THE ECOLOGICAL EFFECTS OF RECREATIONAL USE ON SUBALPINE MEADOW PLANT COMMUNITIES IN JEFFERSON PARK, MT. JEFFERSON WILDERNESS AREA, OREGON

by

DICK VANDER SCHAAF

A THESIS

Presented to the Department of Biology
and the Graduate School of the University of Oregon
in partial fulfillment of the requirements
for the degree of
Master of Science

June 1982

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Stanton A. Cook

This study examined the effects of hiking with regard to individual species changes within a community-type, comparison of individual species changes between community-types, and changes at the community-type level. Results revealed that Graminoid species tended to increase near trails while woody and herbaceous dicots, lichens, and bryophytes tended to decrease in cover near trails. Woody dicots were the most susceptible species in all four community-types studied. It was observed that a species may show different amounts of change in percent cover, depending on the community-type in which it occurs. The Short Alpine Sedge Wet Meadow and Rawmark Pumice Community-Types proved to be the most resistant to hiking effects, while the Cascade Blueberry Dry Meadow and Mountain Heather Moist Meadow Community-Types were the most susceptible. Community-type sensitivity was correlated with soil compaction, soil particle size, and the amount of shrubby species present.

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INTRODUCTION

The ever increasing demand for wilderness experiences and the growing awareness of man's influence on natural ecosystems have caused people to begin to question the effects of backcountry users on popular high mountain areas. This study was conducted to gather data on the effects of hiker use on subalpine meadow plant communities in a heavily used wilderness area in Oregon. The Oregon Cascades have not been studied with respect to the effects of hikers on wilderness ecosystems. Thus, with the recent rapid population growth in western Oregon and the increasing popularity of backpacking in this outdoor-oriented state, there is an immediate need for ecological information on potentially threatened wilderness areas in the nearby Cascades.

Research on backcountry impacts has begun in several other popular areas in the western United States. In the heavily travelled Sierra Nevada Mountains of California, the Sierra Club initiated a study of the effects of Club sponsored outings on high alpine meadows (Harvey et al. 1972). Results from the study indicated that large groups of hikers can cause substantial damage to fragile meadow plant communities in a very short time. Concern for ecosystems lying within national parks has prompted several studies in the Rocky Mountains. A study in Glacier National Park in Montana noted the susceptibility of alpine plant communities to visitor use on a self-guided nature trail (Hartley

1973). In Colorado's Rocky Mountain National Park other investigators have observed the differential susceptibility of alpine tundra plant communities to trampling and their corresponding recovery when people have been excluded from the areas for periods of up to four years (Willard and Marr 1970, 1971). At Image Lake in the North Cascades of Washington a long term study was begun on the effects of trampling on subalpine meadow communities (Thornburgh 1962). And in the Wallowa Mountains in eastern Oregon a recent study examined the effects of wilderness use on several plant communities, ranging from open grasslands to subalpine meadows (Cole 1977).

Research on the effects of recreation on ecosystems has also been conducted in other countries. In Japan the effects of visitor use on Mt. Hakkoda have been noted by using Raunkiaer's plant life form classification scheme to group the susceptibility of different life forms of plants (Naito 1969). The Scottish mountains have also been examined in reference to plant community susceptibility and hiker behavior with regards to terrain features (Bayfield 1973). Skiing and road developments in Scottish mountain tundra near Cairngorm have prompted studies of man's impacts on soils, plants, and animals (Watson, et al. 1969). Similar research is beginning in many other already altered regions of the world as the awareness of the long-term nature of these effects increases.

The present project conducted in the Oregon Cascades, differs from the above in that it was directed at the effects of hiking on very closely associated plant communities and their soils in a subalpine

meadow. The results of the research indicate to wilderness managers the need for consideration of these closely associated plant communities in making decisions as to trail relocation, campsite numbers and location, and carrying capacity of wilderness areas.

This research was conducted in the subalpine meadows of Jefferson Park, located in the Mt. Jefferson Wilderness Area in western Oregon (Figure 1). This magnificent basin, with its rolling meadows and shimmering high lakes, plays host to several thousand visitors each summer.

The popularity of Jefferson Park though, is not without its negative consequences. Campsites located around its major lakes are becoming increasingly barren and the composition and structure of trailside plant communities appears to be changing. Trampling along trails causes crushing and breakage of aboveground plant organs and increased soil compaction that is associated with decreased soil porosity. This in turn decreases aeration of soil and reduces percolation of water through the soil. Growth of below ground plant organs is consequently inhibited. Trampling also causes trails to become channels for snowmelt. Surface runoff of water accelerates erosion. Standing surface water, decreased soil temperatures, and altered aeration may bring about plant species changes alongside the trails (Holway and Ward 1963). As the primary trails remain water-filled channels for longer periods into the summer, hikers establish parallel trails on adjacent higher ground. Thus a single, narrow trail often becomes a network of parallel trails set in a broad, 2.0 meter wide band of denuded, compacted soil.

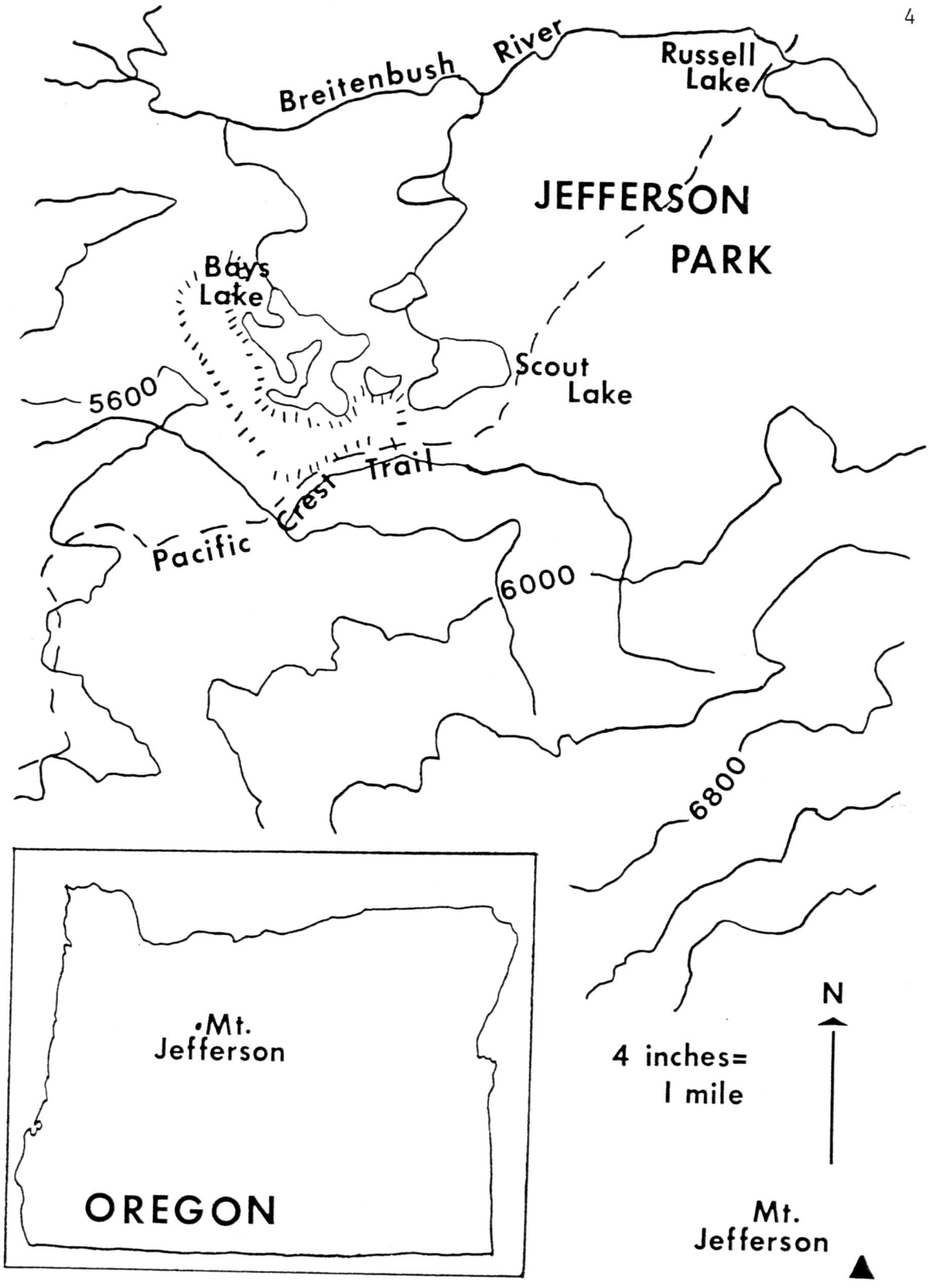


Figure 1. Location Map of Jefferson Park.

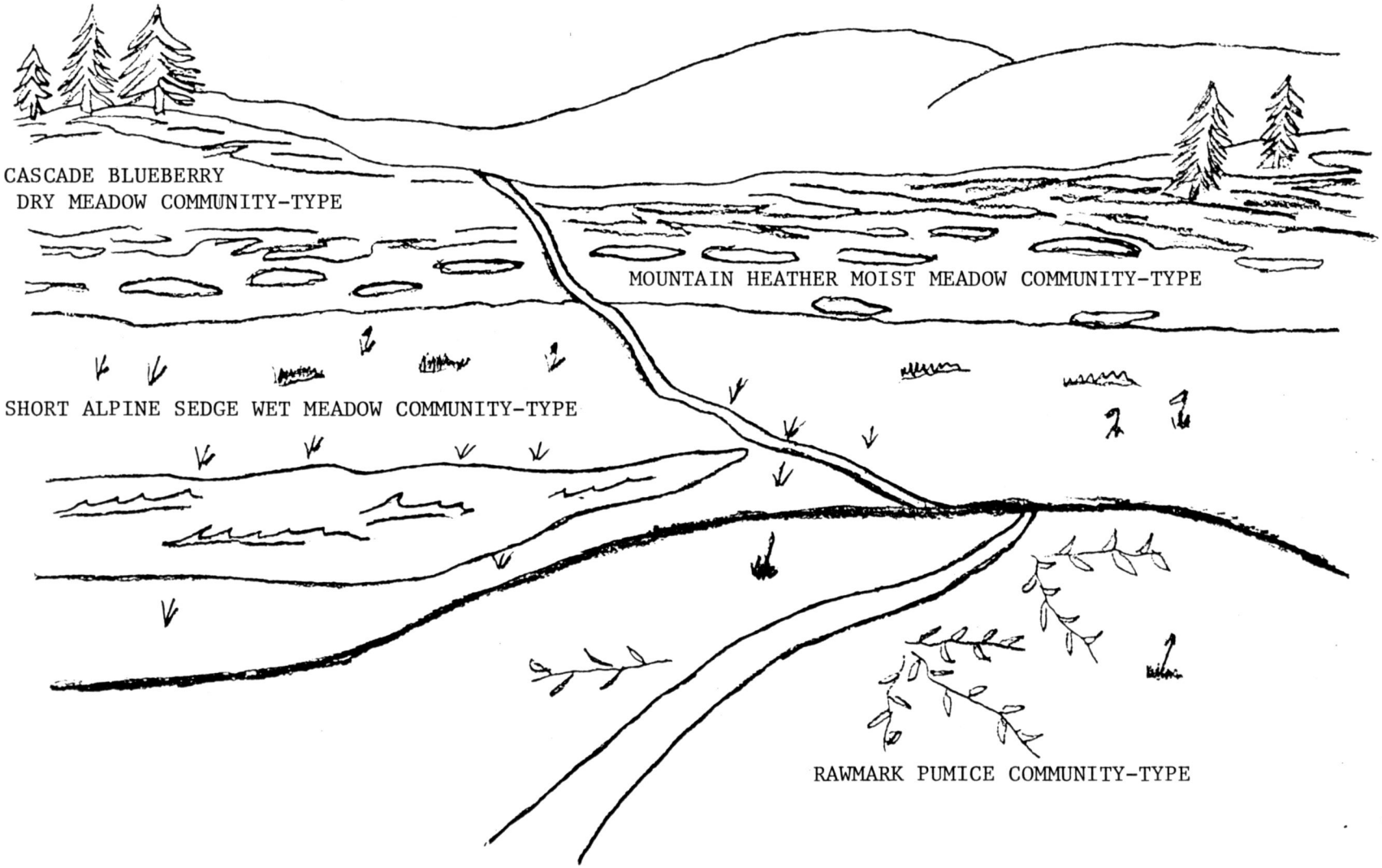
Sustained heavy recreational use of subalpine areas may also have less obvious effects on the "functional ability" of wilderness ecosystems (Hendee, et al. 1978). Functional ability refers to processes such nutrient cycling, nutrient input, and soil formation. It can be examined indirectly in terms of changing soil characteristics and productivity or growth of key species. Virtually no study has been made of changes in soil characteristics in response to recreational use in wilderness areas. However, soil factors have been examined in campgrounds which receive much greater use than most backcountry campsites (Dotzenko, et al. 1967; Monti and Mackintosh 1979; Ward and Berg 1973). Changes in primary productivity caused by recreational use have been examined recently in Glacier National Park (Hartley 1973) and in Olympic National Park (Bell and Bliss 1973).

Site Description

Jefferson Park, one of the largest subalpine meadow complexes in the central Oregon Cascades, occupies a rolling basin 2.5 square km. in area that straddles the Cascade crest to the north of Mt. Jefferson. The Park is divided by a series of north-south running ridges, less than 5.0 meters high, that have created a mosaic of plant associations that usually intergrade with one another. The microtopographical gradient related to these associations is defined primarily by three physical factors: drainage, duration and depth of snowpack, and soil characteristics (Campbell 1973).

Four plant community-types that represent the predominant vegeta-

Figure 2. Schematic Drawing of Relative Positions of Plant Community-Types.



tion in the Park were examined intensively (a community-type being defined as a recognizeable plant assemblage that is repeated throughout the ecosystem when various physical factors of the environment are kept constant - Whittaker 1956, 1967). The community-types are by no means mutually exclusive with regards to species presence, but rather they represent groups of species that are found repeatedly in similar habitats in the High Cascades of Oregon and Washington (Campbell 1973; Douglas 1972; Kuramoto and Bliss 1970; Taylor and Douglas 1978). The community-types were investigated at four sites in the western half of Jefferson Park where most of the visitor use takes place. The community-types studied are described below in the order they occur along a moisture gradient from wet to dry. For a complete listing of species present and their mean percent cover see Appendix A. Figure 2 gives a schematic representation of how each community-type relates to each other in a topographical sense.

Short Alpine Sedge Wet Meadow Community-Type

The wet meadow type is dominated by Carex nigricans Retz, Aster alpigenus (T.&G.) Gray, and Polytrichum juniperinum Hedw. and associated with late snowmelt and soggy soils for most of the summer. The soils are light gray in color, of fine texture, and covered with an algal crust. This community-type occupies low-lying areas in Jefferson Park, ringing the numerous small ponds. The type is best known for its beautiful wildflowers that bloom throughout the summer.

Mountain Heather Moist Meadow Community-Type

The moist meadow type is dominated by Phyllodoce empetriformis (Sw.) D.Don, Cassiope mertensiana (Bong.) G.Don var. mertensiana, and Kalmia microphylla (Hook.) Heller and associated with intermediate drainage and snowmelt. Many small rivulets run through this community and support a rich moss flora. The soils are similar to those of the short sedge community; however a light gray bleached zone (A_2 horizon) lies beneath a deeper organic layer. This community forms a band of vegetation slightly above the short sedge community.

Cascade Blueberry Dry Meadow Community-Type

The dry meadow shrub is dominated by Vaccinium deliciosum Piper and has early snowmelt and good drainage, relative to the other communities. This community merges into the subalpine forest tree clumps that occupy the higher ground in Jefferson Park. Its soils are a distinctive cinnamon-brown in color and have charcoal and Mazama ash mixed in them. Other prominent species in this community include Polytrichum juniperinum Hedw. and Leutkea pectinata (Pursh) Kuntze.

Rawmark Pumice Community-Type

This sterile, gravelly-soiled type has upwards of 75% bare ground and occupies slightly convex areas that remain snowfree for part of the winter. Polygonum newberryi Small var. newberryi is the most prominent species; there is less cover of Lupinus latifolius Agardh var.

latifolius and Arenaria capillaris Poir. The term "rawmark" refers to the lack of soil formation that has taken place in the community (Kuramoto and Bliss 1970). The soil has a small organic fraction and exhibits no discernible horizons.

METHODS

Sampling was done by placing a 20cm. by 50cm. (0.1 meter square) quadrat along transects laid out perpendicularly to the Pacific Crest National Scenic Trail where it ran through a homogeneous plant community. The assumption was made that trampling effects decrease away from the trail, so sampling along the transect should show any differences in species cover and composition that are responses to trampling. Species identifications were made according to The Flora of the Pacific Northwest (Hitchcock and Cronquist 1973). The percent cover of every species encountered within the quadrat was estimated at eight distances along the transect, beginning on trail: 0.0m., 0.5m., 1.0m., 2.5m., 5.0m., 7.5m., 10.0m., and 15.0m. Cover was estimated using a ten point cover class scale (Table 1) devised by Domin-Krajina (Kershaw 1973). The scale is weighted so as to over-represent species that may not contribute significantly to cover (greater than 5%) of a community. Approximately twenty transects, chosen at random distances along the trail through a particular community, were measured for each community-type.

Three replicate measures of soil compaction were taken in each vegetation quadrat. They were made with a pocket penetrometer (Soil-test Inc.).

Table 1. Domin-Krajina Cover Class Scale

Cover Class	Cover Description	Mean Percent Cover	Arcsin Transformation
1	scarce, less than 5%, single plant	1.0	5.74
2	scattered, less than 5%, several plants	2.0	8.13
3	5% cover	4.0	11.54
4	5% to 10% cover	7.5	15.89
5	15% to 20% cover	17.5	24.73
6	25% to 33% cover	29.0	32.58
7	33% to 50% cover	41.5	40.11
8	50% to 75% cover	62.5	52.24
9	75% to 95% cover	85.0	67.21
10	95% to 100% cover	97.5	80.90

Soil samples were collected from all four community-types along transects similar to those used in the vegetation sampling. Samples were collected at 0.0m. (on the trail), 1.0m., and 5.0m. from the trail. The samples were taken from the top 15cm. of the soil, the approximate rooting depth of most of the species present.

In the lab soil samples were weighed, dried in an oven at 60 degrees Centigrade for 24 hours, and reweighed to determine soil moisture content. Particle size was determined using a 2.0mm sieve and the hydrometer method (Bouyoucos 1951) for the remaining fraction. Percent organic matter was determined by the ignition method. Soil pH was measured in the less than 2.0mm fraction using a 1:2 ratio of soil to water.

The vegetation data were analyzed using four statistical tests. Simple linear regressions of cover versus distance for each species in a community-type were computed in order to determine the significance and magnitude of change in cover of individual species. Multiple stepwise regressions using soil compaction and distance as the independent variables were also computed to determine for which species soil compaction was a more important predictor of percent cover than distance was. Analysis of variance was performed on each species to determine at which sampled distances from the trail there was a statistically significant change in cover. Lastly Chi Square tests were conducted for frequency of each species by community-type using data from the vegetation sampling scheme. The purpose of this test was to determine if and where significant changes in a species' presence occurred

with respect to distance from the trail. To meet the assumptions for tests of linear regression and analysis of variance the cover class data were translated into percent cover values and then transformed with an arcsin transformation (Sokal and Rohlf 1969).

The effect of trampling on soil compaction was tested using simple regression and analysis of variance. The small sample sizes of other soil variables measured precluded statistical analyses.

RESULTS

Vegetation Results

The results of the vegetation sampling will be interpreted in three ways - by individual species, by growth forms, and by community-type.

Species Effects

Table 2 summarizes the results of simple linear regression tests made on each species in each community-type; the species are grouped into growth form types. The regression coefficient (slope) denotes the magnitude and direction of the change in cover, with positive slopes indicating species that decrease near trails and negative slopes corresponding to species that increase near trails. Species with slopes that don't significantly differ from zero apparently are not affected by proximity to trails and can thus be thought of as resistant to trampling.

The species that are most adversely affected by trampling, as evidenced by their high positive regression coefficients, are Aster alpigenus, Kalmia microphylla, Phyllodoce empetriformis, Vaccinium deliciosum, and Polytrichum juniperinum. Species that actually increase

Table 2. Linear Regression Coefficients and R^2 Values for Plant Species Sampled. R^2 values are in parentheses. * indicates P=.05, ** indicates P=.01, no asterisk indicates that regression coefficient is not significant.

	Community-types			
Species	Short Sedge Wet Meadow	Mt. Heather Moist Meadow	Blueberry Dry Meadow	Rawmark Pumice
LICHENS				
Cladonia species	2.487** (0.34)	0.776* (0.05)	0.688** (0.08)	
Stereocaulon species	1.885** (0.21)	-0.129 (0.01)	0.310** (0.06)	
BRYOPHYTES				
Marsupella emarginata	1.914** (0.08)	-0.363 (0.01)		
Lophozia ventricosa	insufficient data for analysis			
Polytrichum juniperinum	2.195** (0.07)	1.083 (0.01)	9.675** (0.29)	10.067** (0.37)
Moss 1	-0.328 (0.02)			
Moss 3	0.175 (0.01)			
Moss 4	0.526** (0.04)	0.532 (0.05)	0.256 (0.01)	
Moss 5		1.358** (0.06)		
Moss 7		-0.098 (0.01)		
Rhacomitrium heterostichum	2.537** (0.13)	-0.795 (0.01)	0.540* (0.04)	2.009** (0.07)
Aulacomnium palustre		-0.892 (0.03)		

Table 2. (continued)

Species	Community-types: Short Sedge Wet Meadow	Mt. Heather Moist Meadow	Blueberry Dry Meadow	Rawmark Pumice
WOODY DICOTS				
Cassiope mertensiana		0.484 (0.00)		
Kalmia microphylla	1.387** (0.05)	4.993** (0.30)		
Phyllodoce empetriformis	2.230** (0.07)	4.073** (0.08)	4.169** (0.18)	
Vaccinium deliciosum		2.654** (0.06)	2.715** (0.03)	
HERBACEOUS DICOTS				
Antennaria alpina		-0.134 (0.01)	0.624* (0.03)	1.173* (0.03)
Arenaria capillaris			0.293 (0.03)	1.214 (0.03)
Aster alpigenus	3.941** (0.16)	3.658** (0.22)	2.469** (0.14)	3.076** (0.07)
Caltha biflora		1.187** (0.14)		
Castilleja parviflora	0.343 (0.02)	-0.235 (0.01)	0.719** (0.05)	
Dodecatheon jeffreyi	0.300 (0.01)	1.260** (0.16)		
Gentiana calycosa	0.810** (0.05)	1.810** (0.23)		
Ligusticum grayi		0.358 (0.01)	0.655** (0.09)	
Luetkea pectinata			2.268** (0.05)	
Lupinus latifolius				0.540 (0.00)

Table 2. (continued)

Species	Community-types: Short Sedge Wet Meadow	Mt. Heather Moist Meadow	Blueberry Dry Meadow	Rawmark Pumice
Lycopodium sitchense		0.885* (0.01)		
Microseris alpestris			-0.120 (0.01)	
Polygonum newberryi				-1.603 (0.02)
Spraguea umbellata				0.682* (0.05)
GRAMINOIDS				
Agrostis variabilis	-0.675* (0.04)	-0.400** (0.05)	0.283 (0.02)	0.386* (0.05)
Carex nigricans	0.703 (0.00)	1.500* (0.03)	0.280 (0.00)	-0.575 (0.02)
Carex spectabilis	-0.845* (0.04)			0.578 (0.01)
Juncus mertensianus	-0.793** (0.12)	-1.273** (0.08)		
Juncus parryi		-0.503** (0.07)	0.951 (0.02)	0.318 (0.01)
SITE PARAMETERS				
Penemean (soil compaction)	-0.409** (0.49)	-0.298** (0.19)	-0.589** (0.41)	0.249* (0.06)
Bare ground	-8.849** (0.24)	-11.015** (0.34)	-16.251** (0.45)	-8.993** (0.19)

in cover close to the trail are Agrostis variabilis, Juncus mertensianus, Juncus parryi, and Carex spectabilis. Carex nigricans is the only species that consistently shows no significant change in cover in response to trampling. The species mentioned above show regular, dramatic changes in cover in all of the community-types in which they occur. Other species present showed variable, less dramatic changes in cover. This was partially a function of their relative rarity and of community specific response.

Growth Form Effects

A better way to examine the effects of trampling on plant species is to lump the species into groups representing plant growth forms. The groups present in the sampled meadow communities of Jefferson Park include: lichens, bryophytes, woody dicots, herbaceous dicots, and graminoids. For the most part the species in each group respond uniformly to trampling in all community-types. (Exceptions will be addressed in the discussion section of this paper.) Graminoids, Agrostis variabilis for example, tended to increase near trails, being able to contend with physical trampling pressures, increased surface water, and increased soil compaction (Figure 3). The bryophytes showed a certain amount of resistance to trampling, in the heather community-type in particular; however in general the bryophytes can be considered susceptible to trampling impact and therefore decreased in cover near trails when standing water didn't collect and create favorable conditions for them (Figure 4). The lichens, Stereocaulon

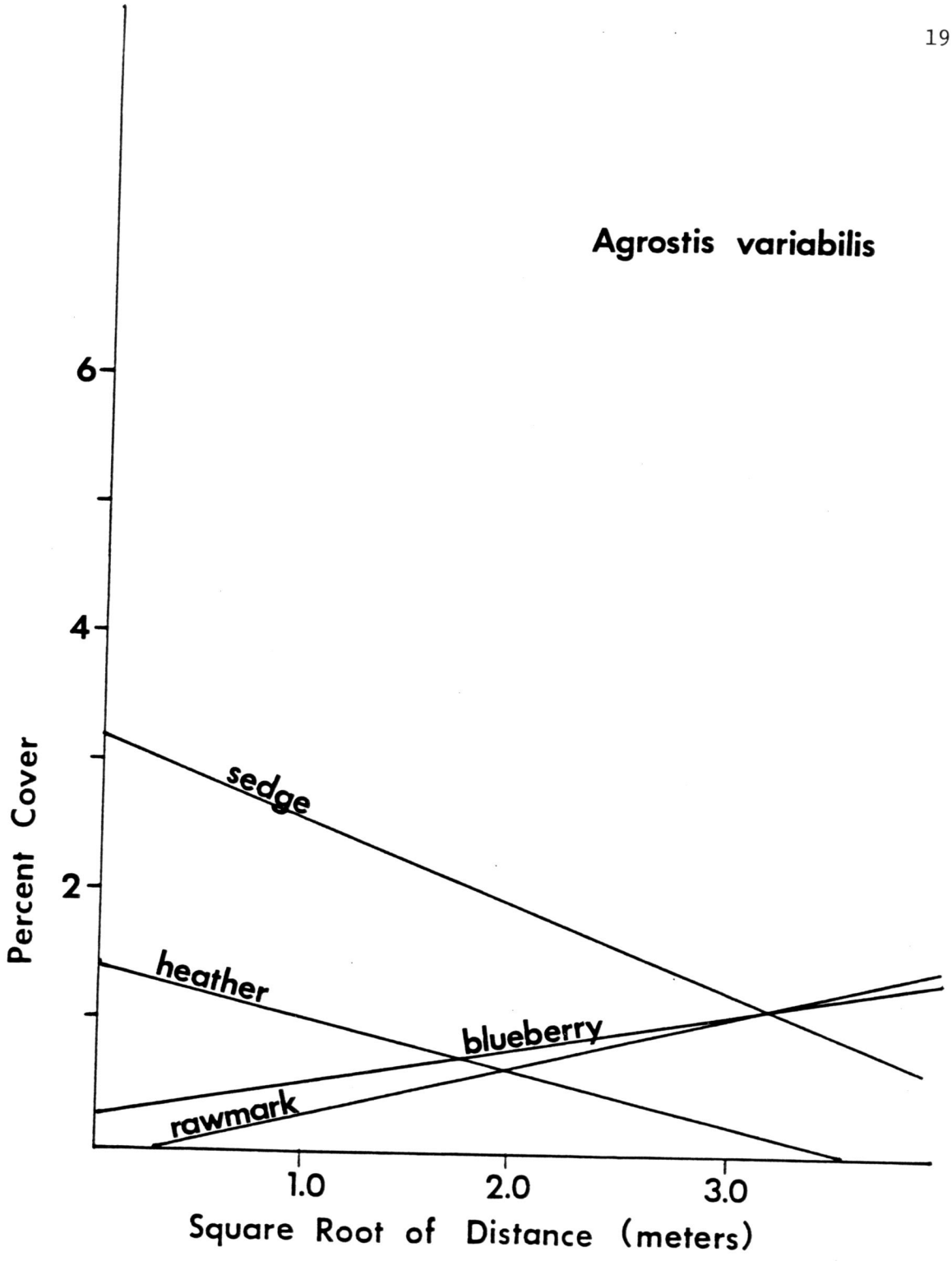


Figure 3. Graph of Linear Regression of Percent Cover on Distance for Agrostis variabilis. sedge=Short Alpine Sedge Wet Meadow Community-Type, heather= Mountain Heather Moist Meadow Community-Type, blueberry= Cascade Blueberry Dry Meadow Community-Type, rawmark= Rawmark Pumice Community-Type.

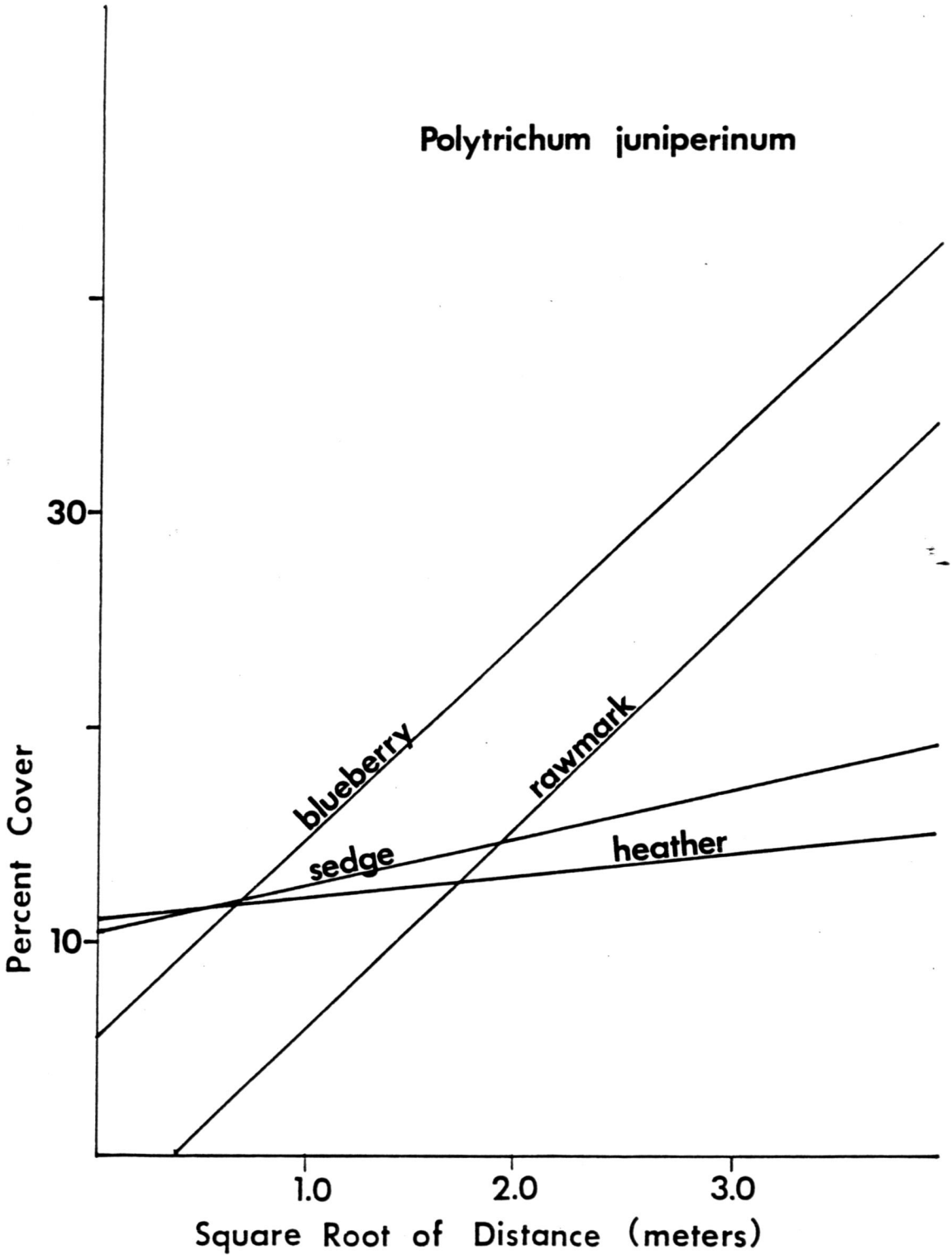


Figure 4. Graph of Linear Regression of Percent Cover on Distance for Polytrichum juniperinum.

and Cladonia species, exhibited consistent decreases in cover up to 5.0 meters away from the trails except in the heather community-type where Stereocaulon showed no significant change (Figure 5). The woody dicots suffered the most from trampling effects. Red heather, blueberry, and laurel species significantly decreased in percent cover in all community-types (Figure 6). Last, the herbaceous dicots displayed decreased cover near trails for most species although several exceptions to this generalization exist (Figure 7).

Many of these exceptions can be attributed to hydric conditions near trails where soil compaction has resulted in increased puddling of water and its standing longer into the short growing season. This is most evident in some bryophyte species which show no significant difference in cover near trails. In the Short Alpine Sedge Wet Meadow Community-Type Dodecatheon jeffreyi and Castilleja parviflora exhibit no decrease in cover near the trail - both species potentially responding positively to increased surface water. The white heather, Cassiope mertensiana likewise shows no decrease in cover in the Mountain Heather Moist Meadow Community-Type, possibly because its compact growth form and needle-like leaves may be less susceptible to mechanical breakage from treading than other woody dicots. Finally in the Rawmark Pumice Community-Type Polygonum newberryi, a large fleshy knotweed, increases near trails, a phenomenon attributed to its colonizing abilities in disturbed ground (Hamann 1972).

Multiple stepwise regressions of cover (dependent variable) on soil compaction and distance from the trail (independent variables)

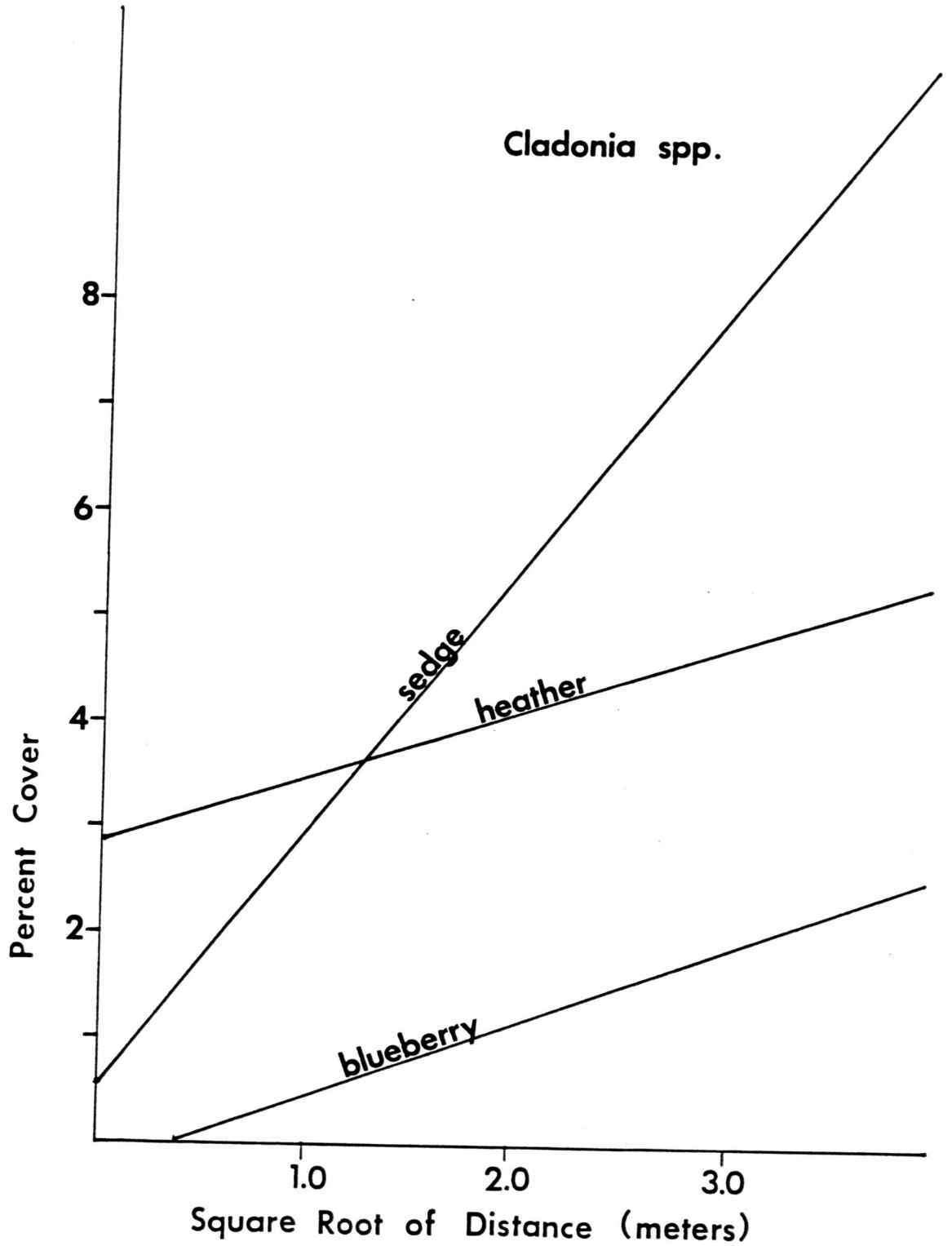


Figure 5. Graph of Linear Regression of Percent Cover on Distance for Cladonia species.

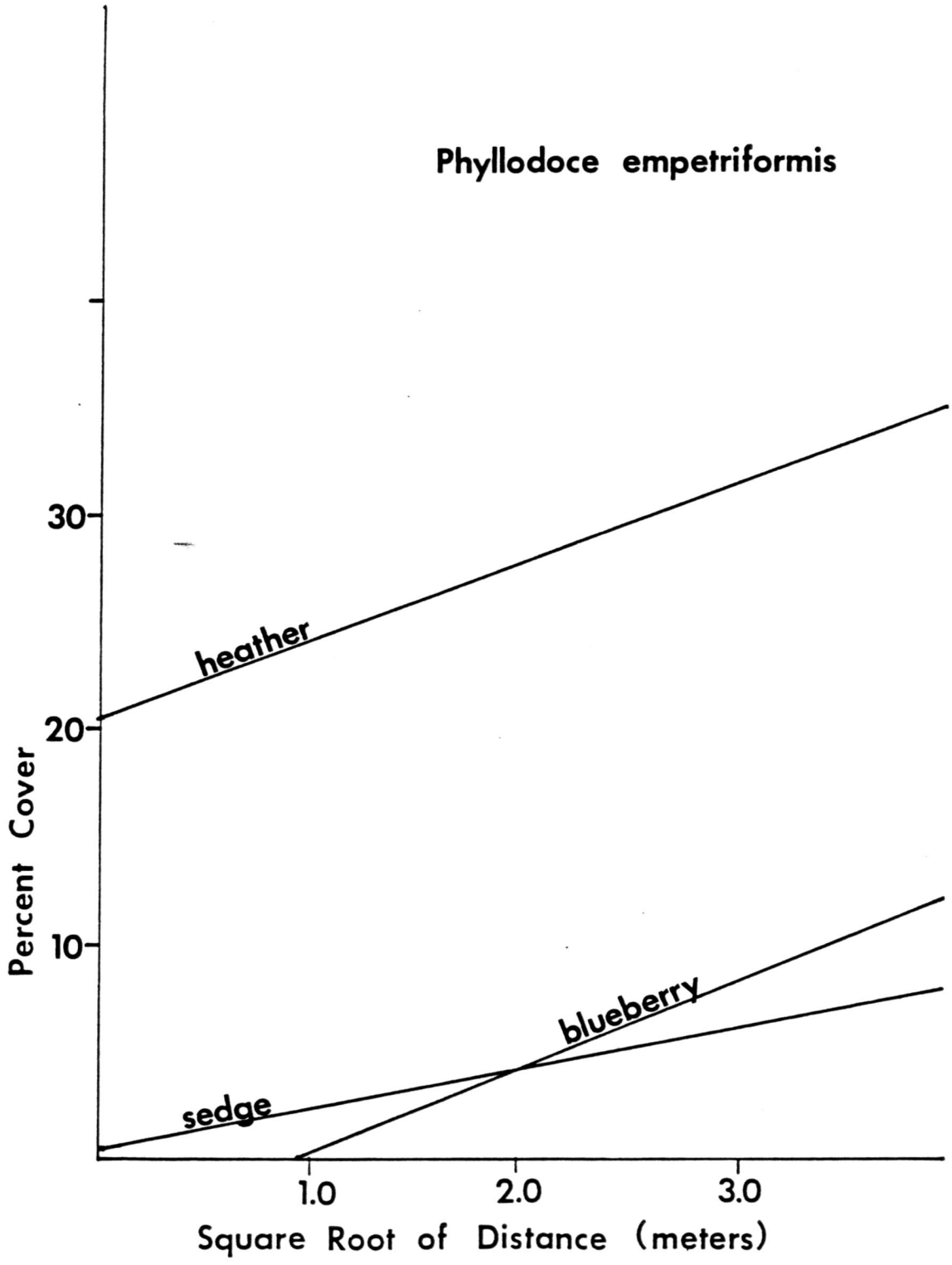


Figure 6. Graph of Linear Regression of Percent Cover on Distance for Phyllodoce empetriformis.

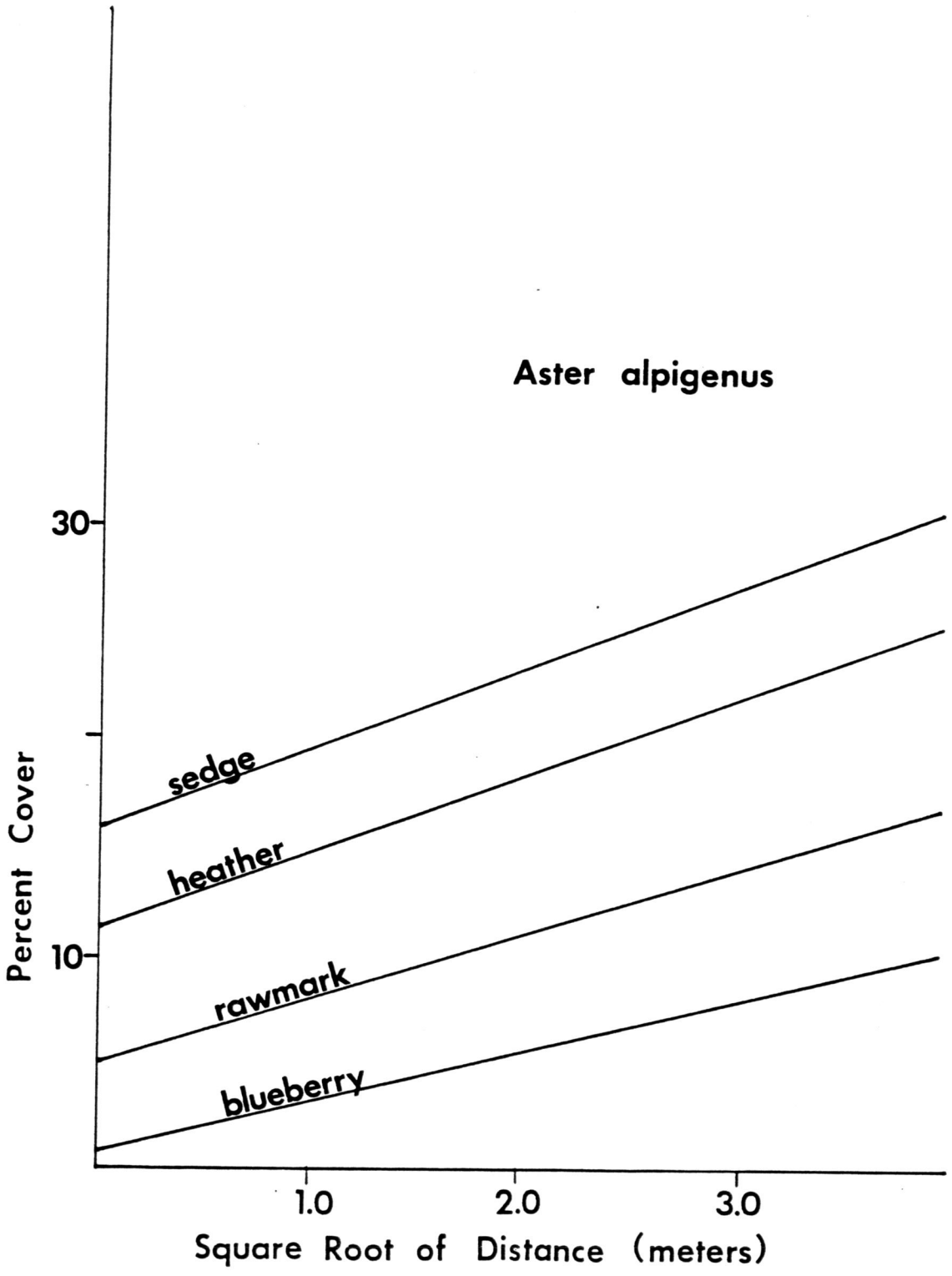


Figure 7. Graph of Linear Regression of Percent Cover on Distance for Aster alpigenus.

showed that species that increased in cover near trails were often more correlated with soil compaction changes than with distance (Table 3). A possible confoundment of this test is that soil compaction itself is significantly correlated with distance when regression tests are run (Table 2). Vaccinium deliciosum, a decreaser near trails in the Cascade Blueberry Dry Meadow Community-Type, was a major exception to this, being more positively correlated with soil compaction than distance. The second major exception occurred in the Rawmark Pumice Community-Type where the change in cover of most of the species present was more correlated with compaction than with distance from the trail.

The analysis of variance and the Chi Square tests proved somewhat less useful in data analysis than the linear regression tests (Appendix B, C). For the most part significant differences in cover and frequency of occurrence happened within 1.0 meters of the trail. Several species exhibited differences up to 2.5 meters away from the trail, these include Arenaria capillaris, Carex nigricans, Castilleja parviflora, Phyllodoce empetriformis, and Rhacomitrium heterostichum. Also the lichen species displayed significant changes up to 2.5 meters away from the trail in several community-types.

Table 3. Multiple Stepwise Regression Results. R^2 Values of Cover as the Dependent Variable with Soil Compaction as an Independent Variable, with Distance as an Independent Variable, and R^2 Values with Soil Compaction and Distance used in a Multiple Stepwise Equation. Values are for selected species only.

Species	R^2 Soil Compaction	R^2 Distance	R^2 Multiple Stepwise
Short Sedge Wet Meadow Community-Type			
Carex spectabilis	0.06529	0.03812	0.06579
Dodecatheon jeffreyi	0.01933	0.00977	0.01933
Juncus mertensianus	0.16658	0.12285	0.17469
Lophozia ventricosa	0.00194	---	0.00325
Moss 1	0.04015	0.02012	0.04150
Moss 3	0.02471	0.00958	0.02502
Stereocaulon species	0.20647	0.20591	0.24235
Mountain Heather Moist Meadow Community-Type			
Juncus parryi	0.16394	0.07435	0.17546
Polytrichum juniperinum	0.08263	0.01041	0.08328
Cascade Blueberry Dry Meadow Community-Type			
Carex nigricans	0.00866	0.00381	0.00866
Carex spectabilis	0.02429	---	0.04416
Luetkea pectinata	0.11227	0.05369	0.11271
Microseris alpestris	0.01211	0.00849	0.05745
Moss 4	0.01026	0.00755	0.01106
Vaccinium deliciosum	0.15418	0.03404	0.16213

Table 3. (continued)

Species	R^2 Soil Compaction	R^2 Distance	R^2 Multiple Stepwise
Rawmark Pumice Community-Type			
Agrostis variabilis	0.17902	0.05128	0.19606
Antennaria alpina	0.10348	0.03784	0.00843
Arenaria capillaris	0.06627	0.02801	0.12127
Aster alpigenus	0.48139	0.06633	0.49079
Bare ground	0.38708	0.18527	0.47246
Carex nigricans	0.11986	0.02212	0.17596
Carex spectabilis	0.31416	0.00650	0.31694
Ligusticum grayi	0.28466	---	0.30214
Lupinus latifolius	0.09564	0.00320	0.09592
Polygonum newberryi	0.05175	0.01634	0.05759

Community Effects

Differences in vegetative composition of communities were measured in several ways. Measurement of the amount of bare ground at different distances from the trail is a rapid method for comparing the effect of trampling between different community-types. Regression of bare ground versus distance from the trail by community-type (Table 2 and Figure 8) indicates that bare ground undergoes the greatest change in the Cascade Blueberry Dry Meadow Community-Type. The Mountain Heather Moist Meadow Community-Type shows less of a change while the Short Alpine Sedge Wet Meadow Community-Type and Rawmark Pumice Community-Type exhibit the least change. The community-types which had the greatest decreases in bare ground with distance from the trail had the greatest cover of woody vegetation.

Community-type sensitivity or susceptibility to treading was also assessed by use of a community similarity index. The index chosen was developed by Spatz in 1970 (Mueller-Dombois and Ellenberg 1974); it compares the presence and absence of species in two communities and also their relative percent covers. This information is then translated into a percent of similarity where indices of greater than 50% denote similar communities and those of less than 50% indicate dissimilar communities.

Each sampled distance within a community-type is considered a separate community and is compared with the assumed minimally-impacted community that is represented by the samples taken at the greatest distance from the trail (15.0 meters for all community-types except

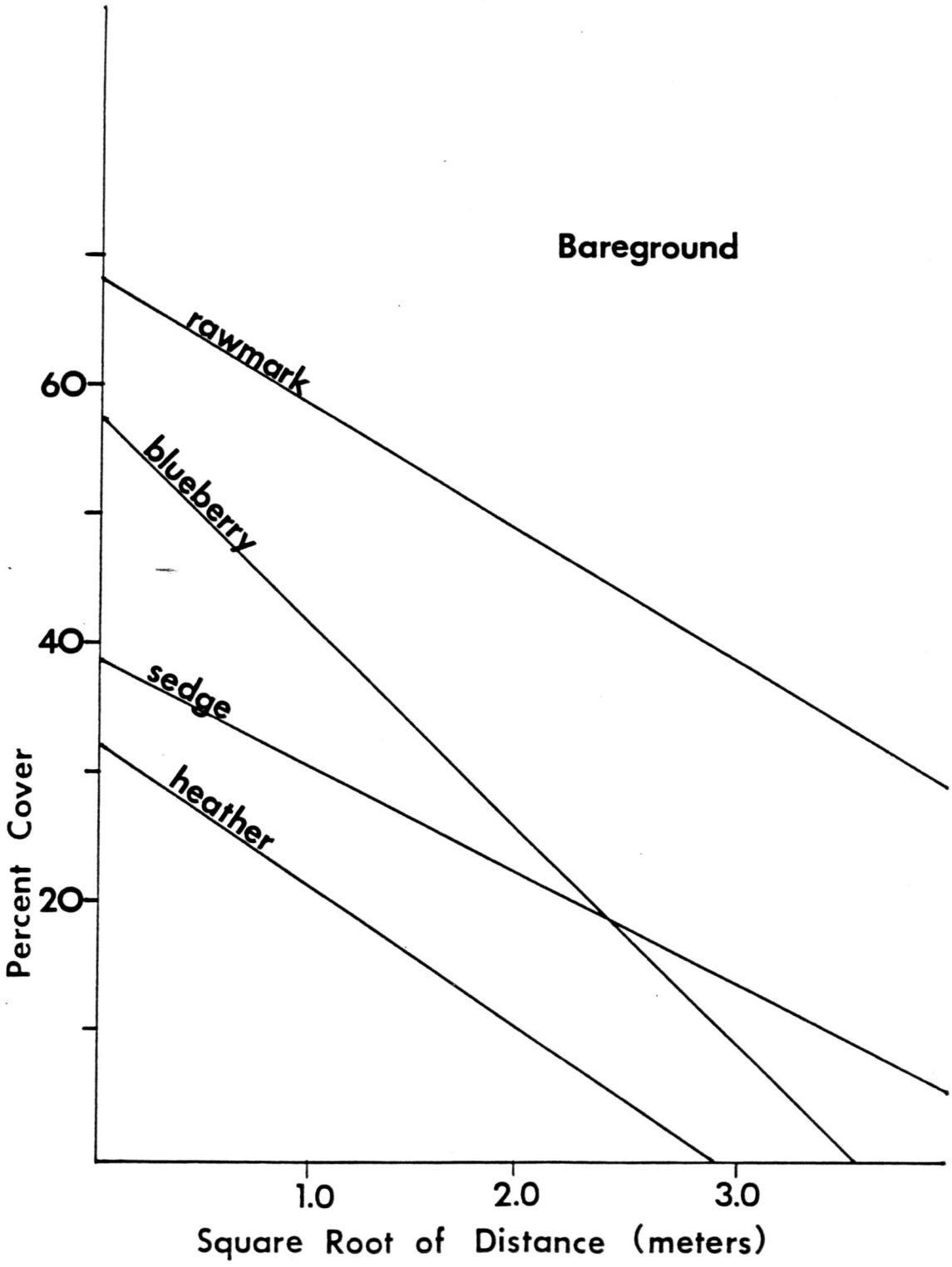


Figure 8. Graph of Linear Regression of Percent Cover on Distance for Bare ground.

the Rawmark Pumice Community-Type in which the last sample taken was at 10.0 meters). The computed similarity indices for the comparisons of each sampled distance with the assumed least impacted community are shown in Table 4 along with regression coefficients and R^2 values for each community-type. This test showed somewhat similar results for all community-types with the Mountain Heather Moist Meadow Community-Type possibly showing greater dissimilarity, ie greater slope, than the others. From Table 4 it can be observed though that the Short Alpine Sedge Wet Meadow Community-Type is the first to reach community similarity (greater than 50% index value) with the assumed idealized, natural community, occurring at 2.5 meters away from the trail. In contrast the Cascade Blueberry Wet Meadow Community-Type never reaches the 50% level of similarity at any of the sampled distances. A graphical analysis of these results is displayed in Figure 9.

Soil Results

Compaction is probably the most important soil variable that was measured. The results of linear regression tests on soil compaction versus distance from the trail are shown in Table 2 where Penemean is the average of the three compaction readings taken in each sampled vegetation quadrat. All community-types except the Rawmark Pumice Community-Type show a significant inverse correlation between compaction and distance, although distinct differences in the magnitude of change in soil compaction exists between community-types (Figure 10). This implies that the soils of each community-type may respond differently

Table 4. Spatz Community Similarity Indices for Community-Types, using arcsin-transformed percent cover values. The similarity index compares the stated distances to the control distances (15.0 or 10.0 meters). 100%=complete similarity, greater than 50%= similarity in a community sense, less than 50%= dissimilarity in a community sense.

	Percent Similarity by Community-Type			
Distance from trail	Short Sedge Wet Meadow	Mt. Heather Moist Meadow	Blueberry Dry Meadow	Rawmark Pumice
0.0 meters	10.87	1.73	0.26	3.27
0.5 meters	31.28	25.32	12.85	20.52
1.0 meters	36.39	35.53	32.78	26.58
2.5 meters	56.42	33.45	36.26	46.05
5.0 meters	55.42	38.62	39.83	38.36
7.5 meters	57.52	57.22	40.45	49.81
10.0 meters	60.71	68.90	43.73	100
15.0 meters	100	100	100	---
Regression Coefficient	14.96	18.05	12.85	15.99
R^2	0.85	0.90	0.80	0.85

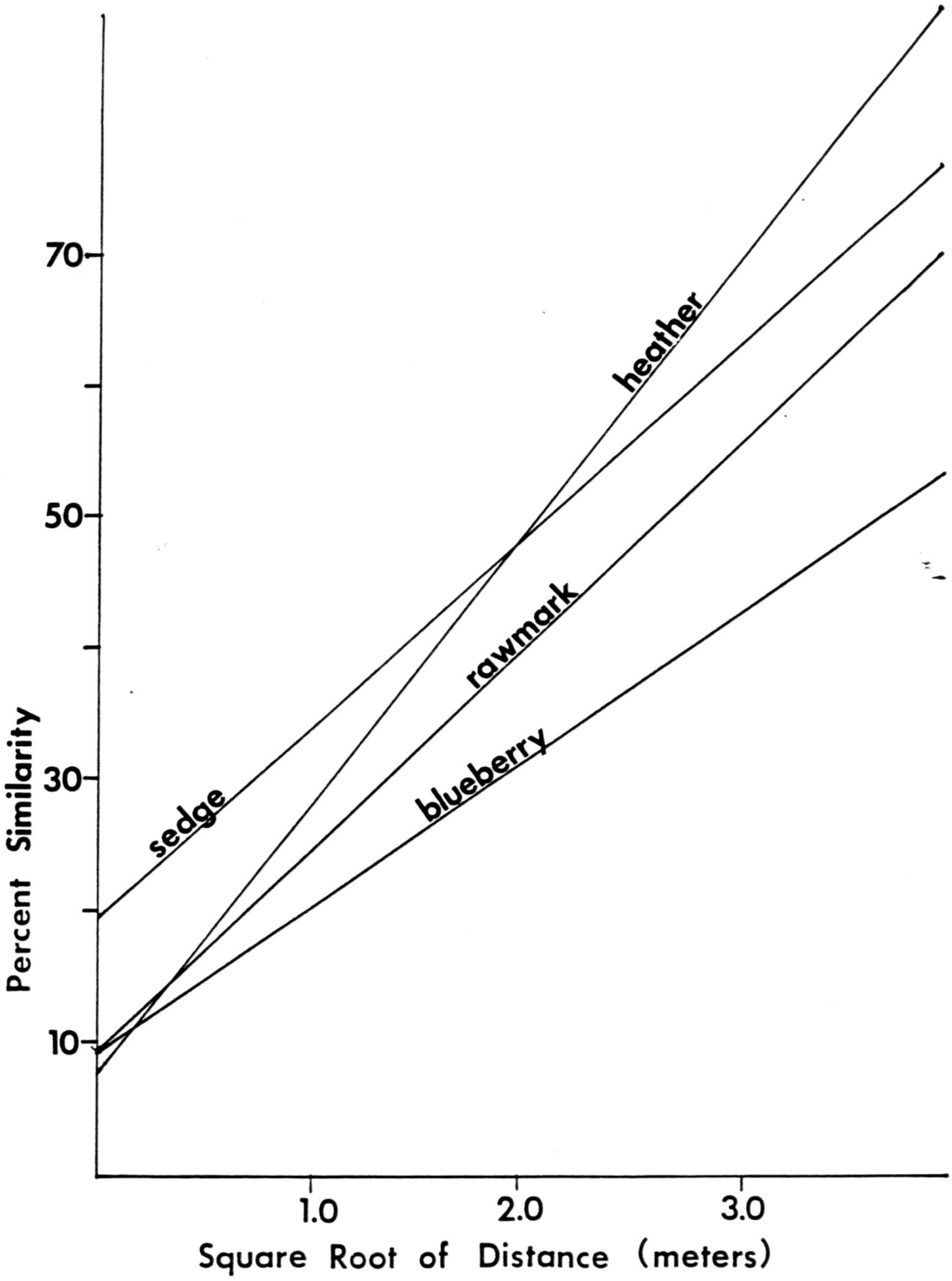


Figure 9. Graph of Linear Regression of Percent Similarity on Distance for Each Community-Type.

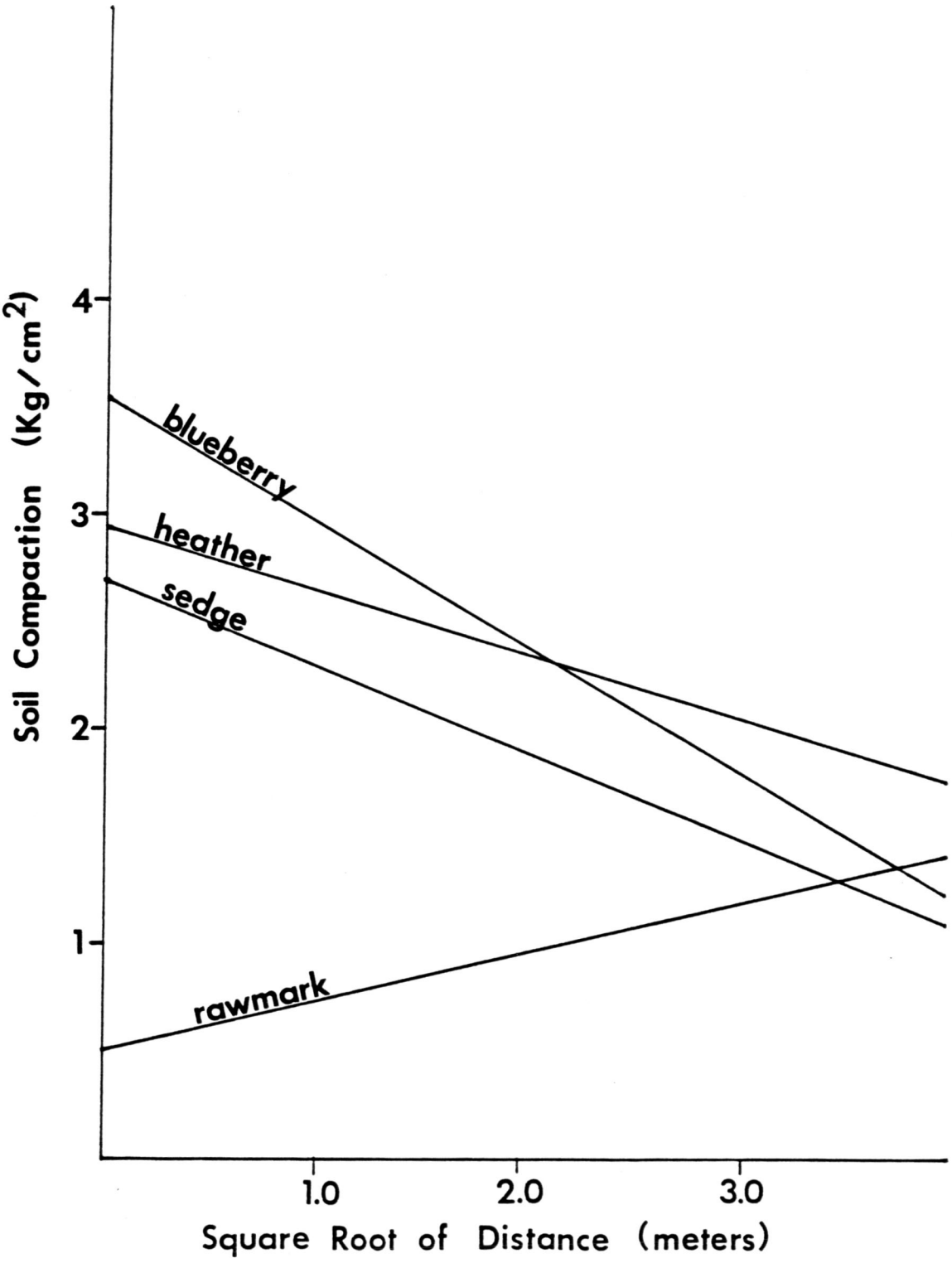


Figure 10. Graph of Linear Regression of Soil Compaction on Distance for Each Community-Type.

to similar amounts of trampling. The exception of the Rawmark Pumice Community-Type is due to the especially gravelly conditions there.

Soil moisture content also differs between community-types. In general there is a trend of significantly increasing soil moisture with distance from the trail in each community-type (Figure 11). It is of interest to note the extremely low values of soil moisture in the Rawmark Pumice Community-Type. Field observations showed an inverse relationship exists between standing surface water and soil moisture.

Other tests showed that soil pH increased slightly near trails while organic matter decreased slightly near trails for all community-types (Appendix D). These results, however, only indicate trends as they were not tested for statistical significance because of the small sample sizes.

Soil texture analysis revealed no clearcut patterns of correlation of percent content of gravel, sand, silt, and clay with distance from the trail over all community-types (Appendix D).

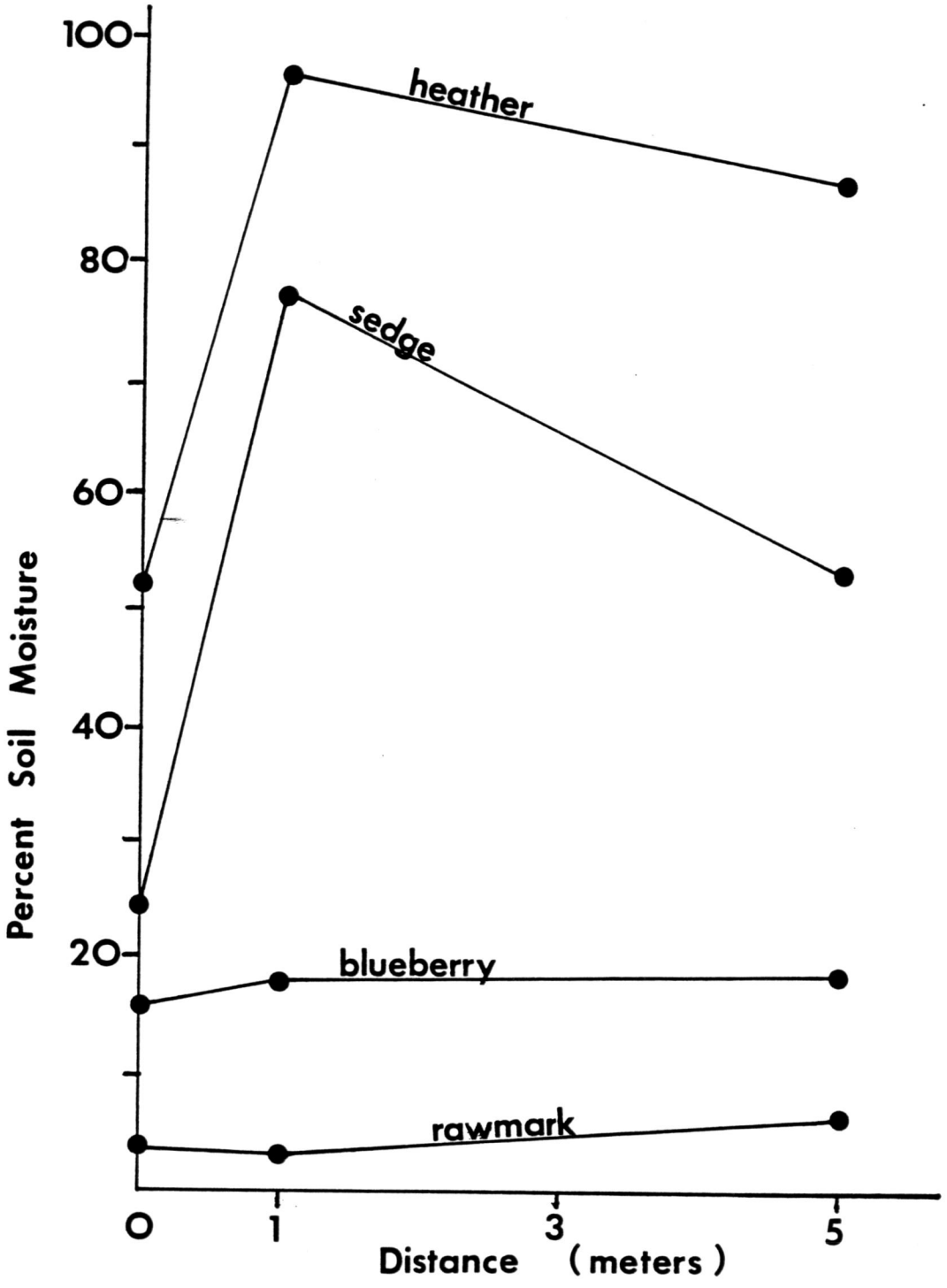


Figure 11. Graph of Soil Moisture Content by Distance from Trail for Each Community-Type.

DISCUSSION

The study in Jefferson Park has shown that recreational use in a wilderness area produces significant alteration of trailside plant communities. The basic research revealed that individual plant species respond differentially to similar amounts of trampling. Furthermore when these species are grouped into plant growth forms - or lifeforms as Raunkiaer termed them (Raunkiaer 1934) - it was observed that the species within a particular group would respond in a similar fashion when examined within the context of a single community-type. However a species can differ in the magnitude of its response to trampling, i.e. amount of change in percent cover, when it is compared between certain community-types. Hence the community-type itself may be thought of as a functional unit in the ecosystem. It influences the response of individual species and groups of species to hiker impact along trails via interactions with soil, water, and vegetation.

In examining the resistance or susceptibility of groups of plants some generalizations can be made. First it is evident that Graminoid species - sedges, rushes, and grasses - are very resistant to trampling and can even take advantage of bared, disturbed ground where other less resistant species once grew. It is easy to understand why Graminoids have this resistance when one examines their growth char-

acteristics and evolutionary history. Graminoids are characterized as having basal, as opposed to apical, meristematic tissue; thus their perennating organs are protected from trampling damage. Also the rhizomatous, sod-forming growth habit makes them ready candidates for invasion of disturbed ground and also aids their resistance to removal. Evolutionarily we think of Graminoids as coevolving with the grazing and trampling pressures pressures of grazing animals in which case basal meristems and rhizomatous habit would aid survival. Rushes and sedges are adapted to trampling and also hydric conditions, both of which occur along trailsides.

In contrast, no other group of plants has this unique combination of traits. The woody dicots with their apical meristematic tissue and aerial branches are prone to breakage. The herbaceous dicots likewise are prone to mechanical damage from trampling; even when their perennating organs are at the soil surface (Aster alpigenus) they don't possess the sod-forming capability of Graminoids. Some of the herbs do, though, seem to respond positively to increased surface water near the trails and show no significant change in cover. These include Castilleja parviflora, Dodecatheon jeffreyi, Arenaria capillaris, and Antennaria alpina, in at least one of the community-types where they are found . The lichens appear to be very susceptible to trampling because of soft tissues and lack of a root system. Finally, the bryophytes respond variously to trampling. They would seem to be susceptible not having a root system and possessing fleshy leaves. Yet they persist near trails where standing water occurs. The mimicking

of alpine bryophyte-snowbed community characteristics by the late snowmelt and resulting cold surface water gives them a competitive advantage to invade bare ground (Holway and Ward 1963), as even detached stems can renew growth readily in some species (Studlar 1980).

Therefore plant community sensitivity is an interaction of many ecosystem variables and user behavior variables. The latter set of factors has not been discussed in this project because it would entail a great deal more additional research to begin to understand its implications for community-type sensitivity and wildlands management. However we are beginning to understand how soil and vegetation parameters affect the sensitivity of Cascade subalpine meadow plant communities.

It is not possible to choose an absolutely most resistant and a most susceptible community-type, as not all of the measures of sensitivity to hiker effects are in complete agreement (Table 5). Nevertheless some generalizations are possible. The old belief that wet habitats are more fragile than dry habitats appears not to be supported by this study, for the Short Alpine Sedge Wet Meadow Community-Type and the dry Rawmark Pumice Community-Type are both highly resistant, as judged by the distance where the Community Similarity Index is greater than 50%. The Cascade Blueberry Dry Meadow Community-Type and Mountain Heather Moist Meadow Community-Type exhibit less resistance to trampling with varying results as to which community-type is the least resistant. The bare ground regression coefficients (slope) are also in agreement with this ordering of community-type sensitivity with the

Table 5. Community-Type Sensitivity as Compared by Several Parameters.

Community-Type	Soil Moisture	Bare Ground Regression Coefficient	Soil Compaction Regression Coefficient	Percent Cover of Woody Species	Combined Percent Silt & Clay Particles	Community Similarity Index Regression Coefficient	Distance at Which Similarity Index Greater Than 50%
Short Sedge Wet Meadow	Wet	-8.849	-0.409	16%	11.23%	14.964	2.5 meters
Mt. Heather Moist Meadow	Moist	-11.015	-0.298	68%	40.98%	18.046	7.5 meters
Blueberry Dry Meadow	Drier	-16.251	-0.589	37%	26.48%	12.848	greater than 10.0 meters
Rawmark Pumice	Driest	-8.933	0.249	0%	8.21%	15.993	2.5 meters

Cascade Blueberry Dry Meadow Community-Type showing the greatest change in amount of bare ground and thus the greatest sensitivity (least resistance) to trampling effects.

Soil factors, such as compaction and the percent of small particles (silt and clay) offer a somewhat different ordering of community-type sensitivity. Soil compaction regression coefficients show the Rawmark Pumice and the Mountain Heather Moist Meadow Community-Types as being least affected, although the changes in compaction occur in different directions. The Short Alpine Sedge Wet Meadow Community-Type and Cascade Blueberry Dry Meadow Community-Type follow respectively. The combined percent of small soil particles, which is correlated with erosion potential (Butzer 1976) and compaction potential, shows community-type sensitivity increasing from the Rawmark Pumice and Short Alpine Sedge Wet Meadow Community-Types to the Cascade Blueberry Dry Meadow and Mountain Heather Moist Meadow Community-Types respectively. This finding corresponds well with the increased cover of bryophytes found alongside the trail in runoff channels in the Mountain Heather Moist Meadow Community-Type.

A new composite indicator of community susceptibility may include the amount of woody plants in the community-types, as the Short Alpine Sedge Wet Meadow and Rawmark Pumice Community-Types are almost devoid of shrubby species while the Mountain Heather Moist Meadow and Cascade Blueberry Dry Meadow Community-Types have woody species cover of 68% and 37% respectively.

Management Implications

With the sustained heavy use that Jefferson Park and numerous other popular backcountry sites receive, the impact on trails and campsites is inevitable. The wilderness manager is thus faced with a seemingly impossible task and equipped with less than adequate tools and techniques to alleviate the problem. Campsite closure, visitor dispersal, trail relocation, and backcountry reservation systems are just a few of the tools of the wilderness manager. All have social, ecological, and monetary costs involved and are often implemented too late to prevent irreversible ecological changes at wilderness sites (Cole 1981).

In the Willamette National Forest, which manages the portion of the Mt. Jefferson Wilderness Area that contains Jefferson Park, proposals have been made to divide the wilderness into zones of "primitivness" for management purposes. A three zone system of semi-primitive, primitive with trails, and primitive without trails has been proposed. The primary management actions involved in the zone system are variable amounts of trail maintenance and campsite improvements such as pit toilets, the intent being to channel visitor use to certain areas by providing certain attractive amenities - toilets and high standard trails for instance. Under this system Jefferson Park would most likely be managed as semi-primitive.

Several obvious problems arise with the zone system concept of wilderness management. First, the zone system acts to weaken the wilderness concept as identified in the Wilderness Act of 1964 by using

management actions that are more consistent with non-wilderness recreational areas than wilderness areas. Second, the act of creating zones for management may be interpreted as needlessly creating sacrifice areas in wilderness and causing more degradation of certain areas that in truth need more protection from hiker overuse. And third, the zoning of wilderness will undoubtedly cause many plant community-types to be lumped together under a certain type of management plan and thus actions, which have variable ecological effects depending on the community-type involved. The research conducted in this project has shown that community-types respond differentially to hiker use; therefore the management of wilderness use should take this into account when designing management plans.

The focus of wilderness management should be a biocentric approach (Hendee and Stankey 1973) as opposed to the anthropocentric approach that has predominated up until the recent past. Plant community-types must be acknowledged when trails are built. And early signs of overuse, like dramatic increases of bare ground and changes in plant community composition near trails, need to be detected and acted upon quickly before long-lasting damage to the ecosystem occurs. With a minimum of training wilderness rangers could play an important role in noticing early signs of environmental change along trails, i.e. the disappearance of lichens and increased cover of Graminoids. Thus deterioration of popular wilderness sites may be held in check with proper management of visitor use. As has been pointed out before, wilderness alteration occurs within a very short time (Harvey, et al

1972) and severe site damage, such as loss of soil, may require 1000 years or longer to recover (Willard and Marr 1971).

When asked by wilderness managers, " Well, what can we do?", I usually preface my remarks by saying that there are no easy solutions, then state that a first step is to limit use in already overused areas to prevent any further degradation there. The encouragement of use of locally dispersed small, permanent campsites in popular areas (Cole 1981) would tend to establish and maintain social and ecological carrying capacities if new campsites are also prohibited. Administrators in the North Cascades National Park in Washington have begun limiting visitors in the backcountry by restricting their numbers in certain fragile and overused areas. The system is implemented in the ranger station where the user must detail his or her trip plans as to proposed campsites. Different areas of different sizes are assigned carrying capacities that are related to available campsites and site fragility. In extreme cases closure of damaged areas to camping may be the only action that will have a significant effect. Public education is also a panacea referred to, but the public not only needs to be educated about zero impact camping techniques but also about alternative recreation possibilities in less used roadless areas.

The importance of maintaining natural ecosystems for recreational uses, for scientific study, and for their inherent biological integrity cannot be overstated. If we are to succeed in preventing any further damage to already damaged areas and in preserving the remaining pristine sites for eternity we will need sensitive wilderness manage-

ment coupled with responsible visitor use.

Out of wilderness has come the substance of our culture, and with a living wilderness ... we shall have also a vibrant, vital culture, an enduring civilization of healthful, happy people who perpetually renew themselves in contact with the earth.

We are not fighting progress, we are making it.

Howard Zahniser

APPENDIX A

Table 1
Species Sampled in Jefferson Park

Graminoids

Agrostis variabilis Rydb.	variant bentgrass
Carex nigricans Retz	black alpine sedge
Carex spectabilis Dewey	showy sedge
Juncus mertensianus Bong.	Merten's rush
Juncus parryi Engelm.	Parry's rush

Herbs

Antennaria alpina (L.) Gaertn. var. media (Greene) Jeps.	alpine pussytoes
Arenaria capillaris Poir. var. americana (Mag.) Davis	mountain sandwort
Aster alpigenus (T.&G.) Gray var. alpigenus	alpine aster
Aster ledophyllus Gray var. ledophyllus	Cascade aster
Caltha biflora DC. var. biflora	marsh marigold
Cassiope mertensiana (Bong.) G. Don var. mertensiana	white mountain heather
Dodecatheon jeffreyi van Houtte	Cascade shooting star
Gentiana calycosa Griseb. var. calycosa	mountain bog gentain
Hieracium gracile Hook.	alpine hawkweed
Kalmia microphylla (Hook.) Heller	alpine laurel
Ligusticum grayi Coult. & Rose	Gray's lovage
Luetkea pectinata (Pursh) Kuntze	partridgefoot
Lupinus latifolius Agardh. var. latifolius	broad-leaf lupine
Lycopodium sitchense Rupr.	Alaskan clubmoss
Microseris alpestris (Gray) Q.Jones	alpine microseris
Phyllodoce empetriformis (Sw.) D. Don	red mountain heather
Polygonum newberryi Small var. newberryi	Newberry's fleeceflower
Potentilla flabellifolia Hook.	fan-leafed cinquefoil
Spraguea umbellata Torr. var. caudicifera Gray	pussypaws

Conifers

Abies lasiocarpa (Hook.) Nutt.	subalpine fir
Tsuga mertensiana (Bong.) Carr.	mountain hemlock

Bryophytes

Aulocomnium palustre (Hedw.) Schwaegr.
Lophozia ventricosa (Dicks.) Dumort.
Marsupella emarginata (Ehrh) Dumort.
Moss 1
Moss 3
Moss 4
Moss 5
Moss 7
Polytrichum juniperinum Hedw.
Rhacomitrium heterostichum (Hedw.) Brid.

Lichens

Cladonia species
Stereocaulon species

APPENDIX A

Table 2
Mean Percent Covers and Standard Errors with Regards to Distance from Trail and Community-Type

Short Alpine Sedge Wet Meadow Community-Type

Species	0.0m	0.5m	1.0m	2.5m	5.0m	7.5m	10.0m	15.0m
Agrostis variabilis	0.12 (0.03)	0.12 (0.04)	0.67 (0.07)	0.22 (0.03)	0.14 (0.04)	0.01 (0.01)	0	0.01 (0.01)
Aster alpigenus	0.01 (0.01)	20.44 (0.07)	15.74 (0.26)	22.65 (0.13)	19.94 (0.11)	22.08 (0.09)	23.64 (0.08)	14.95 (0.12)
Bareground	82.88 (0.45)	12.82 (0.21)	14.11 (0.60)	5.23 (0.24)	3.48 (0.30)	6.33 (0.29)	3.54 (0.33)	10.86 (0.38)
Carex nigricans	0.70 (0.11)	32.73 (0.24)	27.90 (0.31)	21.56 (0.13)	18.74 (0.18)	20.89 (0.10)	18.21 (0.10)	9.84 (0.15)
Carex spectabilis	0.13 (0.06)	0.53 (0.14)	0.18 (0.04)	0.01 (0.01)	0.08 (0.08)	0.01 (0.01)	0	0
Castilleja parviflora	0	0	0	0.05 (0.02)	0.03 (0.01)	0.05 (0.05)	0.05 (0.01)	0.02 (0.01)
Cladonia species	0	0.01 (0.01)	0.29 (0.02)	1.06 (0.03)	2.12 (0.05)	1.81 (0.03)	2.29 (0.04)	2.00 (0.04)
Dodecatheon jeffreyi	0	0	0.13 (0.09)	0.09 (0.02)	0.04 (0.01)	0.05 (0.02)	0.02 (0.01)	0.12 (0.03)
Gentiana calycosa	0.01 (0.01)	0.12 (0.02)	0.22 (0.02)	0.78 (0.04)	0.64 (0.05)	0.40 (0.03)	0.52 (0.04)	0.44 (0.04)
Juncus mertensianus	0.43 (0.05)	0.04 (0.02)	0.05 (0.02)	0	0	0	0	0
Kalmia microphylla	0	0.53 (0.08)	0.12 (0.02)	2.47 (0.20)	0.96 0.08)	0.54 (0.09)	1.04 (0.08)	1.59 (0.09)

APPENDIX A (cont.)

Species	0.0m	0.5m	1.0m	2.5m	5.0m	7.5m	10.0m	15.0m
Lophozia ventricosa	0.01 (0.01)	0.03 (0.01)	0	0	0	0	0.01 (0.01)	0.01 (0.01)
Marsupella emarginata	0.23 (0.04)	1.65 (0.07)	2.70 (0.12)	3.89 (0.06)	5.32 (0.12)	5.18 (0.24)	4.32 (0.09)	3.08 (0.08)
Moss 1	0.08 (0.04)	0.01 (0.01)	0.06 (0.03)	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0
Moss 3	0	0	0.01 (0.01)	0.01 (0.01)	0.09 (0.03)	0	0	0.03 (0.01)
Moss 4	0	0	0	0	0	0.16 (0.03)	0.17 (0.05)	0.02 (0.02)
Phyllodoce empetriformis	0	0.05 (0.05)	0.02 (0.01)	1.87 (0.26)	1.19 (0.17)	1.17 (0.18)	1.03 (0.25)	2.47 (0.33)
Polytrichum juniperinum	1.94 (0.12)	3.89 (0.02)	5.48 (0.20)	6.88 (0.12)	9.19 (0.18)	11.58 (0.18)	8.18 (0.10)	7.12 (0.18)
Rhacomitrium heterostichum	0	0.04 (0.02)	0.05 (0.02)	1.32 (0.12)	1.25 (0.06)	1.20 (0.14)	3.30 (0.32)	1.86 (0.16)
Stereocaulon species	0	0.01 (0.01)	0.32 (0.02)	1.00 (0.03)	2.18 (0.07)	0.64 (0.04)	0.99 (0.03)	1.78 (0.03)

APPENDIX A (cont.)

Mountain Heather Moist Meadow Community-Type

Species	0.0m	0.5m	1.0m	2.5m	5.0m	7.5m	10.0m	15.0m
Agrostis variabilis	0.05 (0.01)	0.05 (0.02)	0.05 (0.01)	0.02 (0.01)	0.02 (0.01)	0	0	0
Antennaria alpina	0	0.01 (0.01)	0.03 (0.03)	0	0	0	0	0
Aster alpigenus	0	9.93 (0.08)	11.50 (0.17)	15.13 (0.08)	14.18 (0.07)	12.83 (0.09)	12.24 (0.10)	13.20 (0.14)
Aulocomnium palustre	0	1.55 (0.33)	0.19 (0.06)	0.29 (0.14)	0.23 (0.14)	0	0	0
Bareground	85.34 (0.61)	2.62 (0.28)	0.22 (0.07)	0.03 (0.03)	1.08 (0.14)	0.64 (0.20)	0	0.14 (0.06)
Caltha biflora	0	0	0	0	0	0.28 (0.04)	0.42 (0.09)	0.44 (0.08)
Carex nigricans	3.75 (0.52)	2.29 (0.15)	0.91 (0.05)	0.08 (0.02)	1.12 (0.10)	3.48 (0.14)	5.72 (0.15)	6.13 (0.22)
Cassiope mertensiana	0	2.12 (0.15)	2.99 (0.30)	2.44 (0.25)	1.17 (0.23)	2.26 (0.23)	0.82 (0.18)	1.15 (0.30)
Castilleja parviflora	0	0.18 (0.04)	0.24 (0.04)	0.29 (0.03)	0	0.08 (0.02)	0.04 (0.02)	0
Cladonia species	0	0.19 (0.03)	0.53 (0.06)	1.88 (0.04)	1.37 (0.03)	1.22 (0.03)	0.34 (0.03)	0.38 (0.03)
Dodecatheon jeffreyi	0	0.35 (0.04)	0.24 (0.02)	0.02 (0.01)	0.27 (0.02)	0.67 (0.04)	0.73 (0.02)	1.15 (0.03)
Gentiana calycosa	0	0.84 (0.03)	0.84 (0.03)	0.28 (0.04)	0.56 (0.04)	1.46 (0.04)	2.09 (0.03)	2.22 (0.02)

APPENDIX A (cont.)

Species	0.0m	0.5m	1.0m	2.5m	5.0m	7.5m	10.0m	15.0m
Juncus mertensianus	1.69 (0.35)	0.01 (0.01)	0.01 (0.01)	0	0	0	0	0
Juncus parryi	0.27 (0.06)	0	0	0	0	0	0	0
Kalmia microphylla	0	1.19 (0.07)	3.31 (0.27)	1.77 (0.12)	1.97 (0.19)	6.08 (0.20)	10.48 (0.30)	13.97 (0.22)
Ligusticum grayi	0	0	0.02 (0.01)	0.02 (0.01)	0.01 (0.01)	0	0	0.22 (0.22)
Lycopodium sitchense	0	0	0	0	0.33 (0.33)	0.01 (0.01)	0.22 (0.11)	0.29 (0.22)
Marsupella emarginata	0	1.79 (0.15)	0.48 (0.14)	0.09 (0.04)	0.59 (0.09)	0.20 (0.05)	0.04 (0.02)	0.12 (0.04)
Moss 4	0	0	0.05 (0.02)	0.05 (0.02)	0	0.02 (0.01)	0.01 (0.01)	0
Moss 5	0	0	0.60 (0.18)	0.30 (0.06)	0.03 (0.01)	0.84 (0.13)	1.05 (0.18)	0.74 (0.12)
Moss 7	0	0.03 (0.03)	0	0	0	0	0	0
Phyllodoce empetriformis	0	24.38 (0.46)	25.38 (0.55)	42.99 (0.08)	40.25 (0.41)	30.82 (0.46)	15.18 (0.58)	22.58 (0.52)
Polytrichum juniperinum	0	11.96 (0.52)	6.23 (0.52)	5.93 (0.21)	12.01 (0.37)	3.09 (0.17)	5.95 (0.28)	3.92 (0.11)
Rhacomitrium heterostichum	0	4.34 (0.14)	1.17 (0.16)	2.55 (0.13)	1.16 (0.17)	0.42 (0.06)	0.59 (0.16)	0.05 (0.02)

APPENDIX A (cont.)

Species	0.0m	0.5m	1.0m	2.5m	5.0m	7.5m	10.0m	15.0m
Stereocaulon species	0	0.06 (0.03)	0.08 (0.02)	0.23 (0.04)	0.10 (0.02)	0.02 (0.01)	0	0
Vaccinium deliciosum	0	4.42 (0.22)	8.83 (0.38)	12.58 (0.30)	6.29 (0.50)	12.20 (0.32)	6.88 (0.44)	6.23 (0.37)

APPENDIX A (cont.)

Cascade Blueberry Dry Meadow Community-Type

Species	0.0m	0.5m	1.0m	2.5m	5.0m	7.5m	10.0m	15.0m
Agrostis variabilis	0	0	0.04 (0.02)	0.01 (0.01)	0.03 (0.02)	0.12 (0.03)	0.01 (0.01)	0.04 (0.02)
Antennaria alpina	0	0	0	0	0.04 (0.02)	0.99 (0.20)	0.10 (0.02)	0
Arenaria capillaris	0	0	0.06 (0.02)	0	0	0.08 (0.02)	0.07 (0.01)	0.03 (0.01)
Aster alpigenus	0	0.07 (0.01)	0.84 (0.08)	0.32 (0.04)	1.02 (0.20)	3.90 (0.26)	1.64 (0.08)	2.29 (0.14)
Bareground	94.13 (0.35)	70.69 (0.58)	23.27 (0.90)	1.56 (0.34)	2.60 (0.49)	2.80 (0.28)	4.23 (0.52)	3.81 (0.74)
Carex nigricans	0	0	0.65 (0.22)	0.03 (0.03)	0.14 (0.08)	0.34 (0.06)	0.03 (0.01)	0.08 (0.04)
Carex spectabilis	0	0.06 (0.03)	0.08 (0.02)	0.46 (0.09)	0.07 (0.01)	0.01 (0.01)	0.02 (0.01)	0.04 (0.02)
Castilleja parviflora	0	0.04 (0.02)	0.05 (0.03)	0.14 (0.03)	0.04 (0.01)	0.57 (0.05)	0.10 (0.02)	0.27 (0.04)
Cladonia species	0	0	0.01 (0.01)	0.04 (0.02)	0	0.16 (0.03)	0.12 (0.03)	0.19 (0.05)
Ligusticum grayi	0	0	0.02 (0.01)	0.01 (0.01)	0.09 (0.02)	0.09 (0.02)	0.10 (0.02)	0.17 (0.03)
Luetkea pectinata	0	4.91 (0.59)	2.48 (0.25)	1.95 (0.15)	2.09 (0.09)	7.30 (0.47)	5.18 (0.16)	3.54 (0.18)
Microseris alpestris	0	0.01 (0.01)	0.04 (0.01)	0.02 (0.01)	0	0	0	0

APPENDIX A (cont.)

Species	0.0m	0.5m	1.0m	2.5m	5.0m	7.5m	10.0m	15.0m
Moss 4	0	0	0	0.10 (0.02)	0.35 (0.12)	0.08 (0.02)	0	0.01 (0.01)
Phyllodoce empetriformis	0	0	0	0	0.49 (0.30)	1.68 (0.41)	0.06 (0.03)	14.95 (0.94)
Polytrichum juniperinum	0	0.01 (0.01)	12.85 (0.79)	25.97 (0.65)	38.57 (0.50)	23.88 (0.42)	36.92 (1.04)	27.85 (0.77)
Rhacomitrium heterostichum	0	0	0.01 (0.01)	0.13 (0.04)	0.01 (0.01)	0.17 (0.05)	0	0.21 (0.06)
Stereocaulon species	0	0	0	0	0	0	0.03 (0.01)	0.04 (0.02)
Vaccinium deliciosum	0	3.87 (0.34)	13.30 (0.41)	21.75 (0.33)	30.01 (0.36)	11.41 (0.79)	13.05 (0.69)	2.80 (0.57)
Juncus parryi	0	0	0.65 (0.22)	0.64 (0.13)	1.35 (0.20)	1.03 (0.10)	0.39 (0.06)	0.22 (0.15)

APPENDIX A (cont.)

Rawmark Pumice Community-Type

Species	0.0m	0.5m	1.0m	2.5m	5.0m	7.5m	10.0m
Agrostis variabilis	0	0	0	0.02 (0.01)	0.03 (0.01)	0.05 (0.01)	0.02 (0.01)
Antennaria alpina	0	0	0.24 (0.09)	0.04 (0.02)	0	1.74 (0.34)	0.09 (0.04)
Arenaria capillaris	0	2.16 (0.21)	2.16 (0.09)	5.71 (0.06)	3.87 (0.08)	2.02 (0.08)	0.85 (0.09)
Aster alpigenus	0.01 (0.01)	4.83 (0.47)	4.24 (0.44)	1.89 (0.23)	1.74 (0.18)	7.76 (0.29)	6.27 (0.30)
Bareground	97.50 (0)	63.68 (0.52)	54.31 (1.19)	69.41 (0.48)	62.55 (1.00)	53.38 (0.67)	40.25 (0.86)
Carex nigricans	0	2.35 (0.28)	1.05 (0.22)	0	0	0	0
Carex spectabilis	0	0.47 (0.08)	0.67 (0.10)	0.96 (0.15)	0.74 (0.20)	0.58 (0.21)	0.17 (0.04)
Juncus parryi	0	0.02 (0.01)	0	0.06 (0.03)	0	0.28 (0.10)	0
Ligusticum grayi	0	0.11 (0.04)	0.10 (0.03)	0.01 (0.01)	0.18 (0.05)	0.02 (0.01)	0
Lupinus latifolius	0	0	1.31 (0.40)	0.07 (0.07)	1.32 (0.62)	0.50 (0.25)	0
Polygonum newberryi	0	6.75 (0.91)	2.81 (0.66)	0.07 (0.07)	0.65 (0.34)	0	0.29 (0.14)

APPENDIX A (cont.)

Species	0.0m	0.5m	1.0m	2.5m	5.0m	7.5m	10.0m
Polytrichum juniperinum	0	0	0.94 (0.21)	3.90 (0.63)	6.18 (0.65)	15.87 (0.48)	27.57 (0.65)
Rhacomitrium heterostichum	0	0	0.13 (0.08)	0.16 (0.08)	0.01 (0.01)	0.49 (0.17)	2.00 (0.42)
Spraguea umbellata	0	0.04 (0.02)	0.01 (0.01)	0.15 (0.02)	0.18 (0.03)	0.06 (0.01)	0.18 (0.04)

APPENDIX B

Results of Analysis of Variance Tests
*= p=.05, **= p=.01 (F-test)

Short Alpine Sedge Wet Meadow Community-Type

		Contrasts between distances						
		0.0-0.5	0.5-1.0	1.0-2.5	2.5-5.0	5.0-7.5	7.5-10	10-15
Species	F	1	2	3	4	5	6	7
Agrostis variabilis	0.04		*					
Aster alpigenus	0.00	**						*
Carex nigricans	0.00	**						*
Carex spectabilis	0.19							
Castilleja parviflora	0.53							
Cladonia species	0.00			*				
Dodecatheon jeffreyi	0.60							
Gentiana calycosa	0.03							
Juncus mertensianus	0.00	**						
Kalmia microphylla	0.00			**				
Lophozia ventricosa	0.72							
Moss 1	0.70							
Moss 3	0.23					*		
Moss 4	0.04					*		
Marsupella emarginata	0.00							
Phyllodoce empetriformis	0.03			*				
Polytrichum juniperinum	0.01							
Rhacomitrium heterostichum	0.00			*				
Stereocaulon species	0.00				*	*		
Bare ground	0.00	**						

APPENDIX B (cont.)

Mountain Heather Moist Meadow Community-Type

		Contrasts between distances						
		0.0-0.5	0.5-1.0	1.0-2.5	2.5-5.0	5.0-7.5	7.5-10	10-1
Species	F	1	2	3	4	5	6	7
Agrostis variabilis	0.34							
Antennaria alpina	0.62							
Aster alpigenus	0.00	**						
Aulocomnium palustre	0.03	**	*					
Caltha biflora	0.00					*		
Carex nigricans	0.00							
Cassiope mertensiana	0.17	*						
Castilleja parviflora	0.03	*			*			
Cladonia species	0.00			**			*	
Dodecatheon jeffreyi	0.00	*						
Gentiana calycosa	0.00	**	*			*		
Juncus mertensianus	0.00	**						
Juncus parryi	0.00	**						
Kalmia microphylla	0.00							
Ligusticum grayi	0.53							
Lycopodium sitchense	0.53							
Marsupella emarginata	0.02	**						
Moss 4	0.44							
Moss 5	0.05							
Moss 7	0.45	*	*					
Phyllodoce empetriformis	0.00	**		*			*	

APPENDIX B (cont.)

		Contrasts between distances						
		0.0-0.5	0.5-1.0	1.0-2.5	2.5-5.0	5.0-7.5	7.5-10	10-15
Species	F	1	2	3	4	5	6	7
Polytrichum juniperinum	0.00	**				*		
Rhacomitrium heterostichum	0.00	**	*					
Stereocaulon species	0.18							
Vaccinium deliciosum	0.00	**						
Bare ground	0.00	**	*					

APPENDIX B (cont.)

Cascade Blueberry Dry Meadow Community-Type

		Contrasts between distances						
		0.0-0.5	0.5-1.0	1.0-2.5	2.5-5.0	5.0-7.5	7.5-10	10-15
Species	F	1	2	3	4	5	6	7
Agrostis variabilis	0.38							
Antennaria alpina	0.00					**	**	
Arenaria capillaris	0.13							
Aster alpigenus	0.00					*		
Carex nigricans	0.18		*	*				
Carex spectabilis	0.12							
Castilleja parviflora	0.04					**	*	
Cladonia species	0.05					*		
Juncus parryi	0.09							
Ligusticum grayi	0.08							
Luetkea pectinata	0.01	**						
Microseris alpestris	0.33							
Moss 4	0.04							
Phyllodoce empetriformis	0.00							**
Polytrichum juniperinum	0.00		**					
Rhacomitrium heterostichum	0.15							
Stereocaulon species	0.24							
Vaccinium deliciosum	0.00	*				**		*
Bare ground	0.00	**	**	**				

APPENDIX B (cont.)

Rawmark Pumice Community-Type

		Contrasts between distances					
		0.0-0.5	0.5-1.0	1.0-2.5	2.5-5.0	5.0-7.5	7.5-10
Species	F	1	2	3	4	5	6
Agrostis variabilis	0.24						
Antennaria alpina	0.01					**	**
Arenaria capillaris	0.00	**		*			
Aster alpigenus	0.01	**				*	
Carex nigricans	0.08	*					
Carex spectabilis	0.42						
Juncus parryi	0.08					**	**
Ligusticum grayi	0.27						
Lupinus latifolius	0.20						
Polygonum newberryi	0.01	**					
Polytrichum juniperinum	0.00						
Rhacomitrium heterostichum	0.03						
Spraguea umbellata	0.16						
Bare ground	0.00	**					

APPENDIX C

Results of Chi Square Tests
*=p=.05, **=p=.01

Short Alpine Sedge Wet Meadow Community-Type

	Contrasts between groups of distances		
	0.0m.-0.5,1.0m	0.5,1.0m-2.5,5.0m	2.5,5.0m-7.5,10,15
Species	1	2	3
Agrostis variabilis			*
Aster alpigenus	*		
Carex nigricans	*		
Carex spectabilis			
Castilleja parviflora		*	
Cladonia species	*	*	
Dodecatheon jeffreyi			
Gentiana calycosa	*		
Juncus mertensianus	*	*	
Kalmia microphylla	*		
Lophozia venticosa	*		
Moss 1			
Moss 3			
Moss 4			*
Marsupella emarginata			
Phyllodoce empetriformis		*	
Polytrichum juniperinum	*		
Rhacomitrium heterostichum		*	
Stereocaulon species	*	*	
Bare ground	*	*	

APPENDIX C (cont.)

Mountain Heather Moist Meadow Community-Type

	Contrasts between groups of distances		
	0.0m-0.5,1.0m	0.5,1.0m-2.5,5.0m	2.5,5.0-7.5,10,15m
Species	1	2	3
Agrostis variabilis			*
Antennaria alpina			
Aster alpigenus	*		
Aulocomnium palustre	*		*
Caltha biflora			
Carex nigricans		*	*
Cassiope mertensiana	*		
Castilleja parviflora	*		
Cladonia species	*	*	
Dodecatheon jeffreyi	*		*
Gentiana calycosa	*		*
Juncus mertensianus	*		
Juncus parryi	*		
Kalmia microphylla	*		*
Ligusticum grayi			
Lycopodium sitchensis			
Marsupella emarginata	*		
Moss 4			
Moss 5			
Moss 7			
Phyllodoce empetriformis	*		*

APPENDIX C (cont.)

	Contrasts between groups of distances		
	0.0m-0.5,1.0m	0.5,1.0m-2.5,5.0m	2.5,5.0m-7.5,10,15m
Species	1	2	3
Polytrichum juniperinum	*		
Rhacomitrium heterostichum	*		
Stereocaulon species			*
Vaccinium deliciosum	*		
Bare ground	*		

APPENDIX C (cont.)

Cascade Blueberry Dry Meadow Community-Type

	Contrasts between groups of distances		
	0.0m-0.5,1.0m	0.5,1.0m-2.5,5.0m	2.5,5.0m-7.5,10,15m
Species	1	2	3
Agrostis variabilis			
Antennaria alpina			
Arenaria capillaris			*
Aster alpigenus	*		*
Carex nigricans			
Carex spectabilis			
Castilleja parviflora			
Cladonia species			*
Juncus parryi		*	
Ligusticum grayi			
Luetkea pectinata	*		
Microsteris alpestris			
Moss 4		*	*
Phyllodoce empetriformis			*
Polytrichum juniperinum	*	*	
Rhacomitrium heterostichum			
Stereocaulon species			
Vaccinium deliciosum	*	*	*
Bare ground		*	

APPENDIX C (cont.)

Rawmark Pumice Community-Type

	Contrasts between groups of distances		
	0.0m-0.5,1.0m	0.5,1.0m-2.5,5.0m	2.5,5.0m-7.5,10m
Species	1	2	3
Agrostis variabilis		*	
Antennaria alpina			
Arenaria capillaris	*	*	*
Aster alpigenus	*		*
Carex nigricans		*	
Carex spectabilis	*		
Juncus parryi			
Ligusticum grayi			
Lupinus latifolius			
Polygonum newberryi	*	*	
Polytrichum juniperinum		*	*
Rhacomitrium heterostichum			
Spraguea umbellata		*	
Bare ground			

APPENDIX D

Results of Soil Analyses

Soil Compaction
Kg/cm^2

	Sedge		Blueberry		Heather		Rawmark	
Distance (m)	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
0.0	2.862	0.210	5.000	0.000	3.483	0.414	0.1312	.1059
0.5	2.763	0.118	2.598	0.224	2.704	0.110	0.8521	.2993
1.0	2.125	0.099	2.102	0.156	2.169	0.185	1.1750	.3369
2.5	1.795	0.084	2.052	0.101	2.240	0.082	0.7875	.2545
5.0	1.465	0.077	1.902	0.106	2.065	0.081	1.0333	.3660
7.5	1.592	0.047	2.031	0.077	2.317	0.101	1.3062	.2574
10.0	1.545	0.043	1.862	0.128	1.967	0.089	1.0937	.2166
15.0	1.332	0.067	1.880	0.097	2.053	0.107	---	---

Soil Moisture
% $g\text{-}H_2O$/g-dry wt. soil

	1978		1979	
	Mean	Standard Error	Mean	Standard Error
Sedge				
0.0 m	22.33	0.784	24.8	4.59
1.0 m	44.40	6.008	77.1	7.06
5.0 m	70.60	15.531	52.8	21.99
Blueberry				
0.0 m	54.5	3.915	16.3	3.71
1.0 m	59.1	4.839	17.9	4.41
5.0 m	69.3	13.084	18.5	1.65
Heather				
0.0 m	47.3	9.327	53.2	6.42
1.0 m	88.9	27.040	96.5	8.11
5.0 m	71.7	19.435	85.5	13.47
Rawmark				
0.0 m	*		4.0	0.76
1.0 m	*		3.4	0.45
5.0 m	*		6.6	0.32

* Not sampled in 1978.

APPENDIX D (cont.)

	Percent Organic Matter		pH	
	Mean	Standard Error	Mean	Standard Error
Sedge				
0.0 m	0.0638	0.0222	5.200	0.0577
1.0 m	0.2086	0.0013	4.803	0.1386
5.0 m	0.1942	0.0341	4.833	0.1386
Blueberry				
0.0 m	0.1773	0.0130	4.837	0.0469
1.0 m	0.2467	0.0236	4.780	0.0066
5.0 m	0.2759	0.0341	4.573	0.0918
Heather				
0.0 m	0.1400	0.0277	4.870	0.0231
1.0 m	0.2768	0.0214	4.527	0.0819
5.0 m	0.2441	0.0447	4.370	0.0465
Rawmark				
0.0 m	0.0242	0.0040	4.800	0.0115
1.0 m	0.0199	0.0058	4.860	0.0322
5.0 m	0.0295	0.0041	4.853	0.0289

Particle Size

	% Gravel	% Sand	% Silt	% Clay
Sedge				
0.0 m	5.10	76.24	17.14	4.69
1.0 m	6.88	66.25	16.76	8.87
5.0 m	7.27	81.50	5.73	5.50
Blueberry				
0.0 m	13.89	59.94	17.95	8.22
1.0 m	18.80	60.38	15.05	5.77
5.0 m	15.59	57.92	20.20	6.28
Heather				
0.0 m	2.50	65.52	24.75	8.74
1.0 m	4.63	57.68	24.84	12.85
5.0 m	4.52	54.50	26.36	14.62
Rawmark				
0.0 m	44.04	48.35	2.76	4.85
1.0 m	32.78	58.58	2.68	6.00
5.0 m	35.05	56.73	2.32	5.89

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