EFFECTS OF HIKERS ON SUBALPINE MEADOWS, PARADISE, MOUNT RAINIER NATIONAL PARK, WASHINGTON, USA

by

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ABSTRACT

Recreational impacts on the subalpine-alpine ecosystems of Mount Rainier National Park pose a major problem for park managers. Aerial photographs were analyzed and field data collected in the Paradise meadows area in order to: 1) describe hiker impacts in creating social trails off of maintained trails); 2) develop a systematic method for documenting damage; and 3) relate impacts to site characteristics. A total of 1126 social trails were identified, and measurements were made on the physical variables of elevation, trail slope, length, width, depth, and associated plant community. Trail variables were analyzed by simple linear correlation, multiple regression, and analysis of variance. Elevation and slope gradient were significantly correlated with the width and depth of social trails. Social trail length was not correlated with the other physical variables. With the exception of fellfield, high elevation trails were found to be more eroded than middle and low elevation trails. The heath shrub community was most damaged of five plant communities following the establishment of social trails. Management recommendations are made regarding prioritization of rehabilitation efforts and the establishment of formal trails in sensitive areas.

INTRODUCTION

Recreational uses of the subalpine and alpine environments of Mount Rainier National Park have significantly impacted the natural vegetation and soils through direct damage to vegetation and denudation and indirect erosion of surface soils. Damage began with the first visitors in the 1880's, and escalated in conjunction with national increases in recreational activities and as transportation increased accessibility to the park. Contributing to the problem of damage is that management practices in some areas and a lack of management in others allowed minor impacts to become significant problems. Finally, lack of a quantitative method for assessing impacted areas and ranking rehabilitation projects has prevented National Park Service personnel from effectively dealing with recreational site damage.

Paradise, one of the most heavily used areas in the park with an annual visitation of 1.08 million as of 1986, is among the most impacted sites in the park. Up to 5000 people may visit the meadows area per day during peak use periods in summer. Because of its visibility and proximity, the park is much used by residents from the populated greater Puget Sound area, with 58% of visitors coming from Washington state. Heavy use is facilitated by accessibility combined with the attraction of a magnificent mountain landscape and provision of a multiplicity of visitor services (National Park Service Ranger Station and climbing registration building, Visitor Center, Guide Services hut, National Park Service and concession housing, Paradise Inn, and a day-use picnic area). In particular, public use of Mount Rainier National Park is concentrated around Paradise, although more pristine, less impacted subalpine meadows exist in other parts of the park. Paradise meadows encompass approximately 389 ha, and are accessed by 16 formal hiking trails beginning at the Visitor Center and Paradise Inn. These trails conduct hikers away from the road and developed areas and provide quick access to the spectacular subalpine flower fields.

Mount Rainier National Park staff needs a means for identifying and documenting impacted sites subject to accelerated erosion, and a system to prioritize heavily impacted sites for rehabilitation in subalpine and alpine areas. Linked to these needs, our research objectives were to:

1. Determine the number of impacted sites including social trails in the Paradise meadows area of the park.
2. Develop a systematic method for measuring and documenting these sites.
3. Determine the relationships of social trail damage to site characteristics.

STUDY AREA

Our study was conducted in the Paradise meadows area on the south-facing slope of Mount Rainier, located in the Cascade Range of Washington about 130 km southeast of Seattle (Figure 1). Mount Rainier, 4392 m, is the highest peak in the Cascades. Its mass, height, geologic history, and isolation from surrounding Cascade peaks has determined the types of soil and vegetation now existing on its slopes (Edwards, 1980). Our study encompassed the area bounded on the south by the Paradise Valley Road and Paradise parking lot, on the west by the Nisqually Glacier and moraine, on the north by McClure Rock, and on the east by the Stevens Van Trump historical monument (Figure

1). It included 22 km of maintained trails and a stream network of seven first-order, two second-order, one third-order, and two intermittent streams.

Topography throughout the study area is relatively smooth as a result of Quaternary glaciation followed by long periods of tephra accumulation. The Alta Vista - Skyline Ridge area is the oldest ice-free landform in the study area. The wide, upper end of Paradise Valley was a glacial cirque, as shown by the steep headwall below Panorama Point (Crandell, 1969). Rivers and streams have caused some incision into the overall smooth topography of the area, but the overriding impression is of a recently-glaciated and tephra-deposited surface that has had little time to become significantly modified by the erosive elements of water and wind.

The prevailing storm track is from the south, and Paradise receives heavier accumulations of snow and rain and cooler temperatures year-round than other sides of the mountain. Average annual precipitation is 230 cm, falling primarily as snow. Summers are short and are characterized by a pattern of 3-10 days of warm, dry weather followed by short periods of cloudy or stormy weather. Snowpack ranges from 3 to 9 m per year with the first persistent snowfall in late October and heavy snows continuing through April. Snow usually remains on the ground until late June or July, with some summer-persistent snow fields and ice fields on higher and east-facing sections of the area (United States Weather Bureau, 1980).

A number of plant communities characterize the vegetation cover of Paradise (Henderson, 1974). We generalized these into six communities ranging from lush subalpine meadows with scattered tree cover in the lower elevations of Paradise to sparse fellfield and heath-shrub communities above 2070 m. In mesic areas where water is available throughout the growing season, low elevation swales are dominated by the wet sedge community. With increased elevation, soil moisture lessens, and wet sedge grades into the lush herbaceous community with many showy flowering plants. At about 1950 m elevation, the lush herbaceous community is gradually replaced by a community with low herbaceous species like *Aster alpigenus* and *Antennaria lanata* . These species become dominant where colder conditions, a shorter growing season, and somewhat drier summer conditions favor smaller plant sizes (Hamann, 1972). Above 2070 m, the perennial heath shrub community becomes apparent, continuing up to 2250 m, at which point the sparse vegetation of fellfields is characteristic (Edwards, 1980).

METHODS

Field Methods

In 1986 and 1987 members of the Natural Resources Planning Division of Mount Rainier National Park conducted the "Paradise Social Trail Survey" which documented, mapped and recorded all social trails in the Paradise meadows study area. The length, width, average depth, slope, aspect, elevation, adjacent plant community, percent denudation, and probable cause of each social trail were recorded (Parsons and McLeod, 1980; Cole, 1983). Since the majority of Paradise area impacts were found to be linear despite the varying causes (such as trail abandonment, rest stops, viewpoints, etc.), we identified all impacted sites by the term "social trail." A "social trail" usually refers to an unplanned, informal trail in a recreational area and contrasts with a planned, constructed and maintained trail, but we use the term in a broader context.

Aerial photographs taken in August and September of 1986 at a scale of 1:5000 helped us locate social trails which we then visited in order to collect site-specific data. These larger scale natural color photographs also allowed us to initially estimate the extent of social trails, and insured detection and enumeration of many social trails that would have gone unnoticed with ground surveying alone. As social trails were encountered, they were inventoried and mapped. Sites visible on the aerial photographs were marked on overlays as they were mapped on the ground to prevent duplication. Social trails were located by geographic subarea within Paradise meadows. There were 21 subareas.

Trail length, width, and depth were measured by tape in meters and rounded off to the nearest 5 cm. Elevations in meters were interpolated from contours on the 1:24,000 U.S.G.S. quadrangles. Survey methods were altered slightly in 1987 to account for the variability in dimension characteristics often found in trails greater than 20 m in length. A new trail segment reflecting homogeneous characteristics was recorded whenever there was a change in the plant community, percent bare ground, or in any physical characteristic subclass. Subclasses used for trail segmentation were:

Trail width (cm):	< 31, 31-46, 47-62, 63-91, > 91
Trail depth (cm):	< 5, 5-15, 16-31, 32-62, 63-91, > 91
Slope (deg):	< 10, 10-20, 21-30, 31-40, 41-50, > 50

Longer social trails were segmented to account for variations in soil erosion potential for each trail segment. Thus, segments of social trails could be ranked by their rehabilitation priority, allowing us to prioritize social trails for restoration and to account for the topographic and physical heterogeneity in the landscape.

Slope gradient was measured in degrees using a clinometer. Aspects were estimated by map and compass using the eight primary coordinates (N, NW, W, SW, S, SE, E, NE). Presence or absence of erosional condition was identified by visually estimating the soil volume lost from the site and the degree to which adjacent vegetation appeared to be disturbed. For example, trails with many plants with crushed leaves but no mortality were given a "no erosion" rating, whereas trails with dead plants, exposed roots and collapsing plants received an "erosion evident" rating. Percent bare ground of the trail tread was estimated visually to determine the approximate vegetation cover loss that had occurred in a trail segment. In the fellfield community, where plant cover was normally less than 50%, a separate note was made next to the community type identification to indicate the normal unvegetated area in an undisturbed area. In this way, a comparison could be made between the normal cover and that found on impacted areas. Plant communities were identified by using an unpublished key to subalpine plant communities of Mount Rainier National Park on file at park headquarters.

Analytical Methods

Data from the completed social trail survey were entered into the "dBase III" database management program. All of the data were organized by variables in columns and sorted by row into subarea name and social trail identification number. Quantitative variables were: elevation, aspect, trail segment, slope, length, width, depth, normal percent bare ground (pertaining to fellfield vegetation), and percent bare ground within each social trail. Qualitative variables included: subarea, trail code, dominant plant community, erosional condition, and evidence of prior trail or rehabilitation work.

The plant community variable was converted to a numeric indicator to allow sorting and statistical analysis. A new numeric variable "trail segment" was created and added to all social trail data sets, so that trail segments could be analyzed separately for erosion potential. Most social trails were not segmented and so received a "1" in this column.

Variables chosen for analysis (elevation, slope, length, width, depth, and plant community) were exported from the main data base file into an ASCII format, and then imported into the Statgraphics (version 5) statistical analysis program. An artificial variable, "widxdep," was created by multiplying each social trail's width by it's corresponding depth. We assumed that this variable would give a relative indication of the amount of soil lost at each site.

General summary statistics (mean, standard deviation, minimum, and maximum) were calculated. Linear correlation coefficients (*r*) were calculated using the entire edited data set to determine the presence of significant relationships between the variables of elevation, slope, length, width, and depth. The widxdep variable was excluded from correlation analyses due to obvious problems with auto-correlation. Multiple regression was then run using trail depth as the dependent variable and elevation, slope, and plant community as independent variables. The edited data were then sorted by the two variables of elevation and plant community. More specifically, these subsets were: three elevation classes: Low (1530-1765 m), Medium (1766-1945 m), High (1946-2250 m); and the five plant communities. These two variables were used to examine changes in trail characteristics between each data subset.

A one-way analysis of variance (ANOVA) was run to statistically test for overall differences among groups within each of the six social trail variables. The protected least significant difference (LSD) method was employed to statistically test for significant differences between individual group means within each of the six social trail variables. Logarithmic or square root transformations were used on selected variables to meet the normal distribution and equal variance assumptions for both of these analyses.

RESULTS

A total of 1126 social trails and trail segments were identified in the Paradise meadows study area. General characteristics of these sites are given in Table 1 and social trails are mapped in Figure 2. Sites ranged in elevation from 1530 to 2246 m, and mean slope was 13.4 degrees, but a few sites were as steep as 50 degrees. Mean social trail length was 40.3 m. However, there was considerable variation in trail length. Mean social trail width was 1.00 m and depth 0.13 m. Social trail characteristics displayed considerable variability.

Correlations among the five social trail variables ranged from weakly negative to moderately positive. The strongest relationships were between slope and depth (r = 0.36, P < 0.00); width and depth (r = 0.14, P < 0.00); and elevation and depth (r = 0.13, P < 0.00).

From the multiple regression, slope, elevation, and one plant community (heath shrub) accounted for 17.2% (P < 0.00) of the variance in trail depth. Slope, alone, accounted for 11% (P < 0.00) of the total variance.

To further understand these relationships, social trail data were summarized with respect to three elevation classes: Low (1530-1765 m), Medium (1766-1945 m), and High (1767-2250 m) (Table 2). Analysis of variance tested for significance differences among the physical trail variables of slope, length, width, depth, and widxdep by elevation class (Table 3). Mean slopes of social trails significantly increased with increased elevation class (12.1 to 15.2 degrees, P < 0.00). Social trails at low elevations were significantly (P < 0.00) narrower (0.83 m) than trails at medium elevations (1.11 m) and high elevations (1.14 m). Mean trail depths were significantly greater (P < 0.01) at high elevations (22 cm) than at medium (13 cm) and low elevations (13 cm).

Table 4 shows summary statistics of the data sorted by five generalized plant communities. The heath-shrub community had the largest number of social trails (464) followed by lush herbaceous (297), and low herbaceous (261). The fellfield community contained 90 social trails and the wet sedge community 14. Community elevation increased, as expected, from lush herbaceous at the lowest elevations intergrading successively at higher elevations into wet sedge, low herbaceous, and heath-shrub. Fellfield, of course, was highest. Trails in the heath-shrub community had significantly steeper slopes (16.2 degrees) than slopes in all other plant communities but wet sedge (Table 5). Heath-shrub social trail depths were also significantly greater (0.22 m) than those of other communities. Most other variables were not significantly different when sorted by plant community.

DISCUSSION

The Paradise meadows social trail survey revealed 1126 sites. Social trails were dispersed fairly evenly throughout the Paradise meadows study area, but were particularly concentrated along the Panorama Point loop trail, suggesting that increased accessibility to the higher elevations, associated with inadequate trail planning, has encouraged off-trail hiking, causing these impacts to become prevalent.

The most significant relationship among variables was between slope and social trail depth. The steeper the slope, the more soil erosion, and the more deeply incised the trail. This was particularly true with the heath shrub plant community that tended to occupy steeper slopes at higher elevations, as shown by multiple regression and the ANOVA. Erosion is further exacerbated by the presence of dwarf woody-stemmed heath vegetation, which is especially vulnerable to damage and slow to recover or become re-established.

The pattern of increase in slope of social trails at higher elevation also led hikers to create parallel trails thereby avoiding eroded gullies at higher elevations, which are difficult to walk in, particularly when descending. These parallel trails eventually merge together, leading to wider single trails. Positive correlations of social trail elevation with slope, elevation with depth, and slope with depth were also significant, suggesting that increased slopes at higher elevations and increased runoff velocity promote erosion. Erosion is further enhanced by the removal of vegetative cover by trampling, loss of organic soil horizons, and concentration of surface runoff into gullies (Gray and Leiser, 1982).

The correlation of social trail widths with depths suggested that as social trail widths increased through loss of vegetation, the bare and/or compacted mineral soils become more susceptible to erosion by water, ice (especially needle ice) and wind. Vegetation intercepts rainfall and reduces the direct impact of raindrops which dislodge and move soil particles. With vegetation removed, roots are destroyed and organic matter diminished (Farmer and Van Haveren, 1971). Roots physically restrain soil particles which would otherwise be subject to erosion. Soil organic materials also retard run-off, and roots and plant residues help maintain soil porosity and permeability, promoting infiltration. Thus, loss of normal vegetation cover seriously affects the susceptibility of a given site to subsequent erosion (Gray and Leiser, 1982).

Examining the data sorted by elevation classes, 79% of the social trails can be seen to occur within the low and middle elevations of the study area (1530-1945 m). This is simply due to a concentration of visitor use at lower elevations near automobile access. Many of the officially "abandoned trails" (such as the Moraine Trail, providing the only fairly easy access to Nisqually Glacier) that are still used have been re-designated as maintained trails since the field work was initially conducted for this study. Most of these reopened old trails are also found at low elevations, probably accounting for some of the increased impacts at these elevations. No distinction was made between abandoned trails and true social trails during data collection, which may explain the high degree of variability of social trail lengths throughout the study area.

Helgath (1975) found low correlations between levels of use and trail deterioration, and suggested that the decreased deterioration on some trails was probably caused by a decrease in use induced by steeper slopes. She noted that high use areas in the Bitterroot Mountains, Montana, were characterized by low slopes and low use areas by high slopes. This relation can be applied to the social trail sites within the Paradise meadows area. As distance from access, elevation and slopes increase, social trail use probably decreases; but, the steep slopes themselves contribute to the continual soil loss.

In addition, Liddle (1975) found that hikers in North Wales diverge from obvious paths as wetness and roughness increase, as path or social trail slopes increase, as footing becomes more precarious, and as the distinction between path boundary and adjacent area becomes less defined. The upper elevations of the study area (> 1945 m) have site conditions and social trails that more or less conform to Liddle's observations. The higher elevation areas are characterized by a very gravelly soil texture, and the social trails are visually obvious in the landscape, attracting visitor use. Hikers kick gravel to the sides of the trail, differentially exposing finer soil particles in the trail tread. Finer soils without vegetative cover are then subject to needle ice formation, loosening the soil and making it susceptible to erosion, exposing roots, and causing the already damaged plants to die. Plant removal exposes still more soil to needle ice formation (Edwards, 1980).

In most cases, elevation differed significantly by plant community as anticipated by the observed zonation of vegetation. Of the variables related to human impact (length, width, depth), social trail length did not differ significantly among plant communities. Social trail widths also was not strikingly different in different plant communities, although it showed much variability. This variability was particularly related to the naturally bare fellfield. Social trail depth, however, was fairly sensitive to plant communities, especially for heath-shrub and wet sedge, and less so for low herbaceous and lush herbaceous. The heath shrub was on steep slopes and, being dominated by dwarf woody vegetation which is easily damaged and slow to recover from damage, was particularly subject to erosion as indicated by deep social trails. The wet sedge, with saturated soils, became mucky and eroded after relatively light pedestrian traffic (Willard and Marr, 1970) although these wet-site social trails may be subject to rapid recovery (Palmer, 1979). Trail depth was not high at the highest elevations (fellfield community) because the soils are rocky resisting erosion and because the fellfield sites were often on ridge locations.

MANAGEMENT RECOMMENDATIONS

Mount Rainier National Park has a significant problem of resource damage caused by concentrated visitor use. This problem is exacerbated by the combination of relatively high elevations with slow vegetational recovery rates, extended winters, short growing seasons, steep slopes, volcanic soils susceptible to rapid erosion and susceptibility of a number of plant communities to trampling damage. The results of the analysis presented here indicate that elevation and slope work together to intensify hiker impacts. The majority of social trails surveyed (85%) were denuded of vegetation, allowing erosion to remove soil and further degrade adjacent vegetation. Once a social trail becomes a visible route, it attracts use, and enhanced use results in erosion caused by water, needle ice action and wind, three agents that continue to deepen and widen these trails.

The landscape characteristics of slope and elevation also affect the resulting physical characteristics of social trails. Depth and width of trails tend to increase with increasing slope as erosional processes become more pronounced. Plant community types can be used to generally characterize the overall physical dimensions of social trails within those types. Because of this, plant communities can be used initially to rank rehabilitation efforts of impacts. In particular, management actions should first be focused on social trails in the heath-shrub community as this community is most subject to damage. Second, rehabilitation efforts should center on steep slopes which are especially prone to accelerated erosion. In addition, information may be gathered by assessing the relationships of plant communities to physical landscape characteristics which affect erosion potential, such as relative rates of recovery.

In heath-shrub and fellfield communities, any on-going impacts need to be stopped immediately. These areas are very difficult to rehabilitate because disturbance causes a loss of soil stability allowing needle ice to form, exposing soil particles to further erosion by wind and water (Edwards, 1979, 1980). The longer impacts are allowed to occur at these elevations, the greater the time it will take for them to recover once the impact source is removed (Willard and Marr, 1970, 1971). Once the impact causes are stopped, restoration can wait until funding and personnel are available.

The survey techniques of aerial photography and field checking should both be used when initially assessing the recreational impacts of an area. Aerial photography can be used to identify logical sub-area boundaries and can reveal impacted sites that would otherwise be missed. There are limitations to the amount of information available from photographs, and field checking is always necessary. For example, based on field reconnaissance alone in the Paradise meadows area, 250 social trails were estimated to exist in 1986. But in 1987, using a combination of aerial photographs and field checking, 1126 were found, a 450% increase over the 1986 survey. The photographs enabled field crews to locate old social trails and abandoned National Park Service trails which were no longer attached to the present trail system. Some of these abandoned trails had merely been revegetated at access points to the currently maintained trails, and appeared on the photographs as disconnected lines of denudation without discernible beginning or end points. They would not have been located on the ground without the photos or very detailed field surveying. On the other hand, some significantly eroded sites were not visible on the photographs due to shadows, tree cover, or extreme distortion on the images due to uneven topography, and were only found by field checking.

One of the most significant issues facing Mount Rainier National Park is the natural resource degradation caused by heavy visitor use combined with natural landscape features which promote erosion. Human use has degraded many popular areas, making it necessary to eliminate social impacts and control the associated erosion to protect the ecological integrity of these areas. Once social impacts are removed, degraded sites can be rehabilitated by aggressive restoration techniques. But without removal and corrective action, the scenic resources will progressively decline.

The National Park Service has the difficult task of preserving natural ecosystems which have evolved with little or no pressure from humans, but at the same time providing for the enjoyment of present and future generations (United States Congress, 1916). While this mandate has an inherent contradiction in that it is difficult to truly preserve an area yet allow visitation, wise management of visitor use areas can go far in reducing potential damage caused by multitudes of visitors.

Wise management should include consideration for the potential damage caused by providing easy access to ecosystems that are ill-adapted to human-caused impacts. Subalpine and alpine vegetation in particular is fairly durable and well-adapted to the prevailing environmental conditions found there, but many anthropogenic disturbances can wreak havoc because few species are capable of rapidly colonizing newly available space (Edwards, 1979). Natural cycles of disturbance do occur, and these should be allowed to continue as part of national park policies to preserve natural processes as well as locations, but human -caused disturbances place an additional strain on ecosystems which are incapable of quick response. Therefore, area managers should emphasize the preservation of existing undisturbed habitats, and secondarily should attempt to mitigate damages already extant in areas where natural revegetation is not a viable alternative.

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Table 1. Summary statistics for six variables for all social trails and social trail segments (n = 1126).

	Mean	Standard Deviation	Minimum	Maximum
Elevation (m)	1826	147	1530	2246
Slope (degrees)	13.4	9.0	0.0	50.0
Length (m)	40.3	78.7	0.5	1500.0
Width (m)	1.00	1.74	0.01	25.60
Depth (m)	0.13	0.13	0.00	1.00
Widxdep(m^2) [a]	0.16	0.44	0.00	8.70

[a] Widxdep variable was derived by multiplying width by depth for each social trail.

Table 2. Summary statistics for six social trail variables sorted by three elevation classes.

	Mean	Standard Deviation	Minimum	Maximum
Low Elevation (n=410)				
(1530 - 1765 m)				
Elevation (m)	1680	48	1530	1765
Slope (deg)	12.1	7.7	0.0	50.0
Length (m)	43.8	93.8	0.5	1500.0
Width (m)	0.83	1.51	0.10	25.60
Depth (m)	0.13	0.13	0.00	1.00
Widxdep (m^2) [a]	0.12	0.21	0.00	3.03
Medium Elevation (n=476)				
(1766 - 1945 m)				
Elevation (m)	1841	49	1768	1945
Slope (deg)	13.6	9.1	0.0	45.0
Length (m)	38.5	73.6	1.0	1173.8
Width (m)	1.11	1.79	0.02	20.06
Depth (m)	0.13	0.11	0.00	0.73
Widxdep (m^2) [a]	0.24	0.44	0.00	3.93
High Elevation (n=240)				
(1946 - 2250)				
Elevation (m)	2047	78	1951	2246
Slope (deg)	15.2	10.4	0.0	45.0
Length (m)	37.7	57.6	2.0	580.8
Width (m)	1.14	1.33	0.01	10.00
Depth (m)	0.22	0.24	0.00	1.00
Widxdep (m^2) [a]	0.21	0.54	0.00	3.91

[a] Widxdep variable was derived by multiplying width by depth for each social trail.

Table 3. Results of analysis of variance (ANOVA). Data were sorted by elevation class (see Table 2). Lowtrail = 1530-1765 m, Medtrail = 1766-1945 m, and Hightrail = 1946-2250 m. * indicates no significant difference at 0.05 probability level.

	Slope			Length[a]			Width[a]			Depth[a]			Widxdep[a] [b]		
Lowtrail	*			*			*			*			*		
Medtrail		*		*	*			*		*	*			*	
Hightrail			*	*	*	*		*	*			*			*

[a] Logarithmic transformations for skewed data and/or unequal variances

[b] Widxdep variable was derived by multiplying width by depth for each social trail.

Table 4. Summary statistics for six social trail variables sorted by plant community.

	Mean	Standard Deviation	Minimum	Maximum
Low Herbaceous (n=261)				
Elevation (m)	1849	100	1530	2097
Slope (deg)	10.6	7.2	0.0	45.0
Length (m)	39.1	96.6	2.0	1500.0
Width (m)	1.33	2.41	0.02	20.06
Depth (m)	0.13	0.13	0.00	0.73
Widxdep (m^2) [a]	0.22	0.53	0.00	3.91
Lush Herbaceous (n-297)				
Elevation (m)	1720	79	1536	1951
Slope (deg)	11.9	7.4	0.0	40.0
Length (m)	37.6	41.2	0.7	318.0
Width (m)	0.84	1.44	0.04	21.60
Depth (m)	0.11	0.11	0.00	1.00
Widxdep (m^2) [a]	0.13	0.21	0.00	2.20
Wet Sedge (n=14)				
Elevation (m)	1727	82	1640	1896
Slope (deg)	11.4	6.7	2.0	24.0
Length (m)	46.9	31.0	10.0	119.5
Width (m)	0.73	0.62	0.21	2.50
Depth (m)	0.14	0.13	0.00	0.33
Widxdep (m^2) [a]	0.10	0.11	0.00	0.51

Table 4 (cont.)

Heath Shrub (n=464)				
Elevation (m)	1836	139	1585	2125
Slope (deg)	16.2	9.9	0.0	45.0
Length (m)	39.9	72.5	0.5	892.0
Width (m)	0.87	1.48	0.02	25.60
Depth (m)	0.22	0.22	0.00	1.00
Widxdep (m^2) [a]	0.22	0.61	0.00	8.71
Fellfield (n-90)				
Elevation (m)	2076	130	1646	2246
Slope (deg)	12.3	9.7	0.0	50.0
Length (m)	53.2	133.0	4.0	1173.8
Width (m)	1.11	1.62	0.31	10.00
Depth (m)	0.12	0.12	0.00	0.64
Widxdep (m^2) [a]	0.11	0.11	0.00	0.84

[a] Widxdep variable was derived by multiplying width by depth for each social trail.

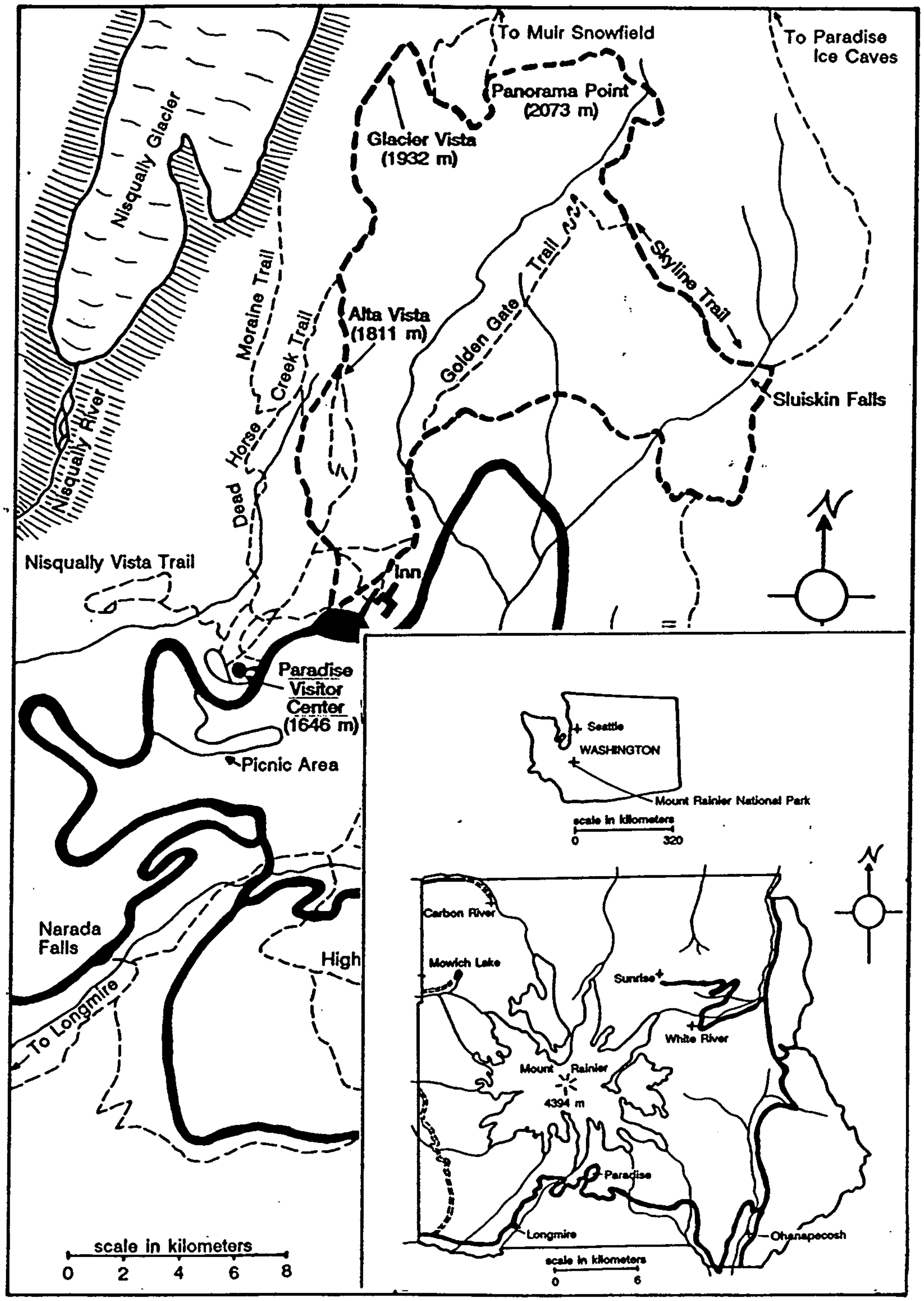
Table 5. Results of analysis of variance (ANOVA). Data were sorted by plant community (see Table 4). * indicates no significant difference at the 0.05 probability level.

	Elevation[a]	Slope[b]	Length[a]	Width[a]	Depth[a]	Widxdep[a]
Lush Herbaceous	*	*	*	*	*	*
Low Herbaceous	*	*	* *	*	* *	* *
Wet Sedge	* *	* * *	* * *	* * *	* * *	* * *
Heath Shrub	* *	* *	* * * *	* * *	* *	* *
Fell Field	*	* * * *	* * * * *	* * * *	* *	* *

[a] Logarithmic transformations for skewed data and/or unequal variances

[b] Square root transformations for skewed data and/or unequal variances

LIST OF FIGURES



To Muir Snowfield
To Paradise Ice Caves
Panorama Point (2073 m)
Glacier Vista (1932 m)
Nisqually Glacier
Skyline Trail
Golden Gate Trail
Moraine Trail
Alta Vista (1811 m)
Dead Horse Creek Trail
Sluiskin Falls
Nisqually River
Nisqually Vista Trail
Inn
Paradise Visitor Center (1646 m)
Picnic Area
Narada Falls
To Longmire
High
scale in kilometers
0 2 4 6 8
Seattle
WASHINGTON
Mount Rainier National Park
scale in kilometers
0 320
Carbon River
Mowich Lake
Sunrise
White River
Mount Rainier
4394 m
Paradise
Longmire
Ohanapecosh
scale in kilometers
0 6

Fig. 1

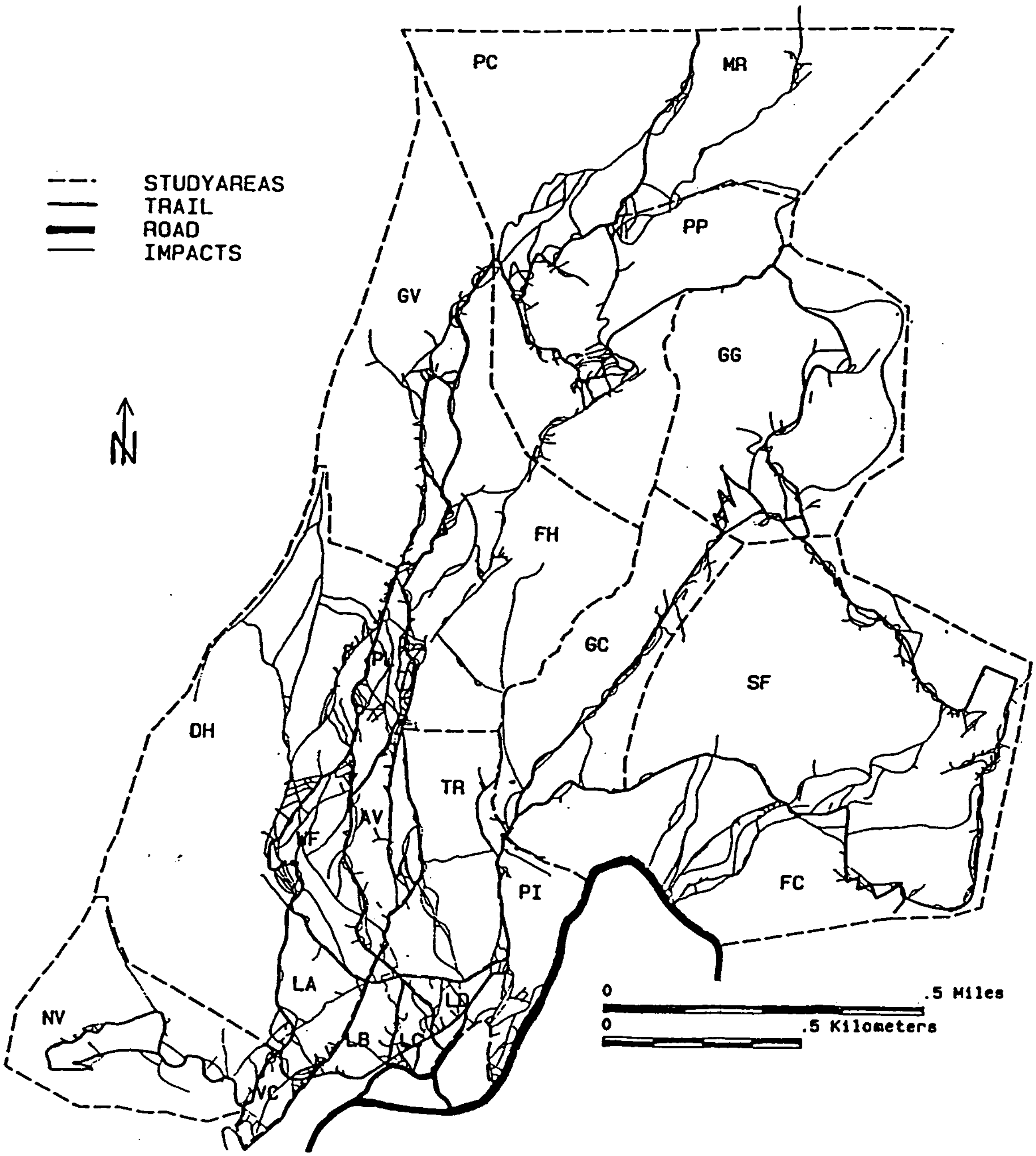

STUDYAREAS
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Fig 2