored by these elusive animals.

Stands of this type appear to be succeeding fairly rapidly to mountain hemlock at lower elevations, 5000 to 6000 feet (1500 to 1800 meters), while at higher elevations the stands appear raw and young, potentially invaded by mountain hemlock or subalpine fir.

Twenty-two stands of Phyllodoce/Lupinus Community Type were sampled. The type locality is stand number 71, elevation 6300 feet (1920 meters), 10% southwest slope on north side of Pyramid Peak. It is characterized by shallow residual soil (Table 8).

Phyllodoce Glanduliflora Community Type. The Phyllodoce glanduliflora Community Type is an upper elevational subalpine or alpine heath which occurs between 6300 and 7200 feet (1920 and 2200 meters). Stands of this type normally occur on gentle northerly facing slopes. Micro-terracing is often a characteristic of the community. This phenomenon, characteristic of most heather types, is caused by the movement of surface soil material

Table 8. Phyllodoce/Lupinus Community Type.

Species	Dominance Type	Dominance Average	Constancy
Lupinus latifolius	4	4.0	100
Phyllodoce empetriformis	4	3.7	95
Cassiope mertensianus	4	2.8	75
Vaccinium deliciosum	3	2.0	60
Luetkea pectinata	2	1.7	70
Polygonum bistortoides	-	1.6	50
Pedicularis ornithorhyncha	2	1.5	60
Carex spectabilis	-	1.5	70
Castilleja parviflora	2	1.5	70
Carex nigricans	3	1.3	50
Antennaria lanata	3	1.2	50
Veronica cusickii	1	1.1	70
Hieracium gracile	1	1.0	75
Luzula wahlenbergii	2	1.0	50
Erigeron peregrinus	-	1.0	50
Potentilla flabellifolia	-	0.7	36
Erythronium spp.	-	0.7	25
Anemone occidentalis	-	0.5	25

downslope being restrained by the heather, thus creating a step-like or terraced micro-topography. The Phyllodoce glanduliflora Community Type may be considered either a subalpine or alpine heather meadow. It is found primarily on the north side of the Park and occurs on residual and often moderately shallow soils which do not dry out in the late summer. Ptarmigan may be found feeding on the fleshy capsules of the heathers. This type integrades with some of the higher elevation Cassiope mertensiana dominated heath types.

The type stand is number 136, 7200 feet (2200 meters) elevation, 15% north slope on Goat Island Mountain. (See Table 9.)

Another community type which could be recognized is the Phyllodoce/Cassiope or heather community type. Almost all stands which could be referred to it, however, could also be referred to the Phyllodoce/Lupinus, the Phyllodoce/Vaccinium or the Phyllodoce glanduliflora types. This type is recognized for British Columbia by Brooke et al. (1970) and for Mt. Rainier by Hamann (1972) however, but such a delineation does not appear to be appropriate or necessary. Brooke's data shows that all stands of his Phyllodoco-Cassiopetum mertensianae association contain enough Vaccinium deliciosum to be included in the Phyllodoce/Vaccinium Community Type. Hamann's data shows that all stands can be placed in one of the three types named above. The Phyllodoce/Cassiope Community Type, therefore, is not recognized as a separate community type.

Table 9. Phyllodoce Glanduliflora Community Type.

Species	Dominance Type	Dominance Average	Constancy
Phyllodoce glanduliflora	4	4.5	100
Cassiope mertensiana	4	3.5	86
Carex spectabilis	3	3.0	100
Aster alpigenus	3	3.0	86
Pedicularis ornithorhyncha	2	2.5	72
Antennaria lanata	3	2.0	72
Veronica cusickii	2	2.0	72
Luetkea pectinata	2	1.5	72
Luzula wahlenbergii	2	1.0	58
Empetrum nigrum	3	1.0	28
Penstamon tolmiei	1	1.0	58
Carex nigricans		1.0	28
Achillea millefolium		+	
Vaccinium deliciosum		+	
Phyllodoce empetriformis		+	

The Dry-Grass Vegetation Type

The Dry-Grass Vegetation Type is comprised of 3 major community types, the *Festuca/Aster*, the *Festuca/Lupinus* and the *Festuca/Potentilla*.

Festuca/Aster Community Type. The *Festuca/Aster* Community Type occurs on all sides of the Park, generally on southerly facing slopes. The average slope is 57% and the elevational range is from 5400 to 6500 feet (1650 to 1980 meters). This type often develops on talus slopes which have had a sufficient accumulation of pumice and residual rocks and soil to fill in the spaces between the talus blocks and allow a plant community to develop.

Soils are coarse textured residual, sandy to stony loam, with practically no horizon development. Pocket gophers are common in this type (as in all fescue types) and keep the soil tilled.

This is one of the driest types in the Park and is dominated by *Festuca viridula* and *Aster ledophyllus*. Other important species include *Ligusticum grayi*, *Polygonum bistortoides* and *Lupinus latifolius*.

Smaller patches are found on the Paradise side than on the drier Sunrise side. Large stands of this type occur on Goat Island Mountain, on the east end of Sunrise ridge, along the Sourdough mountains, on Cushman Crest, in the headwaters of Butter Creek in the Pinnacle Peak area, above Fairy Falls and near Fan Lake. The type is nearly absent in the Mowich Lake area.

Mountain goats, elk and deer may be seen feeding in this type in late evening and early morning. Impact from this activity is not great, however. Besides pocket gophers, which are probably the most important animal, ground squirrels and chipmunks are not uncommon and consume large quantities of seeds and fruits.

Some of the fescue-dominated areas in the eastern part of the Park, and perhaps elsewhere, are the results of fire which is a minor ecologic factor in the creation and maintenance of meadows there. Kuramoto and Bliss (1970), however, thought that fires were a major force in many of the subalpine meadows in the Olympics.

The type stand of the Festuca/Aster Community Type is number 87. It occurs on a 70% southwest slope at 5400 feet (1700 meters) elevation near Fan Lake. (See Table 10.)

Festuca/Lupinus Community Type. The Festuca/Lupinus is another common community type in the Park. It is closely related to the Festuca/Aster type with which it integrades. It is found on gentler slopes and more mesic conditions than the Festuca/Aster. On Yakima Ridge much of the gentle-sloped Evans Creek Drift is covered by this type. It is found throughout the Park but most commonly in the Sunrise area.

Festuca viridula and Lupinus latifolius are the dominants although Ligusticum grayi, Polygonum bistortoides, Anemone occidentalis, Castilleja parviflora and Aster ledophyllus are often present. The composition of the community appears to change drastically from the time when the snow leaves, usually in late June to August when the community is fully developed. As the snow melts, Anemone occidentalis, Claytonia lanceolata, Potentilla

Table 10. *Festuca/Aster* Community Type.

Species	Dominance Type	Dominance Average	Constancy
Festuca viridula	4	4.0	100
Aster ledophyllus	4	4.0	100
Ligusticum grayi	2	2.3	82
Lupinus latifolius	2	2.1	82
Polygonum bistortoides	3	2.0	54
Carex spectabilis	3	1.7	63
Veronica cusickii	1	1.7	72
Anemone occidentalis		1.7	36
Castilleja miniata	3	1.6	54
Phlox diffusa		1.5	45
Erigeron peregrinus	3	1.5	45
Pedicularis contorta	3	1.3	45
Valeriana sitchensis		1.2	45
Potentilla flabellifolia	2	0.7	36
Agoseris alpestris		0.5	18
Castilleja parviflora		0.2	9

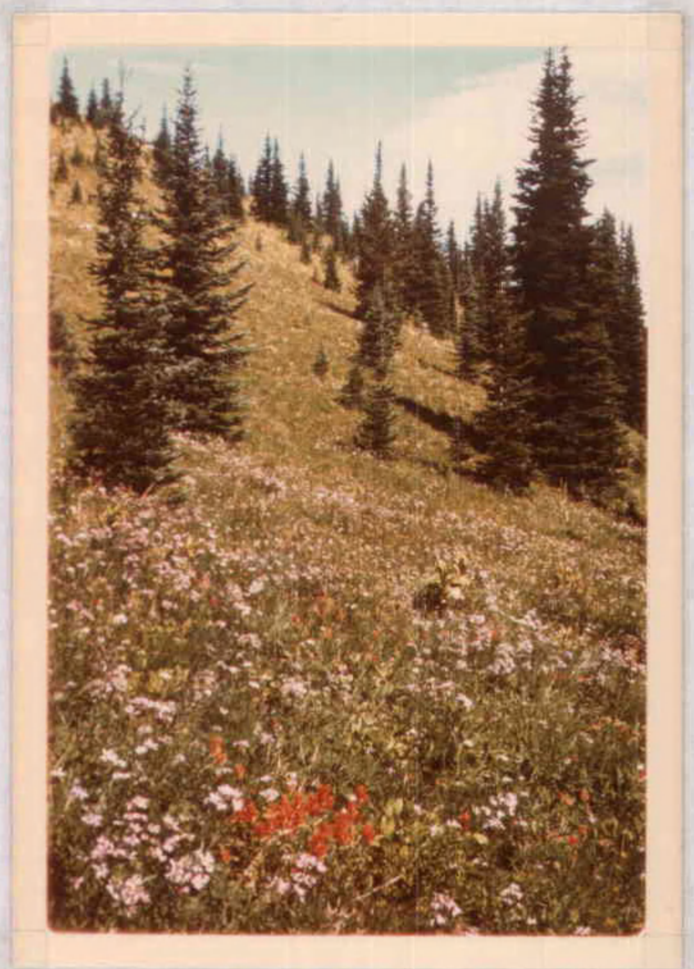

Figure 23. A Festuca/Aster community being re-invaded by fast-growing subalpine firs. Areas of the eastern part of the Park which have been burned have developed similar Festuca/Aster communities and show this type of tree invasion.

flabellifolia, and Ranunculus eschscholtsii are the only species which are conspicuous. Later most of these become less conspicuous and seem to disappear.

Soil under this type is often finer textured and deeper than the Festuca/Aster. A greater water holding capacity due to greater depth may be the single most important difference between the Festuca/Aster and the Festuca/Lupinus types. Lupinus latifolius is found on deep soils whether it is early or late seral and both of these community types have long snow-free seasons. Mountain goats, elk and deer may browse in this type but do not have significant impact at present. And as in the Festuca/Aster type, the most significant animal is the pocket gopher. Before White man settled in the area, the Yakima Indians used this type (especially in Yakima Park) for summer games. The extent of their impact is not determinable now. Sheep were grazed in areas of this type early in the century. The climatic climax for this type appears to be an Abies lasiocarpa or Abies lasiocarpa/Picea engelmannii subalpine forest.

The type stand of Festuca/Lupinus Community Type is numer 133. It occurs on a 30% south slope at 6400 feet elevation (1890) meters) on Sunrise Ridge (Table 11).

Festuca/Potentilla Community Type. The Festuca/Potentilla Community Type is a Dry-Grass type with affinities to the Lush-Herbaceous and Low-Herbaceous Vegetation Types. It occurs most commonly in the northeastern part of the Park, on gentle, dry, well-drained sites. Total ground

Table 11. Festuca/Lupinus Community Type.

Species	Dominance Type	Dominance Average	Constancy
Festuca viridula	5	4.4	100
Lupinus latifolius	4	4.0	100
Ligusticum grayi	2	2.4	86
Veronica cusickii	2	2.4	95
Polygonum bistortoides	2	2.3	82
Carex spectabilis	3	1.7	73
Potentilla flabellifolia	3	1.6	73
Anemone occidentalis	3	1.4	55
Aster ledophyllus		1.4	41
Phlox diffusa	2	1.2	46
Microseris alpestris		1.1	36
Castilleja parviflora		1.0	50
Antennaria lanata	1	0.9	50
Erigeron peregrinus	4	0.9	45
Castilleja miniata		0.4	23
Pedicularis contorta		0.7	9
Valeriana sitchensis		0.6	23

cover is about 85%. Pocket gophers occur but are not as common as in the other fescue types. Other animal impact is not obvious.

This type commonly occurs in the lower subalpine zone from 5500 to 6000 feet (1680 to 1830 meters) and often in patches surrounded by trees, suggesting that this and related low-herbaceous types are seral stages caused by some disturbance such as insects or fire. Trees are re-invading these areas, mostly from the margins of the meadows.

Parts of Grand Park and numerous clearings in the Sourdough Mountains are covered by this type. The acreage it covers, however, makes it a minor community type in the Park. One of its close relatives is the Anemone/Castilleja type which is floristically similar except for the absence or near absence of fescue. I feel that these two types represent slightly different stages in the development of the same community type. The fescue is simply slow to invade these seral communities.

The type stand of the Festuca/Potentilla Community Type is number 344, and occurs at 6300 feet (1920 meters) elevation, on a 12% east slope adjacent to the trail between Hidden and upper Palisade Lakes (Table 12).

The Lush-Herbaceous Vegetation Type

The Lush-Herbaceous Vegetation Type is comprised of four major community types, the Valeriana sitchensis, Valeriana/Veratrum, Lupinus/Polygonum, and Valeriana/Lupinus. These types occur on habitats intermediate among all others on Mt. Rainier. This vegetation type is related to the Heath-Shrub Vegetation Type via the Vaccinium deliciosum Community Type and the Phyllodoce/Lupinus Community Type. It is related to the

Table 12. Festuca/Potentilla Community Type.

Species	Dominance Type	Dominance Average	Constancy
Festuca viridula	4	4.2	100
Potentilla flabellifolia	4	3.5	100
Polygonum bistortoides	3	2.5	100
Anemone occidentalis	4	2.4	75
Veronica cusickii	3	2.2	88
Castilleja parviflora	3	1.8	75
Aster alpigenus	2	1.6	63
Carex spectabilis		1.6	75
Ligusticum grayi		1.6	75
Lupinus latifolius	2	1.6	75
Valeriana sitchensis		1.5	50
Antennaria lanata		1.4	50
Phlox diffusa	3	0.8	37
Aster ledophyllus		0.7	37
Microseris alpestris	2	0.7	37
Erigeron peregrinus	3	0.7	25
Pedicularis bracteosa	3	0.7	12

Dry-Grass Vegetation Type by way of the Lupinus/Polygonum and Festuca/Potentilla Community Types. An integrade between the Lupinus/Valeriana and the Festuca/Aster types also occurs fairly commonly. These types, although never wet, remain moist through the summer and are often the last to reach drought conditions.

Valeriana sitchensis Community Type. The Valeriana sitchensis Community Type is characterized by complete dominance by Valeriana sitchensis. The habitat is cool, moist and shady and the soil is often deep with some horizon development. This type is most commonly found at lower subalpine elevations, 5000 to 5700 feet (1525 to 1740 meters) and among or under tree groups. It succeeds many of the Lush-Herbaceous and Dry-Grass communities after forest cover has been established.

The Valeriana sitchensis type stand is number 352, elevation 5200 feet (1590 meters), 10% northeast slope, south of Owyhigh Lakes, adjacent to trail. It is characterized by deep winter snow pack, mesic habitat, partially developed soil horizon, and an adjacent or overtopping forest cover (Table 13).

Valeriana/Veratrum Community Type. The Valeriana/Veratrum Community Type occurs on northerly and easterly slopes where the threat of avalanche or snow creep is high. All members of this community are perennial herbs. Floristically this community is similar to the Valeriana, Lupinus/Valeriana, and the Vaccinium deliciosum types. The habitat is sometimes similar to the Lupinus/Valeriana or Valeriana types, and

Table 13. Valeriana sitchensis Community Type.

Species	Dominance		Constancy
	Type	Average	
Valeriana sitchensis	5	5.0	100
Carex spectabilis	3	3.0	100
Erythronium montanum	2	2.5	100
Polygonum bistortoides	2	2.0	100
Potentilla flabellifolia	3	1.5	50
Luzula glabrata	3	1.5	50
Carex nigricans	-	1.5	50
Festuca viridula	-	1.5	50
Ligusticum grayi	2	1.0	50
Castilleja parviflora	2	1.0	50
Veronica cusickii	-	1.0	50
Polemonium pulcherrimum	2	1.0	50

sometimes similar to the habitat of Phyllodoce/Vaccinium type. Thornburgh[1] believes that the Phyllodoce/Vaccinium type only occurs on areas which are not swept by avalanches or where winter snow creep is not severe, whereas the Valeriana types, since its members overwinter wholly underground, can withstand the surface shearing of snow creep and avalanches.

The Valeriana/Veratrum type stand is number 351, elevation 5200 feet (1590 meters), 20% east slope, near Owyhigh Lakes. The habitat is often characterized by cool soil and partial shade. Total plant cover is greater than 100% (Table 14).

Lupinus/Polygonum Community Type. The Lupinus/Polygonum Community Type is most commonly found in the northerly and easterly parts of the Park. Soils are moderately deep and moderately fine textured. The habitat is more mesic than that of the fescue types and drier than the other lush-herbaceous types. Floristically, it is an intermediate between the lush-herb and fescue types. Its similarity to these other types can be seen on the SIMORD plot (Figure 10) and similarity indices (Table 4). Sometimes Carex spectabilis may occur as the codominant with Polygonum bistortoides, and in this case Lupinus latifolius occurs as a minor component. I believe that this type corresponds to the Carex spectabilis/Polygonum bistortoides type in the north Cascades and is essentially the same as the Carex albonigra type in the Olympics (Kuramoto, 1968).

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[1] Personal communication.

Table 14. Valeriana/Veratrum Community Type.

Species	Dominance		Constancy
	Type	Average	
Valeriana sitchensis	5	4.8	100
Veratrum viride	4	3.5	100
Arnica latifolia	3	1.5	50
Erythronium montanum	2	1.5	50
Anemone occidentalis	2	1.2	50
Carex spectabilis	2	1.2	50
Lupinus latifolius	2	1.0	50
Castilleja parviflora	-	1.0	50
Sausseria americana	3	0.8	25
Luzula glabrata	-	0.8	25
Veronica cusickii	-	0.8	25
Festuca viridula	3	0.8	25
Polygonum bistortoides	2	0.5	25
Ligusticum grayi	2	0.5	25

This meadow type provides forage for elk and mountain goats. The mountain goats normally take only the flowers and upper stems while elk may modify the structure of the community by clipping some of the species to the ground.

The Lupinus/Polygonum type stand is number 113, elevation 5300 feet (1620 meters), 10% east slope, at Indian Bar (Table 15).

Valeriana/Lupinus Community Type. The Valeriana/Lupinus Community Type is the most colorful and one of the most striking of the "flower fields" on Mt. Rainier. It occurs mostly on the south and west flanks of the mountain and is replaced in the north and east by the drier Festuca/Lupinus type. Integrades between the Lupinus/Valeriana and the Festuca/Lupinus types are not uncommon.

This type is most commonly found on mounds of deep, moderately fine textured soil, and often on parent material of neocene mudflows, especially in Indian Henry's Hunting Ground and Paradise Park. This mounded topography allows the winter snowpack to melt off from the top first and from the bottom last. The phenology of the community follows the receding snowline. The top of the mound becomes free of snow in early July or late June and the bottom later in July or into August. If the area between two mounds is a cold air or water drainage it is occupied by a Carex nigricans community.

Animal influence in this type is not well known. Deer, elk, and mountain goats have been noted browsing on the succulent foliage and flowers. Ground squirrels use some of the fruits, e.g. Lupinus, and Ligusticum in

Table 15. Lupinus/Polygonum Community Type.

Species	Dominance Type	Dominance Average	Constancy
Lupinus latifolius	4	4.5	100
Polygonum bistortoides	4	3.8	100
Carex spectabilis	3	3.3	100
Castilleja parviflora	3	2.3	83
Potentilla flabellifolia	2	2.4	92
Anemone occidentalis	3	2.3	83
Ligusticum grayi	2	2.0	58
Antennaria lanata	2	1.3	58
Veronica cusickii	-	1.2	50
Valeriana sitchensis	2	1.1	42
Erigeron peregrinus	2	0.8	33
Festuca viridula	-	0.8	25
Carex nigricans	2	0.8	42
Erythronium spp.	-	0.8	42
Aster alpigenus	2	0.6	25

the fall. In the drier members of this type winter trailings of the pocket gopher may be found.

Seedlings and saplings of subalpine fir and rarely mountain hemlock may be found invading this type. Invasion is not widespread but the growth rate of established trees is noticeably higher than in the Heath-Shrub types.

The Valeriana/Lupinus type stand is number 80, elevation 5500 feet (1680 meters), 25% west slope, in Indian Henry's Hunting Ground near Mirror Lakes. It is most common in the south and west parts of the Park on the convex surfaces of a hill and swale topography (Table 16).

The Low-Herbaceous Vegetation Type

The Wet-Sedge and Low-Herbaceous Vegetation Types are closely related and consist of community types which may be ordinated into two groups based on soil moisture. The wetter end of the ordination includes the wet-sedge community types. The drier end of the ordination includes the seral low-herbaceous community types. The low-herbaceous group includes the Aster alpigenus, Luetkea pectinata, Saxifraga tolmiei, Eriogonum/Spraguea, Tauschia/Vaccinium deliciosum and the Trisetum spicatum Community Types. Another type, which is an intermediate between the low-herbaceous types and the tall, lush-herbaceous types, is the Anemone occidentalis/Castilleja parviflora type. The Festuca/Potentilla type is somewhat of an intermediate between the Aster Alpigenus and Festuca/Lupinus types. The Vaccinium

Table 16. Valeriana/Lupinus Community Type.

Species	Dominance Type	Dominance Average	Constancy
Lupinus latifolius	4	4.2	100
Valeriana sitchensis	4	4.1	100
Castilleja parviflora	4	3.0	100
Polygonum bistortoides	3	2.9	100
Ligusticum grayi	1	2.4	100
Vaccinium deliciosum	2	2.4	75
Potentilla flabellifolia	2	2.0	75
Erigeron peregrinus	1	2.4	88
Erythronium spp.	2	1.6	63
Veronica cusickii	1	1.5	63
Arnica latifolia	-	1.4	50
Aster alpigenus	-	1.4	50
Carex spectabilis	3	1.2	50
Festuca viridula	1	1.2	37
Pedicularis bracteosa	-	1.1	37
Veratrum viride	-	1.0	37
Phyllodoce empetriformis	2	0.8	25
Luzula glabrata	-	0.8	25
Antennaria lanata	1	0.5	25
Aster ledophyllus	-	0.5	12
Carex nigricans	-	0.4	12
Anemone occidentalis	3		

Figure 24. Yakima Park, Sunrise Ridge. Foreground is a small snow-catch basin dominated by an Antennaria lanata community. Note the small patches of heather invading. The background is mostly Festuca/Lupinus community being invaded by subalpine fir and whitebark pine in the "atoll" or copse pattern. The centers of the atolls are often whitebark pine.

Figure 25. *Valeriana/Lupinus* community in Paradise Park area. It is famous for its rich floral displays. It occurs on mounds. Trees invading this meadow type grow rapidly but are not as common as in the heath-shrub types.

deliciosum is, in some phases, an intermediate between the low-herbaceous types and the heath-shrub types.

The Wet-Sedge Vegetation Type

The Wet-Sedge Vegetation Type is comprised of one major community type and several others which are uncommon and closely related.

Carex Nigricans Community Type. The Carex nigricans Community Type is the major community of the wet-sedge group (Figure 18). The C. nigricans/C. Spectabilis, C. nigricans/Aster alpigenus, C. nigricans/ Antennaria lanata types might even be considered variants of this basic type. The similarity between these four community types is high, above 43% in all cases (Table 4).

This type occurs in small basins or cold air drainages and microfrost pockets throughout the Cascades and Olympics. The habitat is characteristically wet, sometimes drying in fall. Often the water table is at the surface during the entire, but short growing season. The temperature is cool, being modified greatly by the high moisture content of the soil. Soil temperature measurements indicate this type has the lowest daytime temperature but that night temperatures, due to the moderating effect of water, may not be as low as in the dry-grass types, especially on a clear night. Based on the total heat load during the summer, however, this is probably the coldest type.

Successionally this type replaces a pioneer moss type dominated by Polytrichum spp. and/or Marsupella sp. in moist, raw basins or gentle slopes; or replaces Saxifraga tolmiei in snow catch basins at higher elevations and may invade ponds or slow moving streams from the margins by vegetative growth and expansion of the colony.

This type is known to occur from the Oregon Cascades to the Olympics (Kuramoto and Bliss, 1970) to the North Cascades (Douglas, 1970) to the Mt. Garibaldi area of British Columbia (Brooke et al., 1970) and Banff (Kuramoto and Bliss, 1970). It is one of the most widespread and most easily recognized subalpine communities in the Cascades.

The Carex nigricans type stand is number 093, elevation 5400 feet (1640 members elevation, 5% southeast slope near Fan Lake (Table 17).

Carex nigricans/Carex spectabilis Community Type. The Carex nigricans/Carex spectabilis Community Type is closely related to the Carex nigricans Community Type. It occurs on moist to wet habitats, sometimes drying out slightly in the fall. The fertility of the soil appears higher in the C. nigricans/C. spectabilis type than in the Carex nigricans and the soil texture is finer than in other wet-sedge communities. The type consistently occurs on flats, small basins or gentle drainage ways rarely over 5% slope. The aspect of these communities is variable but mostly northerly. Elevational range is from 5200 to 6700 feet (1590 to 2050 meters), although most commonly between 5500 and 6100 feet (1680 and 1860 meters).

Table 17. Carex nigricans Community Type.

Species	Dominance Type	Dominance Average	Constancy
Carex nigricans	5	5.0	100
Carex spectabilis	1	1.5	68
Potentilla flabellifolia	1	1.5	66
Aster alpigenus		1.2	40
Vaccinium deliciosum	2	1.0	50
Luetkea pectinata		0.9	36
Phyllodoce empetriformis	1	+	
Cassiope mertensiana	1	+	
Lupinus latifolius		+	
Castilleja parviflora		+	
Polygonum bistortoides		+	
Tauschia stricklandii		+	

In some instances this type appears to be replacing a C. nigricans community, presumably as organic material and soil depth is being built up. Climatic shifts may account for some of the apparent vegetation change due to drying of the habitat. In later stages of succession herbaceous species such as Potentilla flabellifolia, Polygonum bistortoides, Castilleja parviflora and Ligusticum grayi appear to be invading, suggesting succession to a tall-herbaceous type. In others there is evidence for succession toward a heath-shrub type.

This type is sometimes found on flat areas of deep soil where the native vegetation was destroyed by man. Some places on the old golf course are now covered by this type, e.g. near the Paradise campground. Another disturbed area where this type is found is near the site of the settlement in the Glacier Basin mining development. Both of these situations, plus others, support the belief that Carex spectabilis is a fairly rapid invader on mesic to moist sites with deep, moderately fine textured soil. Other situations where Carex spectabilis is believed to have invaded rapidly are areas of rather deep soil material which were recently covered with permanent snowpack. These areas are better drained than those previously discussed and support communities of the Lupinus latifolius/Polygonum bistortoides Community Type in which Carex spectabilis is often a codominant.

Carex nigricans/Carex spectabilis type stand is number 100, elevation 5800 feet (1770 meters), 20% south slope, near Sluiskin Falls in Paradise Park. It is closely related to the Carex nigricans type but Carex nigricans is not the sole dominant and the site has a longer growing season (Table 18).

Carex nigricans/Aster alpigenus Community Type. The Carex nigricans/Aster alpigenus Community Type is closely related to the Carex nigricans Community Type. It occurs on moist to wet habitats, perhaps not as cold as the Carex nigricans type nor with as short a growing season. Floristically it is very similar to the C. nigricans type with the definite increase in Aster alpigenus from a minor component to co-dominance. This community is found on all sides of the Park wherever the proper set of environmental and edaphic factors prevail, although it is not common anywhere.

Six stands of the Carex nigricans/Aster alpigenus Community Type were sampled, but no type stand was selected. They occur on mostly gentle, moist slopes or flats and appear to be a seral stage in the development of a heath-shrub type (Table 19).

Antennaria lanata Community Type. The Antennaria lanata Community Type is very similar to the wet-sedge meadows. It occupies the same topographic position but the habitat is drier and the growing season is longer. Patches of the Antennaria lanata Community Type occur in Grand Park and on both the north and south sides of Sunrise Ridge. On the south facing slopes of Sunrise Ridge (mostly covered by dry fescue types) this type dominates small snow catch-basins or depressions; otherwise the topographic position is usually flat.

Table 18. Carex nigricans/Carex spectabilis Community Type.

Species	Dominance Type	Dominance Average	Constancy
Carex nigricans	4	4.0	100
Carex spectabilis	4	3.4	100
Potentilla flabellifolia	4	1.9	78
Aster alpigenus	4	1.3	40
Vaccinium deliciosum	1	1.2	47
Luetkea pectinata		0.9	36
Phyllodoce empetriformis	3	+	20
Cassiope mertensiana	3	+	28
Antennaria lanata		+	16
Tauschia stricklandii		+	4
Polygonum bistortoides		+	25

Table 19. *Carex nigricans/Aster alpigenus* Community Type.

Species	Average Dominance	Constancy
Aster alpigenus	4.3	100
Carex nigricans	3.5	83
Carex spectabilis	1.5	50
Phyllodoce empetriformis	1.5	67
Potentilla flabellifolia	1.3	50
Vaccinium deliciosum	0.8	33
Cassiope mertensiana	0.8	33
Tauschia stricklandii	0.7	16
Luetkea pectinata	+	16
Caltha spp.	+	
Kalmia polifolia	+	

Antennaria lanata reproduces vegetatively underground and thus forms rather thick mats in suitable habitats. Carex nigricans is a common associate or codominant, occurring more frequently at lower elevations and on moister habitats, although Antennaria lanata is the clear dominant. Carex nigricans was replaced by Antennaria lanata on these habitats which will succeed to a heath-shrub community.

The known elevational range for the type is from 5900 to 7100 feet (1800 to 2150 meters). Topographic position is a flat or small basin with the slope not exceeding 10%. Aspects are generally northerly, although sometimes southerly if the topography is a basin. It is rare or absent in the south and west parts of the Park.

On the drier habitats of this type the Festuca/Potentilla or Anemone/Castilleja types appear to be replacing it. On habitats which are moist (not wet) through the season, this type is replaced by a heath-shrub community.

This type has not been reported for anywhere but Mt. Rainier, although it may occur in the northeast portion of the Olympics or North Cascades.

Six stands of the Antennaria lanata Community Type were sampled, but no type stand has been selected. This type occurs in the bottoms of snow accumulation pockets in otherwise generally warm dry habitats. It is most common in the northeast part of the Park (Table 20).

Saxifraga tolmiei Community Type. The Saxifraga tolmiei Community Type occurs in the subalpine and the alpine zones. The habitat is sandy or gravelly, moist or wet from snowbank seepage, cool and sometimes windswept.

Table 20. Antennaria lanata Community Type.

Species	Average Dominance	Constancy
Antennaria lanata	4.5	100
Carex nigricans	3.3	100
Aster alpigenus	2.0	67
Potentilla flabellifolia	1.5	67
Luetkea pectinata	1.3	33
Polygonum bistortoides	1.2	50
Cassiope mertensiana	1.2	33
Phyllodoce empetriformis	0.8	33
Castilleja parviflora	+	
Carex spectabilis	+	
Vaccinium deliciosum	+	
Lupinus latifolius	+	
Anemone occidentalis	+	
Erigeron peregrinus	+	

The winter snowpack remains well into summer. The growing season is short, perhaps the shortest of any subalpine community. Some areas of this type did not become free of snow at all during the summer of 1971.

Much of the area now dominated by this type was covered with permanent snow or ice 70 years ago. The snow fields (e.g. above Paradise Park) have receded during these 70 years thus allowing this pioneer community to develop. Successional forces, therefore are more allogenic than autogenic.

This community can potentially be replaced by several other types, mostly of the low-herb, wet-sedge or lush-herb types (Table 21).

Luetkea pectinata Community Type. Stand number 169 is tentatively designated as the type stand for this community type. It occurred at 6300 feet (1920 meters) on a 20% east slope. More stands need to be studied before an accurate type stand can be chosen. Only eight stands were sampled which had a high dominance by Luetkea; moreover, about half of these are more accurately referred to another type (Table 22).

Other Communities

In addition to the major community types named and identified in the previous section, several others are recognized. These are uncommon, local types covering little acreage and few samples of them were taken.

The Minulus lewisii C.T. is dominated by Mimulus lewisii, M. tilingii, Epilobium alpinum, Petasites frigidus, Carex nigricans and several species of moss. It occurs along cold streams in the subalpine and alpine zones and is

Table 21. Saxifraga tolmiei Community Type.

Species	Average Dominance	Constancy
Saxifraga tolmiei	2.8	100
Luzula wahlenbergii	2.1	75
Polybonum newberryi	1.7	63
Carex spectabilis	1.2	63
Juncus drummondii	1.0	50
Carex nigricans	0.9	63
Hieracium gracile	0.7	38
Castilleja parviflora	0.7	38
Luetkea pectinata	0.5	12
Phyllodoce empetriformis	0.5	24
Eriogonum pyrolaefolium	0.5	24
Penstamon tolmiei	+	
Antennaria lanata	+	
Cassiope mertensiana	+	
Anemone occidentalis	+	
Lupinus latifolius	+	

Table 22. Luetkea pectinata Community Type.

Species	Dominance Type	Dominance Average	Constancy
Luetkea pectinata	5	4.2	100
Carex nigricans	3	2.7	75
Antennaria lanata	4	1.4	50
Veronica cusickii	3	1.4	63
Cassiope mertensiana		1.4	50
Carex spectabilis		1.4	37
Lupinus latifolius		1.4	37
Phyllodoce empetriformis		1.0	25
Vaccinium deliciosum		0.9	37
Castilleja parviflora		+	
Polygonum bistortoides	2	+	
Potentilla flabellifolia		+	
Saxifraga tolmiei		+	
Luzula wahlenbergii		+	
Juncus drummondii		+	
Deschampsia atropurpurea		+	
Hieracium gracile	2	+	
Aster alpigenus		+	

Figure 26. The Mimulus lewisii Community Type above Paradise Park on the way to the ice caves.

Figure 27. The Luetkea pectinata Community Type near Fan Lake. It is being succeeded by a Phyllodoce/Vaccinium community.

common in the Paradise area, e.g. on the way to the Ice Caves and near the Paradise picnic ground. It is considered to belong to the Lush-Herbaceous Vegetation Type.

The Eriophorum/Sphagnum C.T. is dominated by Eriophorum polystachion, Sphagnum spp., Carex nigricans, Aster alpigenus, and Carex spp. It occurs in areas of saturated soil where a lake or pond has been filled in by succession. Examples are found in the Elysian Fields, near Clover Lake, Cayuse Pass and Frog Heaven. It corresponds to the Eriophoro-Sphagnetum association of Brooke et al. (1970) from British Columbia and is a Wet-Sedge type.

The Vaccinium/Xerophyllum C.T. is dominated by Vaccinium membranaceum, Xerophyllum tenax, Epilobium angustifolium, and Phyllodoce empetriformis and bears some resemblance to the Heath-Shrub communities. It is created by fire and will again be replaced by forest. Examples have been found below Yellowstone Cliffs, and near Van Trump Park.

The Anemone/Castilleja C.T. may be recognized as a separate low-herbaceous type or it may be considered to be a form of the Festuca/Potentilla C.T. The floristics and habitats of these two types are similar except for the relatively low occurrence of Festuca viridula and to some extent Potentilla flabellifolia. This type is found on the drier slopes above Paradise and in the Sourdough Range.

The Trisetum spicatum C.T. is found sporadically and is identified by the dominance by Trisetum spicatum. Several other species found in the

Aster alpigenus or Antennaria lanata types may also occur. This type may be found in Grand Park and on some dry, rounded ridge tops near Paradise. It is believed to be a seral community in the Low-Herbaceous Vegetation Type.

The Carex/Kalmia C. T. may be distinguished from the Carex nigricans type on the basis of the presence of Kalmia polifolia. It occurs on a habitat slightly different from the Carex nigricans. Such a habitat is wet and soft, somewhat like that of the Eriophorum/Sphagnum C. T. It occurs near Fan Lake and on the north side of the Park and is a Wet-Sedge V. T.

The Carex/Caltha C. T. occurs along cold rivulets in the lower Subalpine Meadow Zone. The major species include Carex nigricans, Caltha biflora, and Caltha leptosepala. This type is one of the first to be free of snow in the spring but it remains cold and wet throughout the season and is considered a Wet-Sedge V. T.

The Tauschia/Vaccinium C. T. is dominated by Tauschia stricklandii and Vaccinium deliciosum. It is known to occur in Grand Park, Sunset Park and near Fan Lake and occurs on a habitat intermediate between the Carex nigricans C. T. and the Vaccinium deliciosum C. T. The slope is gentle to flat and the site is wet in the spring and rather dry in the fall. This type is not known to occur anywhere but on Mt. Rainier. This may be considered a Heath-Shrub or Low-Herbaceous type.

The Eriogonum/Spraguea C. T. is another high elevation, low-herbaceous type in the Park. It occurs on raw, gentle pumice slopes from 6000 to 7000 feet (1800 to 2200 meters). A similar habitat in the Oregon Cascades is called the cinder desert. This type is early seral or pioneer on raw pumice areas which have recently been freed of year-round snow pack. This type is dominated by Eriogonum pyrolaefolium and Spraguea multiceps and is further characterized by less than 10% ground cover. The type map shows areas of this type as bare ground.

VI. DISCUSSION

Meadow Classification

The subalpine meadow communities comprise a relatively stable, yet dynamic ecotone between the forested Tsuga mertensiana vegetation zone below and the treeless alpine zone above. It is comprised of communities which vary in their composition, structure and dynamics and thus represent identifiable and classifiable entities in the vegetation mosaic. The purpose of this study, however, was not to classify the communities into an artificial hierarchy fashioned around a preconceived notion of what the community types should be, but rather to let the classification develop out of the data. Therefore, the community classification is described in terms of a vegetation hierarchy and a continuum; neither of which describes the nature of the vegetation by itself. Even used together they fail to express the complexity and variability of the vegetation.

The vegetation hierarchy, composed of vegetation types and community types, shows relationships between communities and groups of communities. It expresses an orderliness in the repeatability of groups of species and provides a useful framework which includes generalizations and characterizations about the communities and community groups. Although the vegetation is recognized as variable to one degree or another, the ability to group and characterize similar communities or community types is very useful to the ecologist and land manager.

The five vegetation types--1) Heath-Shrub; 2) Dry-Grass; 3) Lush-Herbaceous; 4) Wet-Sedge; and 5) Low Herbaceous--are characterized by gross physiognomy and species composition and represent useful community groups at a resolution especially useful to management. The subdivisions of the vegetation types--the community types--are recognized by species composition and represent ecological entities at a finer level of resolution.

An ordination of these vegetation and community types and communities points out their relative similarities and in many ways gives a more dynamic picture of their relationships. For example, Figure 10 and Table 4 show relative ordination positions and computed similarity indices for the major community types in which the communities of the Dry-Grass and Lush-Herbaceous V.T.s define a gradient from the dry Festuca/Aster C.T. to the moist Valeriana/Veratrum C.T. The hierarchy shows these communities belonging to two discrete vegetation types and cannot depict the intergradation between them. The communities of the Wet-Sedge and Low-Herbaceous V.T.s show a similar pattern. In this ordination the Phyllodoce/Vaccinium C.T. stands alone. But this may be due to the inadequacies of the ordination procedure.

The defined and described subalpine meadow communities, therefore, are intended to be considered as a somewhat artificial ordering of the vegetation, the purpose of which is to: 1) build a useful hierarchy which includes generalizations about the composition, structure and dynamics of the communities and 2) show the spatial and temporal dynamic nature of the vegetation.

Post Glacial Succession

Nearly all the subalpine communities on Mt. Rainier have developed since the Wisconsin ice age. During the Tazewell stage, ca. 15,000 years b.p., ice and snow covered most of the area we now call the Subalpine Meadow Zone. As the glaciers retreated, pioneer plants moved onto the raw, stony and gravelly soil which was probably derived mostly from glacial drift or pumice eruptions. During the post hypsithermal period that ensued (ca. 8000 to 4000 b.p.) the subalpine vegetation was probably much like that of the central Oregon Cascades around Mt. Jefferson and the Three Sisters. These communities were probably mostly Eriogonum/Spraguea, Carex nigricans, Carex spectabilis/Polygonum, Luetkea pectinata, Saxifraga tolmiei, or Anemone/Castilleja types with lush-herbaceous types gradually moving up from below and heath-shrub types replacing some of these early seral types higher at higher elevations.

Soil development was slow through this period, soil material below the Mt. Mazama Y is coarse and shallow. Soil above this ash layer contains

Figure 28. Low-herbaceous communities in Grand Park. Area where the Daubenmire plot is being taken is dominated by a Tauschia stricklandii community which is being invaded by Lupinus latifolius. Most of Grand Park is covered by low-herbaceous, therefore seral, communities.

much more fine textured and organic material. Mudflows and ash deposits added to the accumulation rate of fine textured soil material.

A cooler, moister period followed the hypsithermal period from 4000 b.p. to present. During this 4000 year period minor climatic fluctuations have occurred but have probably not altered the composition or structure of the subalpine vegetation significantly. A pollen profile from Frog Heaven showed no trend in the succession of conifer species, which also indicated a relatively stable climate during this period. Further pollen studies by Hansen (1947) and Heusser (1960) from other areas indicated that such a static period might have been expected on Mt. Rainier.

During the last 4000 years much of the present vegetation has developed. This includes the development of the lush-herbaceous types, especially the _Lupinus/Valeriana_ type which occurs mainly on mudflows. Many of the mature heath and fescue meadows have developed during this period. We still find many seral communities, however, because of minor climatic fluctuations, such as the little ice age previously mentioned, the lag in the rate of succession on harsh habitats and because of disturbances such as fire.

We are in a warmer, drier period following the ice retreat in the last century. This climatic shift has created a pressure for timberline to move upward. This pressure is seen in the invasion of many subalpine meadows by trees and by the newly formed early seral communities at higher elevations.

Should climatic conditions remain stable we can expect the vegetation to readjust to the relatively new climatic conditions which will force the forestline and treeline up, perhaps as much as 500 feet (150 meters) from their present elevations.

Succession on Upper Slope Pumice Slopes

Early seral and pioneer communities are developing on moderately gentle slopes between 6000 and 7000 feet (1800 and 2200 meters) on all sides of the Park. These areas were covered with permanent snowfields or glaciers at the turn of the century. Probably about 1910, when the Nisqually Glacier began to recede rapidly, these snowfields and glaciers began moving back to their present position. Pumice and ash from recent eruptions and moraine material was left behind and formed a very porous barren soil surface which remains still mostly unvegetated. Pioneer communities such as the *Saxifraga tolmiei*, *Eriogonum/Spraguea* or *Luetkea pectinata* or along streams the *Mimulus lewisii* mostly in the southerly parts of the Park and *Antennaria* and *Aster alpigenus* types in the northeasterly part of the Park are invading these pumice or moraine deserts.

Unless a long-term stabilization of climate or further warming and drying occurs these communities may not develop much beyond their present stage. Succession is so slow at these elevations that it is quite possible that a cooler-wetter period may occur before there is substantial vegetation change.

Some successional trends are recognized, however. The *Saxifraga tolmiei* community appears to be replaced by a *Carex nigricans* community.

The saxifrage pioneers an area recently freed of permanent snowpack. Around the perimeter of the invaded basin the colonies of saxifrage are replaced by Carex nigricans. By the time total ground cover has developed, Carex nigricans will be the dominant species. Outside the invading C. nigricans colonies plants of C. spectabilis are invading. In wetter spots, especially along streams the Saxifraga tolmiei and Carex nigricans C.T. are replaced by the Mimulus lewisii C.T.

The Luetkea pectinata C.T. develops on raw, moist and often unstable alpine soils but is eventually replaced by a heath-shrub community. The successional relationships of the Eriogonum/Spraguea C.T. are not clear. It appears that succession may proceed in more than one direction. The Antennaria lanata C.T. will be replaced by a heath-shrub community, although in some cases this type is relatively stable because of snow-melt patterns. The Aster alpigenus C.T. on dry pumice slopes appears to be replaced by other low-herbaceous communities or eventually a fescue community. A diagrammatic presentation of these presumed relationships is given in Figure 11. Those trends for which there is strong floristic evidence are shown as solid lines; those which are more speculative are shown as dashed lines.

Succession Related to Fire

Communities which are most influenced by fire occur at middle to lower subalpine elevations, 5000 to 6000 feet (1525 to 1825 meters). These are indicated by species such as Vaccinium deliciosum, Epilobium angustifolium, Xerophyllum tenax, and Vaccinium membranaceum. These species represent two major communities, the most important of which is the Vaccinium deliciosum Community Type. Vaccinium deliciosum itself either recovers quickly or is not greatly affected by fire. Douglas and Ballard (1971) showed that fire in a heath community in the North Cascades had little effect on the V. deliciosum but greatly reduced the cover of other important species.

On Mt. Rainier observations indicate that V. deliciosum occurs on areas where there are recent indications of fire. McIntyre (1952) indicated that Yakima and Klickitat Indians often burned upper slope areas in an effort to increase huckleberry production. Griggs (1938) thought that fire was an important factor in initiating or maintaining meadows on Mt. Rainier. Brockman[1] noted old stumps and charcoal in some meadows which indicated past fire in these areas.

In the Olympics, Kuramoto (1968) felt that fire was the major factor in maintaining subalpine meadows.

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[1] Personal communication.

Several references stated that setting fire to subalpine fir "atolls" in Paradise Park on the fourth of July was a common practice early in the century (McIntyre, 1952; Haines, 1962). Sites have been located which appear to have supported former atolls which were probably destroyed by fire. The vegetation now consists of a Vaccinium deliciosum community with tendencies toward a lush-herbaceous community. The recovery successional pattern on such areas is for the V. deliciosum to be replaced by a Valeriana/Lupinus type then for trees to re-invade. In other areas the Vaccinium deliciosum community appears to be succeeding to a heath-shrub community which is believed to be related to fire history. The successional relationships of these communities are shown in Figure 12. Other communities are strongly related to fire history including the Vaccinium membranaceum/Xerophyllum type which occurs most commonly at elevations between 5000 and 5500 feet (1525 and 1675 meters). Sometimes Phyllodoce empetriformis is present on moister areas. This type is found along the Cascade Crest, in Spray Park, in Van Trump Park and in small patches in most other parts of Mt. Rainier National Park. These small patches probably resulted from spot fires from lightning strikes or careless campers. Although evidence of the influence of fire can be found in many regions of the Park, it is not considered a major ecological factor in creating or maintaining subalpine meadows on Mt. Rainier.

Meadow Invasion

Invasion of the subalpine meadows by trees in Mt. Rainier National Park is moderately widespread and readily visible. It was noted by Franklin et al. (1971) who reported that a mass invasion of a heath-shrub community by Abies lasiocarpa had occurred during the 1930's. For their ages they used ring counts on sanded blocks cut from near the base of sampled trees. This invasion is regarded, in general, as a response of the vegetation to milder climate since the little ice age of the 19th century.

Several invasion patterns are apparent, the analysis of which may contribute to the understanding of this phenomenon. Rate of invasion, rate of growth, growth form and spatial pattern of invading trees vary considerably by vegetation type. The following table summarizes these patterns.

Table 23. Growth characteristics of invading trees by Vegetation Type.

Vegetation Type	Growth Rate	Growth Form	Rate of Invasion	Spatial Pattern
Wet-Sedge	Very low	Distorted	Very low	Singly
Heath-Shrub	Low	Distorted	High	Widespread
Low-Herbaceous	Low	Distorted	Low	Singly
Lush-Herbaceous	Moderate	Straight	Moderate	Singly or Small Groups
Dry-Grass	Moderate to High	Straight	Low	Singly or in Copses

It is generally apparent from Table 23 that crooked growth form occurs on habitats of heavy snowpack. Years of heavy snow can even be dated by the location of crooks on the stem. It is also interesting to note that those communities in which there is a high rate of invasion are not those which have the highest growth rates. This indicates that habitat conditions conducive to establishment are not the same as for growth, e.g. in the Dry-Grass communities frequency of establishment is low but growth rate is relatively high, whereas in the Heath-Shrub communities frequency of invasion is high but the growth rate is low.

Establishment success requires the appropriate set of environmental conditions, occurring over a period of several years. Thus the successful invasion of a meadow by trees is a function of favorable environmental factors beginning at the initiation of the reproductive primordia in year n followed by the appropriate conditions for seed and cone development in year n + 1, followed by seed shed in the late part of that year and in the early part of year n + 2, followed by successful germination and anchorage in soil in year n + 3 and survival of drought, heat, snow and biotic factors for subsequent years. Should the environmental factors fail to follow the appropriate pattern at any of these stages then the successful establishment of a seedling would fail.

Following is a discussion of environmental factors considered significant at these stages. Factors affecting cone and seed production are relatively unstudied. The cyclic nature of cone production by Abies lasiocarpa for stations in the Cascades (Franklin, 1968) would make one look for either an internal biological rhythm or an external cycle of critical environmental factors which corresponds to the cycle of cone production.

Lowry (1966) showed that cone production of Pseudotsuga menziesii was statistically correlated to environmental parameters. His analysis showed that there were "biologically valid correlations" between an abundant cone crop in a given October and a warm January in the same year, a March-April with high precipitation 1 1/2 years before seed maturity and a cool July two years before maturity. He emphasized that his results were only clues to the connection between weather and cone crop production, however. The same correlations do not seem to hold for Abies lasiocarpa at high elevations.

Rehfeldt et al. (1971) showed that the 3 to 4 year cycle of western white pine cones was statistically correlated to daily water deficit 1 and 2 years before cone maturity.

Many graphical correlations were tried between weather and A. lasiocarpa cone production on Steamboat Mountain near Mt. Adams, the closest station for which cone crop data are available. Several of these showed some correlation but were discarded as better correlations were found. Finally using accumulated growing degree days (GDD)[1] for biologically significant seasons a strong correlation was derived between cone crop and the temperature regime of the spring and summer 1 1/2 years before cone maturity.

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[1]The lower threshold used is 40° F, the upper is 77° F.

An apparent environmental factor necessary for cone production is a cold March-April 1 1/2 years before seed maturity followed by a warm period beginning in May and continuing until the spring snowpack is gone or about the time of vegetative growth initiation in the summer. This correlation is shown in Table 24.

Conditions for a good or abundant cone crop for subalpine fir therefore apparently is highly correlated to the pattern as well as absolute amount of biologically usable heat 1 1/2 years before seed production--suitable conditions occurring about every three years.

There is also a good correlation between the length of time between the first hard freeze in the fall and the last in the spring and the time between spring snowpack meltoff in the spring and the first hard freeze in the fall--two measures of length of the growing season.

Some seed is subsequently shed in the fall of cone crop years and some is shed in the following winter and spring. Data are not available about the relative success of seed shed at these two times. Presumably seed shed in the spring is that observed germinating on the snow in late snowpack years.

The success of germinated seedlings during the summer following seed maturity is presumably related to the time of snowpack meltoff and occurrence of lethal drought and soil temperatures in that summer. A snowpack melting off about July 1, with moderate maximum temperatures and sufficient soil moisture as a result of snowpack melt and/or precipitation spaced throughout

Table 24. Correlation between spring temperatures and cone crop production 1 1/2 years later. (++ is well above average, + is above average, o is about average, - is below average, = is well below average and M is data missing.

Year	Temperature--March & April[1]	Temperature--May to Snowpack melt-off	Cone crop during following year[2]
1972	-	+	
1971	-	o	+
1970	=	o	+
1969	+	o	=
1968	o	-	=
1967	-	+	++
1966	+	-	o
1965	+	o	o
1964	-	++	+
1963	-	-	o
1962	+	o	=
1961	-	++	+
1960	++	o	?
1959	o	o	?
1958	-	+	+
1957	+	+	
1956	-	+	
1955	=	o	
1954	-	+	
1953	o	o	
1952	+	+	
1951	-	+	
1950	-	o	
1949	+	+	
1948	-	+	
1947	+	-	
1946	o	o	
1945	-	+	
1944	-	o	
1943	+	-	
1942	o	-	
1941	++	-	
1940	+	+	
1939	+	-	
1938	-	+	

Table 24. (Continued)

Year	Temperature-- March & April[1]	Temperature--May to Snowpack melt-off	Cone crop during following year[2]
1937	o	+	
1936	o	+	
1935	=	o	
1934	+	+	
1933	M	M	
1932	-	+	
1931	o	o	
1930	+	o	

[1]Based on Growing Degree Days from 1958 to 1972 and on average monthly temperature for earlier years.

[2]Conecrop records from Franklin (1968) for 1962 to 1967, from Franklin (Personal communication) 1968 to 1972 and 1959 from personal observation.

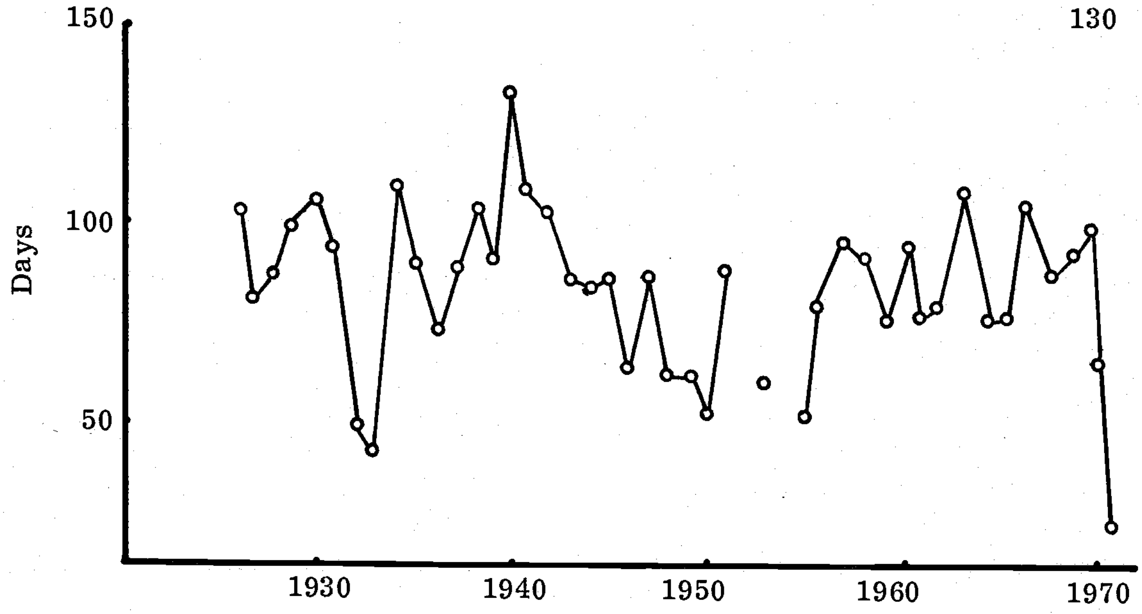

Figure 29. Days between last day of spring snowpack and first fall freeze.

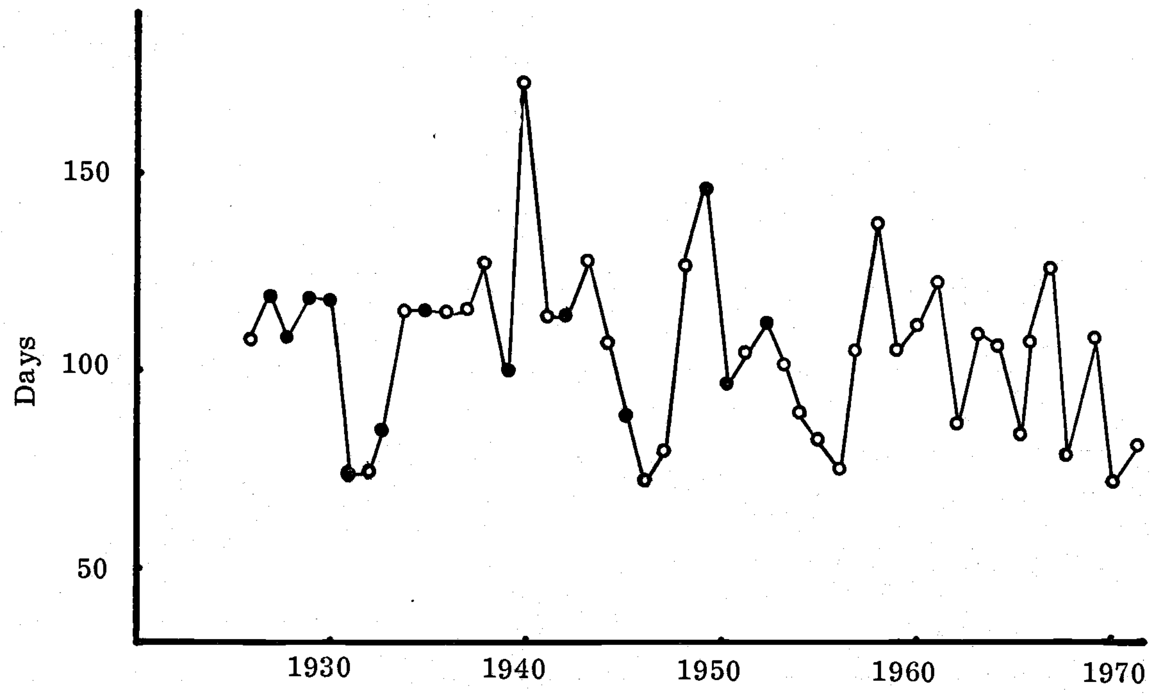

Figure 30. Days between last hard freeze ($\leq 28^{\circ}$ F) in spring and first hard freeze in fall. Solid circles based on incomplete or estimated data.

the summer are considered important factors for successful seedling germination and establishment.

Conditions for successful establishment of tree seedlings therefore begin with a cold March-April followed by a warm period from May until snowpack meltoff 1 1/2 years before seed maturity and survival of the immature cone through the winter, followed by suitable time of snow pack meltoff in the spring following cone maturity, moderate weather during the summer of germination and warm but not too dry conditions in the summer(s) following.

Cone crop records of Abies lasiocarpa near Mt. Rainier are not available before 1959, therefore, analysis of the invasion pattern relative to availability of seed before then must rely on inferences from climatological data.

The main period of tree invasion is indicated by the ages of trees given in Figure 13 which includes the age data of Franklin et al. (1971) and an equal number of age determinations taken over the course of this study. The age distribution shown in this figure indicates a major period of invasion about 1934 with perhaps invasions of smaller magnitudes about 1919, 1925, 1930, 1937, 1944, 1953, 1960. Ages of individual trees in this figure are, at best, ± 1 year and probably ± 2 years.

There are several problems in determining the age of small, slow growing trees. The most common method relies on a count of growth layers. Yet the significance of missing or double rings in conifers at high elevations is unknown. An experiment on noble fir seedlings and saplings on Mary's

Peak, Oregon, showed that repeated counts of rings on the same tree by hand lens or microscope did not give the same result. The range of such counts was ± 2 years for microscope counts and ± 4 years for hand lens counts in trees less than 30 years old. These trees were cut at ground level, yet in some the cotyledonary node was not located. In these cases it was not known how many years' growth were between ground level and the cotyledonary node. Age determinations where maximum accuracy is desired should be done on stem sections where the cotyledonary node is located. On most trees studied, the soil surface was built up to this node after about 20 years. The problem of judging double, incomplete or missing rings still remains and will probably account for some variation in the most careful measurements. Determination of exact years of establishment for individual trees is a critical factor in correlating establishment to climatic phenomena.

Age determination by whorls and bud scale scars yielded ages with a maximum range of ± 3 years in one case and ± in all others. The span becomes wider as the age of the tree becomes greater for all methods. Problems in estimating age by whorl and bud scale scar counts are not known for high elevation species of Abies. I believe that this method is at least as accurate a method of age determination as counting growth layers on small trees and has the additional advantage of being a non-destructive method.

If complete weather records were available for the past 60 years the correlation between weather and cone production, germination, and establishment could easily be tested against the histogram of seedling ages.

Table 24 shows that probable years of seed production based on favorable March-April and May-June temperatures were 1933, 1936, 1937, 1945, 1948, 1951, 1954, 1955, 1956. Also by interpolating using the recognized three year cycle in cone production, cone crops in 1939 and 1942 might also be predicted.

Comparing these possible dates of cone production to the histogram of seedling ages (Figure 13, p. 44) a good correlation appears. It is also apparent that the correlation between late spring snowpack and cone production also holds for this period. We thus have three estimates of years of past cone production to check against the age distribution of established trees: One, the correlation between temperature regime 1 1/2 years before cone production, Two, the correlation between late snowpack years and cone production the same year, and Three, and three-year cycle of cone production.

Since the smoothed curve of tree establishment shows a peak in the middle 1930's it has been suggested (Franklin et al., 1971; Fonda and Bliss, 1969; and Brink, 1959) that periods of tree establishment were related to some more favorable climatic period in which it was warmer and drier and there was a longer, more favorable growing season. Although plausible, there are reasons for not wholly accepting this hypothesis.

High temperatures and drought can be lethal to *Abies lasiocarpa* seedlings. Daubenmire (1943) has shown that 70 day old *A. lasiocarpa* seedlings from the Rocky Mountains have low tolerance to high temperature or soil drought. Four days below the wilting point killed 100% of the seedlings he used and high mortality was noted after brief periods at 55° C (130° F). Preconditioning and timing of high temperatures and low soil moisture are factors which may confound application of such laboratory data to field conditions. The available data indicates that these lethal conditions may exist in subalpine meadows in the Olympics (Fonda and Bliss, 1969; Kuramoto and Bliss, 1970) and on Mt. Rainier. Daubenmire's results would seem to oppose the belief that long summers or a warmer, drier climatic period is conducive to seedling establishment. It is still a fact that many seedlings became established in the early 1930's, just prior to the time average temperatures were higher and precipitation was lower (Figures 4 and 5).

Considering possible errors in determining ages of high elevation conifers, one might estimate that possible years of establishment during that period (Figure 13) were 1923, 1928, 1933, and 1943. Data from Fonda and Bliss (1969) for the Olympics indicates that periods of establishment were 1923 to 1933, 1943 to 1948, 1953 to 1960, and 1966 and 1967; data from British Columbia (Brink, 1959) indicated a peak in establishment from 1927 to 1937; and unpublished data from Mary's Peak, Oregon, indicates periods of establishment of noble fir of 1928 to 1935, and about 1956. Also some establishment in protected places has occurred in 1960, 1963, 1966 and 1969.

When all three correlations are fitted together (and they fit nicely) and compared with ages of established trees, the probable years of establishment on Mount Rainier appear to be 1934, 1936, 1937, 1944, 1950, 1953, 1956, 1957, 1960, 1964, 1969 and probably 1929 and 1925.

The final test of this model would correlate seedling establishment with favorable growing conditions in the years following germination. Because so little is known about the physiological requirements of these trees at very early ages and their link to phenology and the lack of complete meteorological records for Paradise weather station, this test can not be made without further data. The years of establishment, however, are nearly always moderate or above average in terms of precipitation and temperatures during the summer months. This is not surprising since drouth is thought to be a critical factor limiting seedling establishment.

Figure 31. Mass invasion of a Heath-Shrub community by subalpine fir and mountain hemlock in Klapatche Park. These trees, in the two to four foot height class, are mostly about forty years old. The taller ones in the center are about 110 years. Growth rate is much lower in this community type but amount of invasion is often much greater than other communities.

VII. SUMMARY AND CONCLUSIONS

Effective management of an area which was preserved because of great biological and geological significance must be based on detailed knowledge and understanding of the basic biological and geological resources plus the dynamic forces effective in maintaining these systems. This study is an attempt to describe the composition, structure, dynamics and distribution of the most important vegetation zone in Mt. Rainier National Park.

The Subalpine Meadow Zone is a mosaic of meadow vegetation and tree clumps and represents a dynamic ecotone between the closed forest below and the alpine vegetation above. The meadow vegetation is divided into five broad groups: 1) the Heath-Shrub, 2) the Dry-Grass, 3) the Lush-Herbaceous, 4) the Wet-Sedge and 5) the Low-Herbaceous Vegetation Types, which are delimited on the basis of their physiognomy and to a lesser extent their taxonomy. The five vegetation types are divided into 34 more explicit community types which are distinguished by species composition and dominance and represent nodes in a vegetation continuum. Such a continuum is largely a function of the seral nature of the communities in the zone.

The distribution map shows that the drier communities occur most frequently in the northeast part of the Park, the late-seral Lush-Herbaceous types occur at lower subalpine elevations, Heath-Shrub and Low-Herbaceous communities occur on seral habitats and that the general limits of the zone are 5300 to 6500 feet in the southwest part and 5700 to 6900 feet in the northeast part of the Park.

The communities in the Low-Herb V.T. are characteristically early seral. They are replaced by communities in any of the other four vegetation types. The Heath-Shrub communities are early to mid-seral while the Wet-Sedge, Lush-Herbaceous or Dry-Grass communities may occupy a successional position from mid to late-seral. All habitats except rocky outcrops or wet streamsides are considered seral to either a mountain hemlock or an Engelmann spruce-subalpine fir dominated forest community. Although the forest is considered the climax vegetation in this zone, climatic fluctuations, harsh environments, disturbance and the lag in succession due to these conditions make it unlikely that the Subalpine Meadow Zone will ever be completely replaced by forest.

The climatic shift from the little ice age of the last century has opened many new habitats for colonization by subalpine and alpine plants and has caused a noticeable successional change in extant vegetation. Two examples of this are the colonization of high elevation pumice fields and the invasion of meadow communities by trees.

The latter was first noted by Franklin et al. (1971) who reported that a mass invasion had occurred in the 1930's. The selection of their area to be sampled missed other age classes of invading trees, and data taken during this study indicate a more even age distribution than they reported. The maximum period of invasion is still clearly in the early to mid-1930's. The peak of invasion appears to have been in 1934. Climatic and growth data indicates that 1933 was a likely year for a good cone crop and 1934 was an unusually good year for growth of established trees, and presumably for germinating seedlings.

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APPENDICES

APPENDIX I

SIMORD

The reconnaissance data gathered during the field season of 1970 (217 stands) were used in a SIMORD ordination to help show floristic affinities and help delimit natural groupings of stands (community types) and groupings of community types (vegetation types).

SIMORD (Similarity ordination) program was written by W. H. Moir after some earlier work by Whittaker (1967). It is composed of two steps. One, a simple similarity index computation using Sorenson's K index.

$$SIM(I,J) = \frac{1}{n'} \sum_{k=1}^{n} \left(\frac{2\ MIN\ [a_{ik}, a_{jk}]}{a_{ik} + a_{jk}} \right), \text{ for } a_{ij} \text{ or } a_{jk} \geq c$$

This step compares each stand with each other stand (Stands I and J), one at a time. It uses the selected importance parameter (e.g. cover or dominance) and for any two stands, compares each species which occurs in either or both stands and which satisfies the inequality. It is, then, an average of $\frac{2W}{a + b}$ taken n' times where W is the minimum of the two values a and b, a is the importance parameter for stand I and b is the importance parameter for stand J.

A sample calculation: (The importance parameter used is % cover)

	Stand I	Stand J
Species 1	43	14
2	16	3
3	1	0
4	0	5
5	12	5
6	3	1

If the limiting value is 3% cover then the calculation is:

$$SIM = \left(\frac{28}{57} + \frac{6}{19} + \text{Not used}^{*} + \frac{0}{5} + \frac{10}{17} + \frac{2}{4}\right)/5$$

$$= (.5 + .3 + 0 + .6 + .5)/5$$

$$= 1.9/5$$

$$= .45$$

The second step is the ordination (in n dimensions) of the stands based on their similarity indices relative to those of selected reference stands (R1 and R2). The equations used are:

$X = 1 - SIM(i, R1)$

$Y = 1 - SIM(i, R2)$

$DX = 50 + 50 (X^2 - Y^2)$ where R1 and R2 are the X-axis reference stands.

$DY = 50 + 50 (X^2 - Y^2)$ where R1 and R2 are the Y-axis reference stands.

This gives each stand an X and Y dimension and thus ordinates them in two dimensions. Additional dimensions are easily calculated but not easily plotted or interpreted.

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*Neither a nor b satisfied the inequality, $\geq$ 3%.

Two options are available in selecting the reference stands. The first option is to have the computer select them. This may not prove satisfactory if the stand table contains many very dissimilar stands. The computer would pick two stands which may not be very similar to any of the remaining stands and the resulting ordination will throw most other stands into a tight cluster near the center of the axes.

The second option is to select end stands which represent the end points or extremes of some environmental or successional gradients and thus to use SIMORD to ordinate stands along these presumed gradients. Such an ordination is presented in Figure 10.

A more complete discussion of the SIMORD program is given in Dick-Peddie and Moir (1970).

APPENDIX II

DOMINANCE RATINGS

The Poulton Dominance rating system uses five codes to rate the individual species in a stand based on its relative abundance and importance. It is thus a reconnaissance method. These ratings are used directly in the preparation of association tables and in the SIMORD program of computing and ordinating similarity coefficients between stands. The average ratings are used to characterize a community type and are used in the SIMORD computer analyses on the community types.

This rating system is used as follows (modified from Poulton et al., 1971):

5 - The species which dominates the layer. It is dominant in the sense of its impact on the microenvironment beneath its canopy. There can be a maximum of one "5" per layer. Some stands may not have a species which rates a 5, in this case "4" would be the highest rating used.

4 - The species which are codominant with another or are subordinate to one which was rated 5. A layer can thus have more than one 4. In stands lacking a clear dominant, the two or more most important species (ecologically) may be assigned a 4 - dominance rating if they are approximately equal in the stand.

3 - The species which are easily seen by standing in one place and looking casually around. These are important species but not dominant. This may be the highest rating given if the total ground cover is very low.

2 - The species which can be seen only by moving around in the stand or by looking intently while standing in one place.

1 - Species which can be seen only by searching for them in and around other plants.

APPENDIX III

VASCULAR PLANT SPECIES MENTIONED IN TEXT

Family	Genus and Species	Authority	Common Name	Abbrev.
Cupressaceae	Chamaecyparis nootkatensis	(D. Don) Spach	Yellow-cedar	--
Pinaceae	Abies lasiocarpa	(Hook.) Nutt.	Subalpine fir	--
	Picea engelmannii	Parry	Engelmann spruce	--
	Pinus albicaulis	Engel.	Whitebark pine	--
	Pinus monticola		Western white pine	--
Juncaceae	Juncus parryi	Engel.		Ju pa
	Luzula divaricata	Wats.		Lu di
	Luzula glabrata	(Hoppe) Desv.		Lu gl
	Luzula wahlenbergii	Rupr.		Lu wa
Cyperaceae	Carex nigricans	C. A. Mey.	Black sedge	Ca ni
	Carex spectabilis	Dewey		Ca sp
	Eriophorum polystachion	L.	Cotton sedge	--
Gramineae	Deschampsia atropurpurea	(Wahl.) Schule		De at
	Festuca viridula	Vasey		Fe vi
	Trisetum spicatum	(L.) Righter		Tr sp
Liliaceae	Erythronium grandiflorum	Pursh	Glacier lily	Er
	Erythronium montanum	Wats	Avalanche lily	
	Veratrum viride	Ait.	False hellebore	Ve vi
	Xerophyllum tenax	(Pursh) Nutt.	Beargrass	Xe te

APPENDIX III (Cont.)

Family	Genus and Species	Authority	Common Name	Abbrev.
Polygonaceae	Eriogonum ovalifolium	Nutt.	Wild buckwheat	Er ov
	Polygonum bistortoides	Pursh	Mountain bistort	Po bi
	Polygonum newberryi	Small		Po ne
Caryophyllaceae	Arenaria obtusiloba	(Rydb.) Fern.		Ar ob
Ranunculaceae	Anemone occidentalis	Wats.	Western anemone	An oc
Saxifragaceae	Saxifraga tolmiei	T. & G.	Tolmie saxifrage	Sa to
Rosaceae	Luetkea pectinata	(Pursh) Kuntze	Partridgefoot	Lu pe
	Potentilla flabellifolia	Hook.	Mtn. cinquefoil	Po fl
Leguminosae	Lupinus latifolius	Agardh		
	Var. subalpinus	(Piper & Robbins) C.P. Smith	Subalpine lupine	Lu la
Umbelliferae	Ligusticum grayi	Coult. & Rose	Mtn. parsley	Li gr
	Tauschia stricklandii	(Coult. & Rose) Math. & Const.	Tauschia	Ta st
Ericaceae	Cassiope mertensiana	(Bong.) G. Don	White heather	Ca me
	Phyllodoce empetriformis	(SW.) D. Don	Red heather	Ph em
	Vaccinium deliciosum	Piper	Mtn. huckleberry	Va de
	Vaccinium membranaceum	Dougl.	Thinleaved huckleberry	
Gentianaceae	Gentiana calycosa	Griseb.	Gentian	Ge ca
Polemoniaceae	Phlox Diffusa	Benth.	Phlox	Ph di

APPENDIX III (Cont.)

Family	Genus and Species	Authority	Common Name	Abbrev.
Scrophulariaceae	Castilleja miniata	Dougl.	Scarlet paintbrush	Ca mi
	Castilleja parviflora	Bong.		
	Var. oreopola	(Greenm.) Ownbey	Magenta paintbrush	Ca pa
	Pedicularis bracteosa	Benth.		
	Var. latifolia	(Pennell) Cronq.	Bracted pedicularis	Pe br
	Pedicularis contorta	Benth.	Contorted pedicularis	Pe co
	Pedicularis ornithorhyncha	Benth.	Birdbeak pedicularis	Pe or
	Pedicularis rainierensis	Pen. & War.	Rainier pedicularis	Pe ra
	Penstamon procerus	Dougl.		
	Var. tolmiei	(Hook.) Cronq.	Tolmie penstamon	Pe pr
	Vernoica cusickii	Gray	Veronica	Ve cu
Valerianaceae	Valeriana sitchensis	Bong.	Valerian	Va si
Compositae	Achillea millefolium	L.	Yarrow	Ac mi
	Agoseris aurantiaca	(Hook.) Greene	Orange mountain dandelion	Ag au
	Antennaria lanata	(Hook.) Greene	Pussytoes	An la
	Arnica latifolia	Bong.	Arnica	Ar la
	Aster alpigenus	(T. & G.) Gray	Alpine aster	As al
	Aster ledophyllus	Gray		As le
	Erigeron peregrinus	(Pursh) Greene	Mtn. fleabane	Er pe
	Hieracium gracile	Hook.	Hawkweed	Hi gr
	Microseris alpestris	(Gray) Q. Jones		Mi al

APPENDIX IV

CONVERSION FROM DOMINANCE RATING TO PERCENT COVER

Dominance	Percent Cover
5	50 - 100%
4	20 - 49%
3	4 - 19%
2	1 - 3%
1	< 1%

APPENDIX V

KEY TO THE SYMBOLS USED IN FIGURE 10

AND IN TABLES 3 AND 4

Symbol	Community Type
Cn	Carex nigricans
CC	Carex nigricans/Carex spectabilis
CA	Carex nigricans/Aster
Al	Antennaria lanata
Lp	Luetkea pectinata
Aa	Aster alpigenus
PV	Phyllodoce/Vaccinium
TV	Tauschia/Vaccinium deliciosum
PL	Phyllodoce/Lupinus
Vd	Vaccinium deliciosum
St	Saxifraga tolmiei
VV	Valeriana/Veratrum
Vs	Valeriana sitchensis
LV	Lupinus/Valeriana
LP	Lupinus/Polygonum
FP	Festuca/Potentilla
FL	Festuca/Lupinus
FA	Festuca/Aster

APPENDIX VI

TYPE MAP OF SUBALPINE MEADOW ZONE