AN ABSTRACT OF THE THESIS OF

Susan L. Fritzke for the degree of Master of Science in Geosciences presented on April 13, 1992.

Title: Soil Erosion and Vegetation Loss Accelerated by Visitor Use of Paradise Meadows, Mount Rainier National Park.

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Recreational impacts on the subalpine-alpine ecosystems of Mount Rainier National Park have developed over the past century, and today pose a major problem for park managers. Field data were collected during the summer of 1987 in the Paradise meadows area in order to describe visitor impacts on social trails (trails established by informal visitor use off of maintained trails), develop a systematic method for documenting damage, relate impacts to site characteristics, and develop recommendations to mitigate these impacts. A total of 1126 social trails were identified and measurements were made on the physical variables of elevation, trail slope, length, width, depth, associated plant community, trail hierarchy pattern, and percent bare ground. 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 a social trail. Social trail length was not correlated with the other physical variables. Significant correlations were found between plant communities and the width and depth of impacts, and high elevation trails were found to be more susceptible to erosion than middle and low elevation trails.

Multiple regression with trail depth as the dependent variable identified slope as the variable accounting for most of the variance (11.0%). The heath shrub community was the most susceptible of five plant communities to damage following the establishment of social trails. Plant communities were found to have consistent social trail characteristics and can be used to initially prioritize social trail rehabilitation efforts. Management recommendations were made regarding the establishment of trails, prioritization of rehabilitation efforts, and ways to improve documentation of impacts.

Soil Erosion and Vegetation Loss Accelerated by Visitor Use of Paradise Meadows, Mount Rainier National Park

by

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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 erosion of surface soils. This damage began with the first visitors in the 1880's, and increased in conjunction with national increases in recreational activities and as improvements in outdoor equipment and transportation made access to the park easier. Furthermore, management practices in some areas and a lack of management in others allowed minor impacts to become significant problems (Kirschner et al., 1977). Finally, lack of a quantitative method for assessing impacted areas and prioritizing rehabilitation projects prevented National Park Service personnel from dealing with the problem effectively (Rochefort, 1987, personal communication).

Research Purpose

Mount Rainier National Park 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.

Research Objectives

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.
4. Make recommendations to park managers for minimizing social trail damage.

Study Area

Physical Characteristics

My study was conducted in the Paradise meadows 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 National Park consists of 980 square km of which the mountain bulk occupies one-third. Mount Rainier is the highest volcanic peak in the Cascades, attaining 4392 m above mean sea level. (All elevations in this document refer to meters above mean sea level). Its mass, height, geologic history, and isolation from surrounding Cascade peaks has determined the types of soil and vegetation which now exist on its slopes (Edwards, 1980a). My 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 2). 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.

In general, the Paradise sub-surface rock is andesite with surface deposits of ash, pumice, glacial till, mudflow, and talus slope debris in the western and lower elevation sections (Crandell, 1969b). Deep accumulations of ash and pumice are evident from eruptions by Mount Mazama (6,600 years ago) and Mount Rainier (between 2,000 and 450 years ago). Most of the Paradise area was glaciated in the late-glacial period until about 10,000 years ago, and soil development has taken place slowly since then, interrupted by periods of volcanic deposition and erosion (Crandell, 1969a).

Cooling temperatures during the Little Ice Age, 450 to 250 years ago, caused a temporary expansion of the Nisqually and Paradise Glaciers and increased the size of perennial ice fields within the study area, but the presence of old ash and pumice layers and developed soils throughout the meadows suggest that these slopes remained exposed and vegetated during that time (Crandell, 1969b).

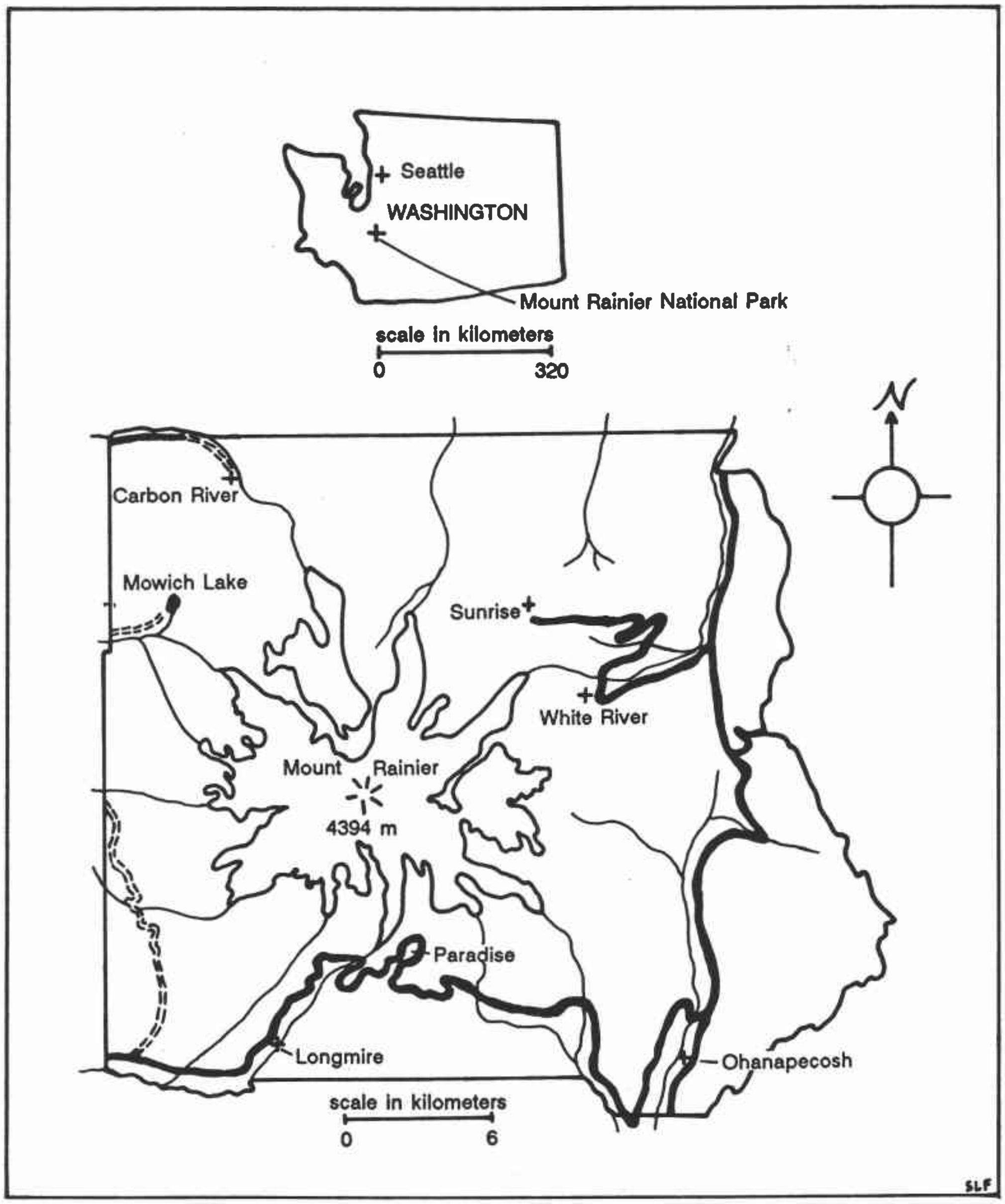

Figure 1. Mount Rainier National Park.

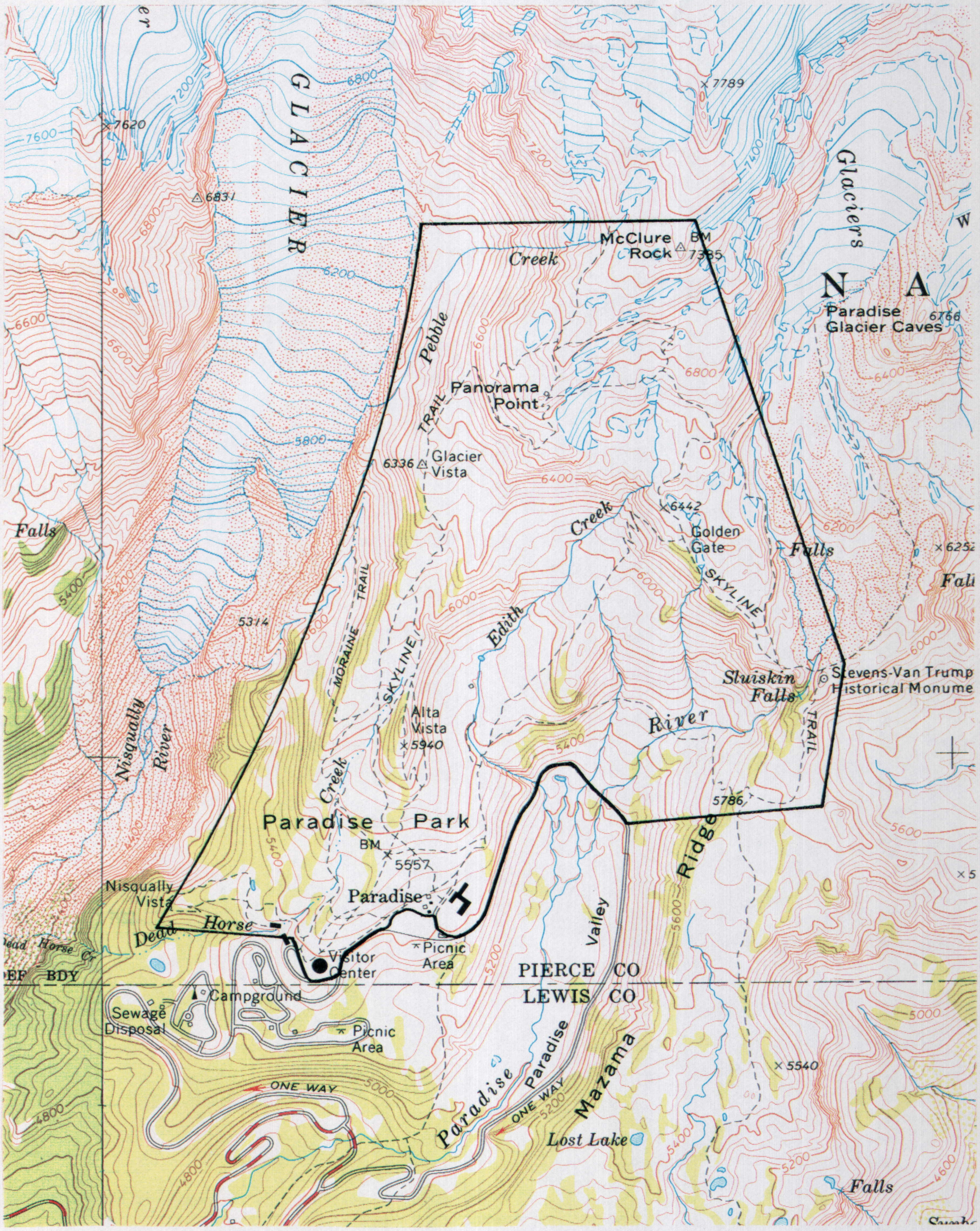

Figure 2. Paradise meadows study area boundaries.

Topography throughout the study area is relatively smooth as a result of 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, 1969b). 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 (Rochefort, 1989). 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 snowfields and icefields on higher and east-facing sections of the area (U.S. Weather Bureau, 1980).

A number of plant communities dominate the vegetation cover of Paradise (Figure 3 and Table 1). I have 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 (Table 1 and Appendix 1).

In mesic areas where water is available throughout the growing season, low elevation swales are dominated by the wet sedge community. As elevation increases and soil moisture lessens, 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, 1980a).

In xeric areas where moisture is either limiting throughout the growing season or becomes limiting toward the end of the summer, the elevation gradient of plant communities differs. At the lowest elevations, the low herbaceous community dominates, grading into a dry grass community where conditions are extremely dry in late summer. The low herbaceous community generally extends intact up to about 1950 m elevation in semi-dry areas, and is gradually replaced by fellfield species, which take over completely above 2100 m. Variations in the subalpine/alpine transition zone are attributed to microclimatic changes, and transitions from one plant community to another are not readily apparent (Edwards, 1980a).

FESCUE - Dry fescue types, dominated by *Festuca viridula, Lupinus latifolius, and Aster ledophyllous*

WET SEDGE - Wet sedge types, occurring on poorly drained habitats, often in basins or cold air drainages. Dominated by *Carex nigricans* and sometimes *Carex spectabilis*.

LOW HERBACEOUS - Low herbaceous or semi-shrub types. An agglomeration of diverse community types, but with similar physiognomy and successional status.

HEATH–LUSH HERBACEOUS MOSAIC - An area dominated by Heath types and Lush - herbaceous types in a mosaic too comlex to map. The heath types usually occur in lower topographic positions (drainages) and the lush herbaceous types usually occur on ridge or mound positions.

LUSH HERBACEOUS - Conspicuous and colorful flowerfields dominated by *Lupinus latifolius, Valeriana sitchensis, Polygonum bistortoides, Castilleja parviflora* and/or *Carex spectabilis.*

HEATH - Shrubby meadow types dominated by heath-like ericaceous shrubs such as *Phyllodoce empetriformis, Cassiope mertensiana, Phyllodoce glanduliflora* and *Vaccinium deliciosum.*

OTHER SHRUB - Other shrubby vegetation. Dominants may include *Salix spp. Sorbus sitchensis, Spirea .densiflora, Alnus spp. Acer spp.* or *Vaccinium spp.*

ROCK - Rock and bare ground including talus and sparsely vegetated pumice fields.

OPEN SUBALPINE WOODS - Sparsely forested subalpine meadow areas. Tree cover from 30 to 70%, understory vegetation variable but similar to the described meadow types.

FOREST - Closed forests of the *Tsuga heterophylla, Abies amabilis,* and *Tsuga mertensiana* zones.

GLACIER - Glaciers and permanent snowfields.

Figure 3. Plant communities of the Paradise meadows area.

(Source: Henderson, 1975)

Table 1. Generalized plant communities in the Paradise meadows area.

Present Study[1]	**Henderson (1974)**	**Henderson (1975)**
Wet sedge (3)	Wet sedge Forest	Sedge meadows Forests or groups of trees
Low herbaceous (2)	Low herbaceous	Low herbaceous
Lush herbaceous (1)	Lush herbaceous	Tall herbaceous meadows Tall shrub meadows Lush streamside meadows
Dry grass	Fescue	Fescue-aster meadows
Heath shrub (4)	Heath Heath - lush herbaceous mosaic	Heath meadows
Fellfield (5)	Rock	Bare rock or soil or sparsely vegetated Krummholz conifers

[1] Numbers in parentheses denote indicator numbers used in statistical analysis. Social trails were not found in the dry grass community.

Recreational Impacts

The Mount Rainier National Park policy, reflecting national policy, aims at preventing recreational impacts and rehabilitating previously impacted sites. This policy is mandated by the park's enacting legislation (U.S. Congress, 1899) and by National Park Service management policies (U.S. Congress, 1916; U.S. Department of the Interior, 1988), but implementing these policies has been hampered by the absence of adequate systems for documenting, categorizing and ranking impacts based on their physical characteristics and social causes (Rochefort, 1987. Personal communication).

The park mandate states that Paradise meadows are to be preserved as they were when the park was established in 1899 (U.S. Congress, 1899); however, damage to the meadows has been occurring since trails were first constructed from Longmire in 1895.

Paradise is one of the most heavily used areas in the park, with an annual visitation of 1.08 million as of 1986 (University of Washington, 1986). Up to 5000 people may visit the meadows area per day during peak use periods in the summer (Johnson, 1989). Because of its visibility and proximity, Mount Rainier National Park is heavily used by residents from the populated greater Puget Sound area, with 58% of visitors coming from Washington state (University of Washington, 1986). Heavy use is facilitated by easy access combined with the attraction of a magnificent mountain landscape and 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.

The Paradise meadows encompass approximately 389 ha, and are accessed by 16 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 (Figure 4). The Paradise Road forms a loop from Narada Falls up to the Visitor Center and Paradise Inn and back down through Paradise Valley. Trails also access the meadows from the road in a number of places.

Most maintained trails in the lower, southern third of the meadows are paved. The remainder have graveled surfaces and/or are rock-lined to help define the trail boundaries. Although these "hardened" trails are protected against human impact, vegetation damage occurs in the area when visitors use abandoned trails, develop new informal trails or continue to use existing social trails. This "off-maintained-trail" hiking and meadow walking is discouraged by the National Park Service, but still occurs because visitor recognition of impacts has remained low despite attempts to educate the public about recreational impacts caused by inappropriate use (Johnson, 1989).

Causes of social trails and sites of concentrated impact in the Paradise meadows are varied, but certain historic activities undoubtedly led to severe impacts, such as the establishment of campsites in the meadows, horse use, ski area concessions, and miscellaneous construction projects.

Other activities associated with a concentration of visitors simply add to the overall degradation of the meadow environment. Causes of impacted areas present today are based on the following situations which can be separated into two distinct problem considerations (from Kirschner et al., 1977):

Management Considerations

1. Old social trails and trails were not rehabilitated when they were abandoned, accounting for nearly half of the sites now needing rehabilitation.

2. New trails were designed and constructed without regard to drainage and snow melt patterns. Frequently social trails melt-out sooner than do established trails, so visitors regularly use what they believe to be real trails.

3. Lack of a strong enforcement policy has allowed the Mount Rainier Guide Services to continue using traditional spring and early-summer approach routes to snow and ice training locations after the snow has melted, despite a contractual agreement prohibiting this use.

4. Lack of interpretive signs and information has prevented visitors from understanding the reasons for restricting off-trail hiking in the Paradise area.

Visitor Problems

5. The "green islands" created by early melt-out of meadows attracts visitors seeking somewhat dry places to relax and enjoy views.

6. Visitors avoid snow-covered or muddy and wet trails because of improper foot wear and/or a lack of understanding about the consequences of off-trail hiking. Instead, they walk parallel to the wet trail on drier ground, which causes widening and deterioration of existing trails.

7. There is widespread misunderstanding of the purpose of the old jute and new excelsior matting used for impact rehabilitation. Many visitors believe the mats are laid down over muddy sections of trail to improve traction for hikers.

8. Visitors are ignorant of the impacts that thousands of visitors can make on such a small area. Early and late-season visitors have no idea of the numbers of people that congregate in the Paradise area on sunny weekend days in July and early August.

9. People tend to walk single file in straight lines, concentrating trampling damage to small linear areas, which increases the potential for long-term impacts.

10. Shortcutting always is a problem on switchbacks, and is caused either by poor trail design, ignorance, impatience, thrill-seeking, or laziness on the part of the hiker.

11. Many impacted areas and social trails are created to access scenic viewpoints, interesting features, rest points, or as the only way to gain access to particular destination points.

Problems exist with both the currently maintained trail system and with older constructed trails, now abandoned. The construction of trails through the meadows has been one of the most damaging activities occurring at Paradise. Old trails have been either abandoned or relocated, but the abandoned trails continue to cause resource damage through their susceptibility to erosion and continue to attract use because of their visibility. Some old trails were rehabilitated in the 1970's with jute matting, seeds, fertilizer, and transplants of the exotic cultivar, red chewings fescue (*Festuca rubra* var. *commatata*). The grass was used to stabilize soil until native seedlings and transplants took hold the first year, and then was expected to die out the second year; however, in many places the grass persists and is spreading (Kirschner et al., 1977). Jute matting was used to prevent erosion and was expected to decompose after three to five years; however, some jute mats are visible twenty years after installation and have slid downslope from the impacted sites they were covering, preventing seedling establishment in many rehabilitated areas.

The current trail system has other problems. While access to the upper slopes and the Muir snowfield is important to hikers and climbers alike, consideration was not given to local variations in snow accumulation and melt-out patterns when new trails were constructed. Some trail sections remain snow-covered into July, while adjacent non-trail areas are snow-free. This pattern encourages off-trail hiking, if only to access the established trail at a point further up or down the slope. Most of these poorly-placed trails in the early melt-out areas have social trails adjacent to them, as can be expected. Despite signs, information displayed and available at the Visitor Center, uniformed employees on the slopes, and marked (wanded) trail routes over snowfields, visitors continue to use social trails. These social trails are visible, dry, and look like real trails.

Sociologic studies were conducted in the summer of 1987 by Dr. Darryl Johnson of the University of Washington Cooperative Park Studies Unit to determine the effectiveness of different sign texts and barriers as a deterrent to off-trail hiking (Johnson,1989). Studies were also conducted by the park's Natural Resources Planning Division personnel to determine the specific causes and use frequencies of some of the large, persistent impacted sites that had resisted rehabilitation work. These studies helped to identify a lack of visitor understanding toward the problem of social trail use and impact creation.

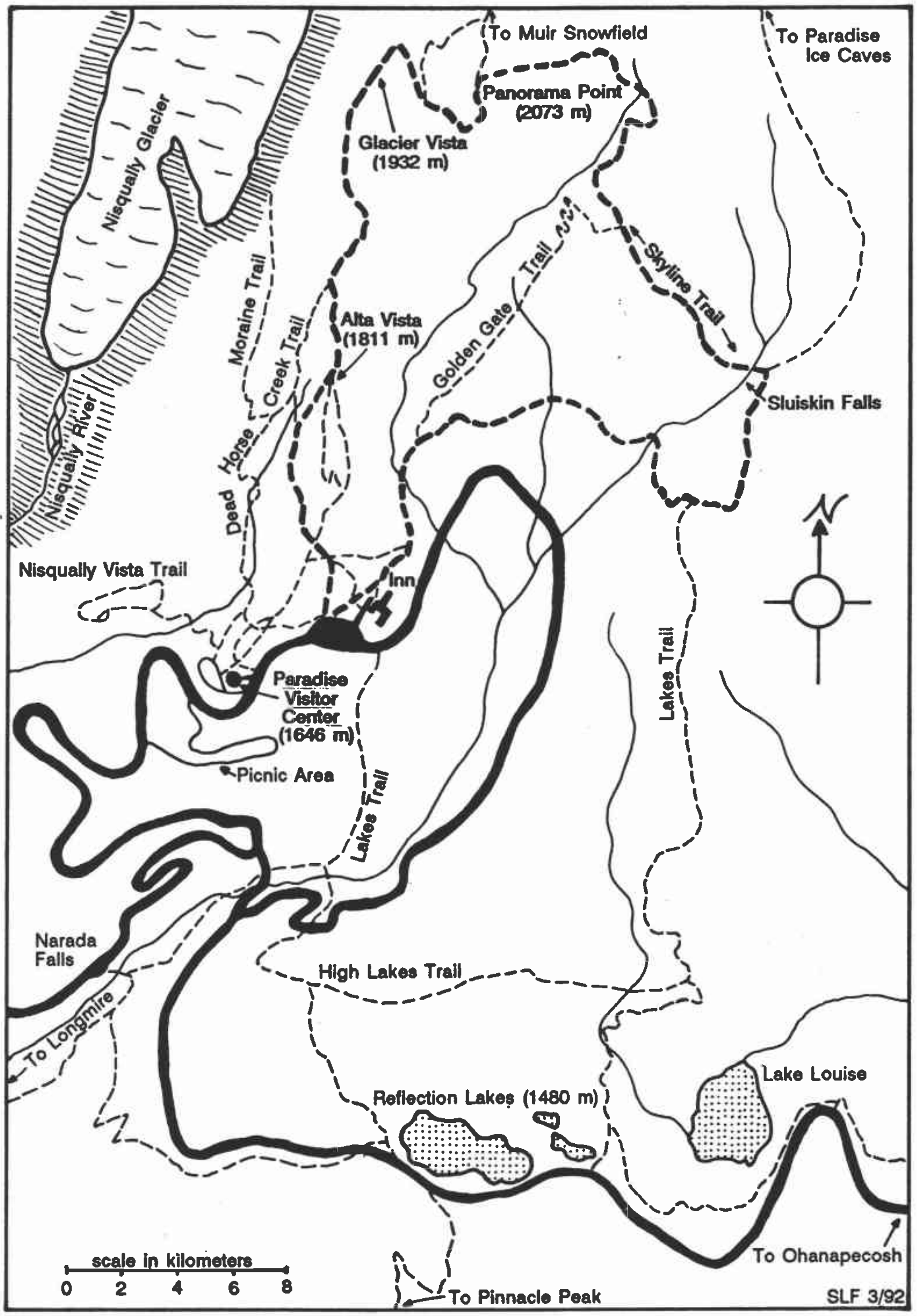

Figure 4. Maintained Paradise meadows area trails, 1987.

LITERATURE REVIEW

One of the first reports which recognized the problem of recreational impacts in the United States was about "excessive tourist travel in the California redwood parks" (Meinecke, 1928). The report qualitatively described the recreational impacts to redwood areas. This general qualitative approach was common until the 1960's in the U.S., although Lutz (1945) conducted an analytical study of trampling in picnic grounds. As the field of 'recreation ecology' (Cole, 1987) became more accepted, emphasis was placed on documenting the directly observable phenomena of vegetation damage caused by loss of soil, employing accepted monitoring techniques. Most research was conducted in state and national parks where recreation was a primary visitor activity. As recreation use increased, academic interest in the field of recreation ecology increased, and significant reviews of recreational impacts, including trampling, were conducted in both the United States and Europe (Speight, 1973; Liddle and Grieg-Smith, 1975, Liddle, 1975; Wall, 1977; Cole and Schreiner, 1981; Liddle, 1988).

European recognition of recreational impacts occurred at the same time as in the United States, but researchers concentrated their studies on the mechanisms of impacts, especially those caused by trampling (Bayfield 1971, 1973; and others). Formative work on trampling conducted by Bates (1935) on agricultural habitats assessed the relative importance of two types of treading impacts (direct mechanical injury to vegetation and indirect effects of soil change) on changes in vegetation species composition. This approach led to studies experimenting with different levels of use to assess differences in impact susceptibility as influenced by changes in vegetation type, soil type, and season (Hartesveldt, 1963; Dotzenko et al., 1967; International Union for the Conservation of Nature, 1967; and others).

As recognition and interest in recreational impacts increased in the 1960's, researchers began to do more rigorous studies based on comparisons of impacted versus un-impacted sites, attributing differences in vegetation and soils impacts to recreation activities. However, in the United States many of these studies failed to look at the exact causal mechanisms for impacts, possibly due to the large number of environments where impacts were occurring -- from picnic areas to wilderness campsites -- and the multiplicity of impacts that occurred together (Cole, 1987). In Europe, more elaborate experimental designs and techniques -- including multivariate statistics and mechanical and mathematical modeling -- were developed to relate the amount of trampling to the resulting visible, physiological and chemical effects (Speight, 1973; Liddle, 1975; Blom, 1979).

Soil erosion rates and susceptibility were included in trampling studies in the United States beginning in 1970 with Ketchledge and Leonard, who provided estimates of erosion rates on trails in the Adirondack Mountains. Ketchledge and Leonard (1970), as well as later researchers, documented the occurrence of soil compaction (which was usually measured by penetration resistance or soil bulk density) caused by repeated trampling, and mentioned loss of the organic horizon and changes in percent exposed mineral soil. These studies emphasized intensity of traffic versus social trail variables such as trail depth and width (Dale and Weaver, 1974; Cole, 1985, and others), and little attention was placed on other erosion susceptibility parameters such as soil texture or aggregate stability (Cole, 1987, Klock and McColley, 1979). Some theoretical studies attempted to model recreational effects on erosional processes utilizing the Universal Soil Loss Equation developed by W.H. Wischmeier in 1960 (Kuss and Morgan, 1980, 1984; Morgan, 1985), but practical applications were not found for these efforts.

Methods for monitoring social trails were developed by Parsons and McLeod (1980) and Cole (1983). These techniques provided quick, repeatable documentation of sites with separate impact parameters (such as length, width, depth, vegetation loss) which could then be evaluated separately or as a whole. These methods were adapted for my thesis study. The measurement system previously used in the park (Schreiner and Moorhead, 1979) was developed to measure campsite and devegetated areas and was found to by very time consuming and not practical where impacts were mostly linear and where impact densities were high, such as in the Paradise meadows.

At Mount Rainier, recreational impacts were first documented formally in 1959 by C.F. Brockman, who assessed Paradise meadow damage by comparing used and unused meadows. Unfortunately, the high degree of heterogeneity within both meadow types made comparative results inconclusive. This study was quickly followed by the first study assessing soil compaction and vegetation changes resulting from use in some of the park's backcountry sites (Thornburgh, 1962). This was a more rigorous and quantitative study which identified the need for valid control areas if comparisons were to be evaluated, and the varying responses of certain species to trampling stresses. Almost ten years later, Singer (1971) studied the differential stresses of trampling intensities and frequencies in an alpine meadow in the park, which showed no statistical difference in loss of vegetation percent cover between areas with different treatments.

The National Park Service at Mount Rainier National Park began attempting to rehabilitate recreational impact sites in the late 1960's as a result of these studies (Kirschner et al., 1977). The research focus on impacts in the park turned to developing rehabilitation techniques by which damaged ecosystems could be returned to more natural conditions (Ahlstrand, 1973; Dalle-Molle, 1977) and included more information on the susceptibility of various plant species to differing degrees of use, but ignored differences in soil erodability as determined by impact site location.

Beginning in 1978, the Mount Rainier staff began recognizing the susceptibility of some of the higher elevation plant communities. Research by Ola Edwards (1979) assessed the structure and human impact on the vegetation of Mount Rainier's alpine zone, and suggested that rehabilitation of impacted areas was difficult if not impossible due to the short growing season, susceptibility of the sandy loam soils to needle-ice formation, and soil erosion and loss subsequent to disturbance (Edwards, 1979). Continued research in the subalpine and alpine zones with attempts to restore some disturbed sites (Edwards, 1980a, 1980b) again indicated a need for protection of the subalpine and alpine vegetation of the park, particularly in heavily used areas.

In 1987 and 1988, the relationship of soil textures to the erodibility of social trails was evaluated in Mount Rainier National Park (Fritzke and Ripple, 1987, Ripple, 1989). Analysis of soil textures indicated no significant correlation between soil texture and elevation or plant community, but significant differences were found between soils sampled from different sides of Mount Rainier, suggesting the need to incorporate area soil textures into a prioritization system for social trail rehabilitation. Recommendations were made to improve social trail data collection methods by recording physical variations within trails.

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" (Appendix 2). I participated in the 1987 survey, which documented, mapped and recorded all social trails in the Paradise meadows study area. The length, width, average depth, slope, aspect, elevation, plant community, percent denudation, and probable cause of each social trail were recorded. Since the majority of Paradise area impacts were found to be linear despite the varying causes of abandoned trails, rest stops, viewpoints, etc., all sites were identified by the term "social trail".

Aerial photographs taken in August and September of 1986 at a scale of 1:5,000 helped locate social trails which were then visited in order to collect site-specific data. These larger scale natural color photographs also provided an initial estimate of the extent of social trails, and insured detection and enumeration of many social trails that would have gone unnoticed with ground surveying alone.

To facilitate a systematic approach of locating social trails identified on the aerial photographs, the Paradise area was divided into 21 sub-areas bounded by obvious landmarks such as established trails, ridgetops, other significant topographic breaks, or streams. These sub-areas were identified by two-letter abbreviations according to local adjacent landmarks, as follows:

AV	Alta Vista	**MR**	McClure Rock
DH	Dead Horse Creek	**NV**	Nisqually Vista
FM	First Hill-Marmot Hill	**PI**	Paradise Inn
FC	Fourth Crossing	**PL**	Parking Lot
GV	Glacier Vista	**PP**	Panorama Point
GG	Golden Gate	**PC**	Pebble Creek
GC	Golden Gate Corridor	**SF**	Sluiskin Falls
L1	Lower Meadow 1	**TR**	Theosophy Ridge
L2	Lower Meadow 2	**VC**	Visitor Center Meadow

L3 Lower Meadow 3

L4 Lower Meadow 4

WF Waterfall Meadow

Each sub-area was surveyed by identifying social trails on the aerial photos and then in the field, beginning in one corner of the unit, locating these known sites on the ground. 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 identified using a hierarchical system based on sub-area abbreviations, followed by numbers and letters. Therefore, names of social trails began with two letters signifying the sub-area location. Main social trails originating from an established trail were given numbers beginning with "01". Secondary social trails diverging off of these main social trails were then given a letter following the main social trail number, to designate a spur. For example, a social trail was found in the Dead Horse Creek area, and so was given the code DH01. A spur along that trail would then have been designated DH01A, and so on. Alternating numbers and letters comprised the rest of the name and therefore indicated the social trails' status as primary, secondary, etc. Most sub-areas have a social trail numbering system beginning at 0 at the southwestern-most point, and proceeding northeasterly. Sub-area maps were drawn to aid in accurately locating each trail and spur within the sub-area.

Trail length, width, and depth were measured by tape in meters and rounded off to the nearest 5 cm. Elevations were interpolated from contours on the 1:24,000 U.S.G.S. quadrangles and expressed in meters above mean sea level. Survey methods were altered slightly in 1987 to account for the variability in dimension characteristics often found in trails greater than 20 meters 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: < 31cm, 31-46cm, 47-62cm, 63-91cm, > 91cm
Trail depth: < 5cm, 5-15cm, 16-31cm, 32-62cm, 63-91cm, > 91cm
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 the prioritization process 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 (corrected for magnetic north) using the eight primary coordinates (N, NW, W, SW, S, SE, E, NE). The presence or absence of erosional condition was identified by visually estimating the soil volume lost from the site and by how disturbed the adjacent vegetation appeared to be. 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 ocularly 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 percent bare 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.

Current trail use was roughly determined by looking for foot prints and by visual observations of visitors walking in these areas. Notes were also made concerning wildlife use of trails. Probable causes of social trails were determined by casually observing and recording weekly visitor use patterns in high use areas throughout the summer. No distinction was made between apparently abandoned trails and true social trails during the data collection.

Appearance of each social trail was documented by photographing all measured trails. To facilitate future relocation of the photo points, all photos of main social trails were taken from the point of origin along the established trail. Photographs of spurs off the main social trails were taken from the main social trail to the spur. This method will greatly simplify the problem of relocating trails in any area, which was a problem in the past.

Analytical Methods

Data from the completed social trail survey were entered into a database management program (dBase III). All of the data were organized by variables in columns and sorted by row into area name and social trail identification number. Numeric 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. Character variables were: area, trail code, dominant plant community, erosional condition, and evidence of prior trail or rehabilitation work (Appendix 2).

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 segments could be analyzed separately for erosion potential. Most social trails were not segmented and so received a "1" in this column.

The variables chosen for analysis (trail area and code, elevation, trail segment, slope, length, width, depth, plant community, and percent bare ground) were exported from the main data base file into an ASCII file, and then imported into a statistical analysis program (Statgraphics).

Summary statistics were first run, and these revealed three rows of missing or incomplete data. These rows were removed to prevent skewing the results, and reduced the data set from 1129 to 1126 social trails. An artificial variable, WIDXDEP, was created by multiplying each social trail's width with it's corresponding depth. I assumed that this variable would give a general 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. The edited data were then sorted by the four variables of elevation, trail class, plant community, and levels of percent bare ground. More specifically, these four variables are: (1) three elevation classes: low (1530-1765 m), medium (1766-1945 m), high (1946-2250 m); (2) trail classes based on branching from the main trail system: first order (social trails which split directly off of maintained trails), second order (social trails which split off of first order social trails), third and fourth order (social trails which split off of second and third order social trails, respectively); (3) plant communities; and (4) levels of percent bare ground. These four variables were used to examine changes in trail characteristics between each data subset. Multiple regression was then run using trail depth as the dependent variable and elevation, slope, and plant community indicators as independent variables.

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. Logarithm or square root transformations were used on selected variables to meet the normal distribution and equal variance assumptions for both of these analyses.

RESULTS

General Characteristics of Social Trails

A total of 1126 social trails were identified in the Paradise meadows study area. General characteristics of these sites are given in Table 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.

Relationships Among Social Trail Variables

Table 3 shows a matrix of simple correlation relationships between five social trail variables: elevation, slope, length, width, and depth. Correlations ranged from weakly negative to moderately positive. Five of the ten relationships (shown in bold) were statistically significant ($P < 0.05$). 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 ($r = 0.13$, $P < 0.00$).

A multiple regression was run. I first attempted to use width x depth as the dependent variable, but the variance accounted for was very low because of the high variability in trail width. I then ran a multiple regression with trail depth as the dependent variable and slope, elevation, plant community indicator, and length as independent variables. Slope, elevation, and one plant community accounted for 17.2% ($P < 0.000$) of the variance in trail depth. Slope, alone, accounted for 11% ($P = 0.000$) 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), as shown in Table 4. Analysis of variance (Table 6a) tested for significance among these elevation classes with respect to the physical trail variables of elevation, slope, length, width, depth, and plant community. Mean slopes of social trails significantly increased with increased elevation class (12.1 to 15.2 degrees) (Table 4). Social trails at low elevations were significantly narrower (0.83 m) than trails at medium elevations (1.11 m) and high elevations (1.14 m). Mean trail depths were significantly greater at high elevations (22 cm) than at medium (13 cm) and low elevations (13 cm). The derived variable of widxdep also reflects this trend.

Table 5 presents a matrix of correlation relationships between mean social trail variables within each elevation class. The only significant relationship at low elevations was between mean slope and mean depth ($r = 0.23$, $P < 0.00$). Medium elevation social trails exhibited a greater number of significant correlations, namely a negative correlation between mean elevation and mean length ($r = -0.12$, $P = 0.01$) and moderate positive correlations between elevation and width ($r = 0.10$, $P = 0.04$), slope and depth ($r = 0.36$, $P = 0.00$),and width and depth ($r = 0.15$, $P = 0.00$). The correlation coefficients for high elevation social trails exhibited the strongest and greatest number of significant relationships as compared to low and medium elevations. Significant ($P = 0.00$) negative relationships were found between elevation and slope ($r = -0.19$), elevation and width ($r = -0.21$), and elevation and depth ($r = -0.36$). As with the low and medium elevation sites, moderately positive correlations were found between slope and depth ($r = 0.43$, $P = 0.00$), and width and depth ($r = 0.22$, $P = 0.01$).

Table 2. Summary statistics for six variables for all social trails (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
Width x Depth(m^2) [a]	0.16	0.44	0.00	8.70

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

Table 3. Correlation coefficient matrix for five independent variables for all social trails (n = 1126).

	ELEV	SLOPE	LENGTH	WIDTH	DEPTH
ELEV	-	**0.09**	-0.03	**0.07**	**0.13**
	-	(0.00)	(0.25)	(0.02)	(0.00)
SLOPE		-	0.00	0.04	**0.36**
		-	(0.91)	(0.15)	(0.00)
LENGTH			-	0.02	0.02
			-	(0.55)	(0.53)
WIDTH				-	**0.14**
				-	(0.00)
DEPTH					-
					-

Top number is the correlation coefficient *r* .

Bottom number is the significance level (P- value).

Significant correlations ($P < 0.05$) are indicated by bold print.

Table 4. 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
Width x Depth (m^2)	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
Width x Depth (m^2)	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
Width x Depth (m^2)	0.21	0.54	0.00	3.91

Table 5. Correlation coefficients for five social trail variables with three elevation classes.

	ELEV (m)	SLOPE (deg)	LENGTH (m)	WIDTH (m)	DEPTH (m)
Low Elevation (n=410) (1530 -1765 m)					
ELEV	- -	0.08 (0.09)	0.02 (0.75)	0.07 (0.18)	0.06 (0.22)
SLOPE		- -	-0.03 (0.59)	0.01 (0.79)	**0.23** (0.00)
LENGTH			- -	0.05 (0.33)	0.06 (0.23)
WIDTH				- -	0.06 (0.23)
DEPTH					- -
Medium Elevation (n=476) (1766 - 1945 m)					
ELEV	- -	-0.06 (0.18)	**-0.12** (0.01)	**0.10** (0.04)	-0.02 (0.71)
SLOPE		- -	0.04 (0.36)	0.03 (0.46)	**0.36** (0.00)
LENGTH			- -	0.03 (0.46)	0.03 (0.51)
WIDTH				- -	**0.15** (0.00)
DEPTH					- -
High Elevation (n=240) (1946-2250 m)					
ELEV	- -	**-0.19** (0.00)	0.07 (0.27)	**-0.21** (0.00)	**-0.36** (0.00)
SLOPE		- -	0.00 (0.97)	0.02 (0.77)	**0.43** (0.00)
LENGTH			- -	-0.07 (0.27)	-0.04 (0.55)
WIDTH				- -	**0.22** (0.01)
DEPTH					- -

Table 6. Results of analysis of variance (ANOVA) protected least significant difference method.

Table 6a. Data sorted by elevation class (see Tables 4 and 5).
(Lowtrail = 1530-1765 m; Medtrail = 1766-1945 m; Hitrail = 1946-2250 m)

Variable[1]	Category	Significance Between Categories [2]	ANOVA P-values Among Categories
Slope:	Lowtrail vs. Hitrail	*	0.000
	Lowtrail vs. Medtrail	*	
	Medtrail vs. Hitrail	*	
Length: [3]	Lowtrail vs. Hitrail		0.705
	Lowtrail vs. Medtrail		
	Medtrail vs. Hitrail		
Width: [3]	Lowtrail vs. Hitrail	*	0.000
	Lowtrail vs. Medtrail	*	
	Medtrail vs. Hitrail		
Depth: [3]	Lowtrail vs. Hitrail	*	0.008
	Lowtrail vs. Medtrail		
	Medtrail vs. Hitrail	*	
WidxDep: [3]	Lowtrail vs. Hitrail	*	0.000
	Lowtrail vs. Medtrail	*	
	Medtrail vs. Hitrail	*	

1 Variable refers to overall social trail variables.

2 Significance at 0.05 probability level indicated by *.

3 Logarithmic transformations for skewed data and/or unequal variances.

Table 6 (cont.)

Table 6b. Data sorted by social trail hierarchy order (see Tables 7 and 8).

Variable[1]	Category	Significance Between Categories [2]	ANOVA P-values Among Categories
Elevation:	First vs. Second	*	0.001
	First vs. Third/Fourth	*	
	Second vs. Third/Fourth	*	
Slope:	First vs. Second		0.406
	First vs. Third/Fourth		
	Second vs. Third/ Fourth		
Length: [3]	First vs. Second	*	0.000
	First vs. Third/Fourth	*	
	Second vs. Third/Fourth		
Width: [3]	First vs. Second	*	0.000
	First vs. Third/Fourth	*	
	Second vs. Third/Fourth		
Depth: [3]	First vs. Second		0.256
	First vs. Third/Fourth		
	Second vs. Third/Fourth		
WidxDep: [3]	First vs. Second	*	0.000
	First vs. Third/Fourth		
	Second vs. Third/Fourth		

1 Variable refers to overall social trail variables.
2 Significance at 0.05 probability level indicated by *.
3 Logarithmic transformations for skewed data and/or unequal variances.

Table 6 (cont.)

Table 6c. Data sorted by plant community (see Table 9).

Variable[1]	Category	Significance Between Categories[2]	ANOVA P-values Among Categories
Elevation:[3]	LowHerb vs. LushHerb	*	0.000
	LowHerb vs. WetSedge	*	
	LowHerb vs. Heath		
	LowHerb vs. Fellfield	*	
	LushHerb vs. WetSedge		
	LushHerb vs. Heath	*	
	LushHerb vs. Fellfield	*	
	WetSedge vs. Heath	*	
	WetSedge vs. Fellfield	*	
	Heath vs. Fellfield	*	
Slope:[4]	LowHerb vs. LushHerb	*	0.000
	LowHerb vs. WetSedge		
	LowHerb vs. Heath	*	
	LowHerb vs. Fellfield		
	LushHerb vs. WetSedge		
	LushHerb vs. Heath	*	
	LushHerb vs. Fellfield		
	WetSedge vs. Heath		
	WetSedge vs. Fellfield		
	Heath vs. Fellfield	*	
Length:[3]	LowHerb vs. LushHerb		0.153
	LowHerb vs. WetSedge		
	LowHerb vs. Heath		
	LowHerb vs. Fellfield		
	LushHerb vs. WetSedge		
	LushHerb vs. Heath		
	LushHerb vs. Fellfield		
	WetSedge vs. Heath		
	WetSedge vs. Fellfield		
	Heath vs. Fellfield		

1 Variable refers to overall social trail variables.

2 Significance at 0.05 probability level indicated by *.

3 Logarithmic transformations for skewed data and/or unequal variances.

4 Square root transformations for skewed data and/or unequal variances.

Table 6c (cont.)

Variable[1]	Category	Significance Between Categories [2]	ANOVA P-values Among Categories
Width: [3]	LowHerb vs. LushHerb	*	0.002
	LowHerb vs. WetSedge		
	LowHerb vs. Heath	*	
	LowHerb vs. Fellfield		
	LushHerb vs. WetSedge		
	LushHerb vs. Heath		
	LushHerb vs. Fellfield	*	
	WetSedge vs. Heath		
	WetSedge vs. Fellfield		
	Heath vs. Fellfield		
Depth: [3]	LowHerb vs. LushHerb		0.000
	LowHerb vs. WetSedge		
	LowHerb vs. Heath	*	
	LowHerb vs. Fellfield	*	
	LushHerb vs. WetSedge		
	LushHerb vs. Heath	*	
	LushHerb vs. Fellfield	*	
	WetSedge vs. Heath		
	WetSedge vs. Fellfield		
	Heath vs. Fellfield	*	
WidxDep: [3]	LowHerb vs. LushHerb		0.000
	LowHerb vs. WetSedge		
	LowHerb vs. Heath	*	
	LowHerb vs. Fellfield	*	
	LushHerb vs. WetSedge		
	LushHerb vs. Heath	*	
	LushHerb vs. Fellfield	*	
	WetSedge vs. Heath		
	WetSedge vs. Fellfield		
	Heath vs. Fellfield	*	

1 Variable refers to overall social trail variables.

2 Significance at 0.05 probability level indicated by *.

3 Logarithmic transformations for skewed data and/or unequal variances.

Table 6 (cont.)

Table 6d. Data sorted by percent bare ground (see Table 10).

Variable[1]	Category	Significance Between Categories[2]	ANOVA P-values Among Categories
Elevation: [3]	LowBare vs. MedLoBare		0.000
	LowBare vs. MedHiBare		
	LowBare vs. HiBare	*	
	MedLoBare vs. MedHiBare		
	MedLoBare vs. HiBare	*	
	MedHiBare vs. HiBare	*	
Slope:	LowBare vs. MedLoBare		0.135
	LowBare vs. MedHiBare		
	LowBare vs. HiBare		
	MedLoBare vs. MedHiBare		
	MedLoBare vs. HiBare		
	MedHiBare vs. HiBare		
Length: [3]	LowBare vs. MedLoBare		0.960
	LowBare vs. MedHiBare		
	LowBare vs. HiBare		
	MedLoBare vs. MedHiBare		
	MedLoBare vs. HiBare		
	MedHiBare vs. HiBare		
Width: [3]	LowBare vs. MedLoBare		0.005
	LowBare vs. MedHiBare		
	LowBare vs. HiBare	*	
	MedLoBare vs. MedHiBare		
	MedLoBare vs. HiBare	*	
	MedHiBare vs. HiBare	*	

[1] Variable refers to overall social trail variables.

[2] Significance at 0.05 probability level indicated by *.

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

Table 6d (cont.)

Variable[1]	Category	Significance Between Categories[2]	ANOVA P-values Among Categories
Depth: [3]	LowBare vs. MedLoBare		0.000
	LowBare vs. MedHiBare		
	LowBare vs. HiBare	*	
	MedLoBare vs. MedHiBare		
	MedLoBare vs. HiBare	*	
	MedHiBare vs. HiBare		
WidxDep: [3]	LowBare vs. MedLoBare		0.000
	LowBare vs. MedHiBare		
	LowBare vs. HiBare		
	MedLoBare vs. MedHiBare		
	MedLoBare vs. HiBare	*	
	MedHiBare vs. HiBare		

1 Variable refers to overall social trail variables.
2 Significance at 0.05 probability level indicated by *.
3 Logarithmic transformations for skewed data and/or unequal variances.

Social trail variables were split with respect to three trail order classes, reflecting the hierarchy in trail branching patterns: first order, second order, and third and fourth order combined. Table 7 summarizes these relationships, Table 6b, summarizing ANOVA, provides statistical verification of the validity of the relationships. First order trails were significantly lower in elevation (mean = 1815 m), and were also significantly longer (mean = 50.1 m) than second and third/fourth order trails. Furthermore, first order trails stood out as being significantly wider and deeper than second order trails. Neither social trail depth or slope were found to be significantly correlated to trail hierarchy. Linear correlations of the six variables classified by social trail hierarchy (Table 8) show numerous significant relationships between variables in the first and second order social trails, but only two significant relationships between variables in the third/fourth order trails. The variable of percent bare ground was added to the analysis to determine possible correlations with other physical variables.

The first order hierarchy had seven significant correlations between social trail variables (Table 8), namely elevation with slope ($r = 0.09$, $P = 0.01$), with width ($r = 0.09$, $P = 0.02$), with depth ($r = 0.18$, $P < 0.00$), and with percent bare ground ($r = 0.21$, $P < 0.00$). Correlations between width and depth ($r = 0.13$, $P < 0.00$) and depth to percent bare ground ($r = 0.11$, $P < 0.00$) were also significant. The most highly correlated relationship was between slope and depth ($r = 0.34$, $P < 0.00$).

There were eight significant correlations between social trail variables in the second order class (Table 8). These were elevation to width ($r = 0.17$, $P < 0.00$) and percent bare ground ($r = 0.21$, $P < 0.00$); slope with width ($r = 0.17$, $P < 0.00$), and with percent bare ground ($r = 0.12$, $P = 0.02$); width with depth ($r = 0.29$, $P < 0.00$), width with percent bare ground ($r = 0.16$, $P < 0.00$), and depth with percent bare ground ($r = 0.14$, $P < 0.00$). Again, the highest correlation between variables overall within the second order class was between slope and depth ($r = 0.36$, $P < 0.00$).

Correlation analysis among variables in the third and fourth order class displayed two significant relationships, reflecting the same pattern seen for the first and second order social trails (Table 8). These were moderately strong relationships between elevation and width ($r = 0.39$, $P < 0.00$), and between slope and depth ($r = 0.57$, $P < 0.00$).

Table 7. Summary statistics for six social trail variables sorted by trail hierarchy. [a]

	Mean	Standard Deviation	Minimum	Maximum
First Order (n = 672)				
Elevation (m)	1815	137	1536	2189
Slope (deg)	13.7	9.3	0.0	50.0
Length (m)	50.1	97.3	0.7	1500.0
Width(m)	1.22	2.21	0.01	25.60
Depth (m)	0.13	0.13	0.00	1.00
Width x Depth (m^2)	0.17	0.52	0.00	8.70
Second Order (n=401)				
Elevation (m)	1837	156	1530	2246
Slope (deg)	13.0	8.4	0.0	40.0
Length (m)	26.1	30.9	0.5	263.0
Width (m)	0.63	0.44	0.01	4.02
Depth (m)	0.14	0.13	0.00	0.90
Width x Depth (m^2)	0.13	0.24	0.00	2.11
Third and Fourth (n=53)				
Elevation (m)	1886	171	1625	2234
Slope (deg)	12.7	8.9	0.0	35.0
Length (m)	22.7	36.2	2.8	253.0
Width (m)	1.42	2.72	0.05	20.00
Depth (m)	0.09	0.08	0.00	0.30
Width x Depth (m^2)	0.15	0.31	0.00	2.00

[a] First order social trails are those which split off of maintained trails.
Second order trails split off of first order trails and are not attached to established trails.
Third and Fourth order trails split off second and third order trails, respectively.

Table 8. Correlation coefficient matrices of six social trail variables sorted by social trail hierarchy. [a]

	ELEV (m)	SLOPE (deg)	LENGTH (m)	WIDTH (m)	DEPTH (m)	BARE (%)
First Order Trails (n=672)						
ELEV	-	**0.09**	-0.02	**0.09**	**0.18**	**0.21**
	-	(0.01)	(0.54)	(0.02)	(0.00)	(0.00)
SLOPE		-	-0.02	0.03	**0.34**	0.03
		-	(0.59)	(0.50)	(0.00)	(0.38)
LENGTH			-	-0.01	0.00	0.06
			-	(0.86)	(0.91)	(0.12)
WIDTH				-	**0.13**	0.01
				-	(0.00)	(0.79)
DEPTH					-	**0.11**
					-	(0.00)
BARE [b]						-
						-
Second Order Trails (n=402)						
ELEV	-	0.08	0.01	**0.17**	0.08	**0.21**
	-	(0.09)	(0.89)	(0.00)	(0.09)	(0.00)
SLOPE		-	0.09	**0.17**	**0.36**	**0.12**
		-	(0.08)	(0.00)	(0.00)	(0.02)
LENGTH			-	-0.05	0.03	-0.00
			-	(0.36)	(0.58)	(0.93)
WIDTH				-	**0.29**	**0.16**
				-	(0.00)	(0.00)
DEPTH					-	**0.14**
					-	(0.00)
BARE [b]						-
						-

Table 8 (cont.)

Third and Fourth Order Trails (n=53)

ELEV	-	0.20	0.18	**0.39**	0.04	0.16
	-	(0.15)	(0.19)	(0.00)	(0.78)	(0.25)
SLOPE		-	0.08	0.14	**0.57**	-0.03
		-	(0.56)	(0.31)	(0.00)	(0.85)
LENGTH			-	-0.04	0.12	0.05
			-	(0.77)	(0.40)	(0.72)
WIDTH				-	0.17	0.12
				-	(0.22)	(0.40)
DEPTH					-	0.06
					-	(0.67)
BARE [b]						-
						-

[a] First order social trails are those which split off of maintained trails.
Second order trails split off of first order trails and are not attached to established trails.
Third and Fourth order trails split off second and third order trails, respectively.

[b] Percent bare ground variable derived from raw field data.

Table 9 shows summary statistics of the data sorted by five generalized plant communities. Statistical verification by ANOVA is given in Table 6c. No social trails were located in the dry grass community. Of the five remaining 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. 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.

The data were also sorted by four classes of percent bare ground, a variable recorded at each social trail location (Table 10, ANOVA statistics are in Table 6d). Of the 1126 social trails within the study area, 78% of the sites showed a high percent bare ground (85-100% bare), and the remaining 22% of social trails were distributed relatively evenly within the three lesser bare ground classes (0-15%, 16-49%, and 50-84% bare). The high percent bare ground class had the highest average elevation (1845 m, $P = 0.00$). Social trail slope,length, width and depth when sorted by percent bare class were generally not significantly different except for the high elevation trails, which exhibited significantly more bare area than other trails (Table 6d).

Table 9. 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)	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)	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)	0.10	0.11	0.00	0.51
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)	0.22	0.61	0.00	8.71

Table 9 (cont.).

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)	0.11	0.11	0.00	0.84

Table 10. Summary statistics for six social trail variables sorted by percent bare ground class.

	Mean	Standard Deviation	Minimum	Maximum
Low Percent Bare (n=90)				
(0-15%)				
Elevation (m)	1762	106	1615	2173
Slope (deg)	12.3	9.1	0.0	45.0
Length (m)	35.4	35.9	3.0	180.0
Width (m)	1.11	2.41	0.10	20.06
Depth (m)	0.12	0.11	0.00	0.73
Widxdep (m^2)	0.11	0.43	0.00	3.00
Intermediate Low Percent Bare (n=62)				
(16-49%)				
Elevation (m)	1750	95	1597	2146
Slope (deg)	12.5	7.5	0.0	35.0
Length (m)	30.0	25.3	3.4	148.3
Width (m)	0.84	0.74	0.04	4.00
Depth (m)	0.11	0.13	0.00	0.50
Widxdep (m^2)	0.13	0.11	0.00	0.42
Intermediate High Bare (n=101)				
(50 - 84%)				
Elevation (m)	1768	102	1646	2146
Slope (deg)	12.0	7.9	0.0	35.0
Length (m)	36.2	38.6	4.0	253.7
Width (m)	0.79	1.13	0.03	9.52
Depth (m)	0.12	0.13	0.00	1.00
Widxdep (m^2)	0.13	0.34	0.00	1.93
High Percent Bare (n=873)				
(85-100%)				
Elevation (m)	1845	152	1530	2246
Slope (deg)	13.7	9.2	0.0	50.0
Length (m)	41.9	87.4	0.5	1500.0
Width (m)	1.00	1.84	0.04	25.60
Depth (m)	0.14	0.13	0.00	1.00
Widxdep (m^2)	0.22	0.51	0.00	8.71

DISCUSSION

Social Trail Characteristics

The Paradise meadows social trail survey revealed 1126 sites, one quarter of which were divided into trail segments due to significant changes in slope, width or depth. Social trails were dispersed fairly evenly throughout the Paradise meadows study area (Figure 5), 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 (Rochefort, 1989).

Correlation analysis (Table 3) indicates that as elevation increased, social trail widths increased. This relationship can be attributed, in part, to the increased natural percent bare ground in the heath shrub and fellfield communities. Established trails become less well-defined in these high elevation communities, and visitors, being unconstrained by the sparse vegetation, tend to walk wherever they want. Cole (1983) also found that exposed rocks within the trail tread area tended to lead to excessive widening of trails as hikers attempted to skirt the rocks. Both the fellfield and heath shrub communities are sensitive to such random trampling patterns. Impacts are further exacerbated by long-term damage to the woody parts of the plants, abrasion of soft plant tissues, and soil compaction. These trampling effects result in the gradual die-back of the woody heather as stems are broken, roots damaged and exposed by soil erosion, and plants dessicated (Edwards, 1980b).

The most significant relation among variables was between slope and social trail depth. The steeper the slope, the more soil erosion, and the deeper 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. Erosion is exacerbated by the presence of dwarf woody-stemmed vegetation, which is especially vulnerable to damage and slow to recover or become re-established (Edwards, 1980b).

The pattern of increase in slope of social trails at higher elevation (Table 3) also led

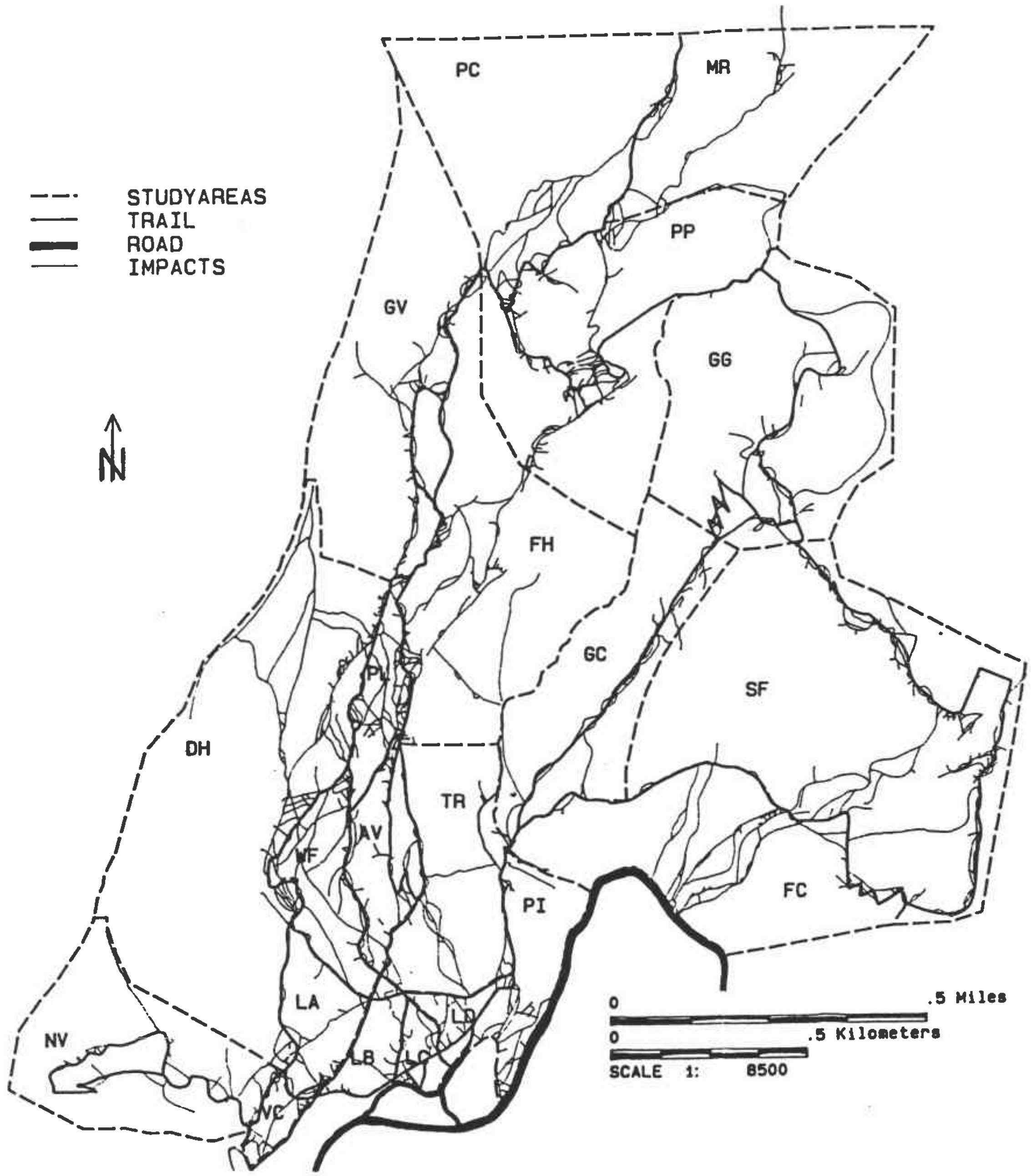

Figure 5. Paradise meadows social trails,

based on aerial photograph analysis and ground surveys, 1987.

visitors to create parallel trails to avoid eroded gullies at higher elevations, which are difficult to walk in (Stanley et al., 1977). These parallel trails eventually merge together. 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, 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 compacted soils become more susceptible to erosion by wind, water and ice (especially needle ice). 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. Thus, loss of normal vegetation cover seriously affects the susceptibility of a given site to subsequent erosion (Gray and Leiser, 1982).

Examining the data split into elevation classes (Tables 4 and 5), 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 (Johnson, 1989). Many of the officially "abandoned trails" (such as the Moraine trail, providing the only fairly easy access to the Nisqually Glacier) that are still used have been re-designated as maintained trails since the field work was conducted for this study (Rochefort, 1989). 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 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 slopes of sites increased, use may or may not have decreased, but the slopes themselves contribute to the continual soil loss.

At the highest elevations within the study area, slopes, widths and depths of social trails were negatively correlated with elevation. The upper elevations of the study site are fairly flat except in drainages (Edwards, 1979), and most impacts at the very highest elevations were on this flat terrain. Most visitors come to Paradise for the day, only, and are not acclimatized for hiking at over 2000 m elevation, so they tend to remain on either the established trails or on social trails that are easily followed and have fairly level routes through the sparse vegetation and rocks (Johnson, 1989). The decrease in overall impact within the upper elevation zone may be partially explained by this apparent decrease in use, as well as the level topography.

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 when the distinction between path boundary and adjacent area becomes less defined. The upper elevations of the study area (>1945 m) have site condition and social trails that more or less conform to Liddle's observations. The area is characterized by a very gravelly soil texture, and the social trails are visually obvious in the landscape, attracting visitor use. Hikers kick gravels to the sides of the trail, differentially exposing finer soil particles in the trail tread. Finer soils are then subject to needle ice formation making soil susceptible to erosion, exposing roots, and causing plants to die. Plant removal exposes still more soil to needle ice formation (Edwards, 1980a).

Hierarchical analysis of social trails (Tables 7 and 8) suggests that the first order social trails, found primarily at lower elevations, have more visitor use than first order trails at higher elevations. On the other hand, second, third and fourth order trails -- which branch off of first order sites -- are found at middle elevations where visitors, frustrated with poorly designed trail layouts and unsure of where each trail is leading, tend to split off and make their own way through the area (Rochefort, 1989). Development of second and higher order trails at middle elevations also occurs because off-trail hiking is both physically easier because vegetation is lower to the ground and soils are drier, and these areas are perceived to be less susceptible to trampling damage (Johnson, 1989). On the other hand, at lower elevations, lush herbaceous vegetation in wet habitats is perceived as being vulnerable to damage and people stay on the already developed social trails (Singer, 1971).

Social trail lengths decreased with increased trail hierarchy because secondary and tertiary branching usually lead the person to whatever the destination point is, instead of just generally branching away from the maintained trails as the first order trails do.

In first and second order classes, depths also decreased with increased hierarchy, which is most likely due to these higher order sites being less used and having less slope than the first order sites. Widths, however, increased with increased hierarchy as a function of elevation, because as elevation increases the vegetation becomes more susceptible to trampling and thus tends to expose the soils which are then exposed to sheet erosion.

The sensitivity of plant communities to social trails can be evaluated by referring to the summary of social trail variables sorted by plant community (Table 9) and variable significance values (Table 6c). Plant communities differed significantly in elevation. The slope variable was poorly related to plant communities except for heath-shrub, which was found on steeper slopes. 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. 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. Multiple regression showed a significant relationship of trail depth to elevation and the heath-shrub community, which is found on the steepest overall slopes within the study area. Heath is especially sensitive to trampling damage as it is woody and slow to recover (Edwards, 1980b). Trail depth was not high at the highest elevations (fell field community) because the soils are rocky and resist erosion.

CONCLUSIONS

Mount Rainier National Park has a significant problem of resource damage caused by concentrated visitor use. This problem is exacerbated by the combination of physical landscape features (elevation and slope) with variable plant community susceptibility to trampling. The results of the social trail survey data analysis presented here indicate that elevation and slope work together to intensify social 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 results in erosion caused by water and wind, two 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. Elevation effectively limits the number and extent of impacts by making higher elevation sites more difficult to reach by visitors.

Social trail hierarchies (first, second, third, and fourth) serve as an indicator of the severity of the impacts present. This is shown by a close relationship between the physical dimensions of social trails (width, depth, length) and the hierarchical class.

Plant community types can be used to generally characterize the overall physical dimensions of social trails within those types. Because of this, communities can be used initially to prioritize 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. In addition, information may be gathered by assessing the relationships of plant communities to physical landscape characteristics which affect erosion potential, such as slope.

Multiple regression analysis identifies slope, elevation, and the heath-shrub plant community as the major factors accounting for social trail depths. The predictive value of this relationship, however, is low (17 percent). The reason for this may be because of the high variability in the social trail characteristics explaining depth. This relationship may be improved by doing trail characteristic analysis involving data stratification, and by including other site variables in the data analysis such as visitor use levels and drainage pattern affects on the social trails.

In conclusion, one of the most significant issues facing Mount Rainier National Park is the natural resource degradation caused by heavy visitor use combined with long winters, short growing seasons, and vegetation and soils susceptible to trampling damage. 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 (U.S. Department of the Interior, 1986).

The National Park Service has the difficult task of preserving natural ecosystems which have evolved with little or no pressure from humans, while providing for the enjoyment of present and future generations (U.S. Congress, 1916). While the park service mandate has an inherent contradiction in that it is difficult to truly preserve an area while allowing visitation, wise management of visitor use areas can go far in reducing potential damage caused by multitudes of visitors. Paradise meadows provide an excellent opportunity for visitors to be introduced to the subalpine and alpine ecosystems of the Cascades, but the fact that these systems may take hundreds of years to recover naturally after damage has occurred (Edwards, 1980a) makes it imperative to protect the remaining resources.

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 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 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.

General Recommendations to Park Managers:

The following general recommendations to park managers were developed based on experience working with social trail documentation and rehabilitation for three field seasons at Mount Rainier National Park and Yosemite National Park. The study and methods presented in this thesis were developed in the Paradise meadows area of Mount Rainier National Park. Many of the results and recommendations are applicable only to the Cascades and Olympic ranges of Oregon and Washington. However, the documentation and survey methods can be universally applied wherever social impacts have been identified. The system has been in use at Mount Rainier National Park since 1987 with minimal changes, forming a data base of social impacts needed by management to prioritize rehabilitation efforts.

The Paradise meadows study area consisted exclusively of southerly (SW-S-SE) aspects, so the aspect parameter was not used in data analysis. Since aspect is known to affect microclimatic conditions and therefore vegetation, soils, and erodability (increased moisture decreases dessication of injured plants, but increased sunlight allows for faster vegetative hardening and decreased succulence, from Kuss, 1986), it should be included in the analysis of areas with variable aspects to assess possible relationships and significance when aspect varies significantly between sites.

When new trails are established or re-designated from abandoned status, more attention should be given to proper site planning factors including plant community, slope, and soil conditions. The ability of soil to drain, to resist erosion, and to support plant growth (Leonard and Plumley, 1979) should be assessed to insure that these new trails are put in appropriate locations where further problems will not result.

Avoid developing trails in the heath-shrub plant community and on or across steep slopes. These areas are most susceptible to irreversible damage, occurring on steep slopes at high elevations where the growth season is short and vegetation recovery is slow. In addition, discourage the development of social trails in these areas, and make efforts to block off and rehabilitate existing social trails in this community.

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, 1980a, 1980b). 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 & Marr, 1970, 1971). Once the impact causes are stopped, restoration can wait until funding and personnel are available.

Data analyses should be modified to accommodate multiple plant communities. For the present analysis, impacted sites that were located within two or more communities were arbitrarily assigned to be in one, based on location, elevation, and adjacent impacted site classifications, to simplify the analysis. Significant interactions may show up in sites found in ecotones, and in those sites where vegetation changes along with significant changes in slope, elevation, etc.

Impacted sites usually exhibit a significant loss of soil substrate, so that physical modification as well as revegetation is necessary to restore the site to pre-disturbance conditions (Van Horn, 1979). Filling these eroded sites with soil is necessary because scars left unfilled will attract visitor use after revegetation, and will continue to erode even after revegetated, because of channeling of runoff. When restoring impacted sites, replacement soils should replicate the original soil texture as closely as possible. By introducing soils with different texture, it is possible that species will invade this new habitat that are not otherwise found in the area, such as native "invaders" from lower elevations and introduced weed species. By using soils with similar composition, local pioneer species are more likely to become established.

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 be necessary. For example, based on field reconnaissance alone in the Paradise meadows, 250 social trails were estimated to exist in

1986, and 1126 were found in 1987 (a 450% increase) using a combination of aerial photographs and field checking. 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 had 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. 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.

When overflow parking areas or new pullouts and parking areas are established, thought also should be given to the potential for impacts to the adjacent (off-road) ecosystem caused by introducing more visitors to the particular area. For example, overflow parking at Paradise is directed down the one-way loop through Paradise Valley. Visitors come to the area to hike on the trails through the subalpine meadows, and when directed to park on the loop road, they try to directly access the established trails they know are uphill from them. This has resulted in at least six social trails through the Fourth Crossing subarea which connects the loop road to the established trails leading towards Paradise Inn and Sluiskin Falls. Since established parking areas encourage trampling (Willard and Marr, 1970), it would behoove managers to plan and establish trails providing low-impact access to those areas. Until then, the public should be directed to other areas that have established trail systems.

Enforcement of rules governing strict use of established trails is necessary, especially in highly used areas such as Paradise and Sunrise. This should involve fines, and must be in conjunction with a strong and widely dispersed interpretation program emphasizing why trampling is so destructive to these areas, and why developed areas have to be treated in a special way.

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APPENDICES

APPENDIX 1.

Generalized Plant Communities in the Paradise Meadows Area, after Henderson (1974).

Wet Sedge: Dominated by black sedge (*Carex nigricans*) and associated with Jeffrey's shooting star (*Dodecatheon jeffreyi*) and elephant heads (*Pedicularis groenlandicum*). This community occurs where the water table is at or near the surface, generally in lower-elevation swales.

Low Herbaceous: This type has plants less than 8" in height at maturity, and occurs in wet areas that become dry later in the summer. Common plants are the alpine aster (*Aster alpigenus*), pussy toes (*Antennaria lanata*), Tolmie saxifrage (*Saxifraga tolmei*) and partridgefoot (*Luetkia pectinata*).

Lush Herbaceous: This type has plants generally taller than 8" in height, characterized by tall, lush vegetation with complete ground cover. Important species include the tall blue lupine (*Lupinus latifolius*), sitka valerian (*Valeriana sitchensis*) and the magenta paintbrush (*Castilleja parviflora*).

Dry Grass: The dry grass community occurs where sandy soils are very dry late in the summer. The type is dominated by green fescue (*Festuca viridula*).

Heath Shrub: This community type has continuous winter snow and is dominated by ericaceous shrubs occurring between 5200' and 7000' in elevation. Common species are the yellow mountain-heather (*Phyllodoce glanduliflora*), red mountain-heather (*Phyllodoce empetriformis*), white mountain-heather (*Cassiope mertensiana*), and blue-leaf huckleberry (*Vaccinium deliciosum*).

Fellfields: These occur on gentle slopes (15-30%) that are generally south-facing; plants are low growing, forming a matted mosaic with the rocks. Species commonly occurring in the fellfield areas are showy sedge (*Carex spectabilis*), yellow mountain-heather (*Phyllodoce glanduliflora*), crowberry (*Empetrum nigrum*) and Lyall's lupine (*Lupinus lepidus*).

APPENDIX 2

Paradise Social Trail Survey

Date: ______________________ Observers: ______________________
Elevation (ft): ______________________ Aspect: ______________________
Area: ______________________ Border Trails: ______________________
Trail Code: ______________________ Photo Number: ______________________

Trail Segment:	1	2	3	4	5	6
Slope (deg):	______	______	______	______	______	______
Length (m):	______	______	______	______	______	______
Width (m):	______	______	______	______	______	______
Depth (m):	______	______	______	______	______	______

Dominant plant community bordering the impact site:
___ heath-shrub (HS) ___ lush-herbaceous (LH) ___ low-herbaceous (LO)
___ dry-grass (DG) ___ wet-sedge (WS)
___ fellfield (FF) ___ % bare

Erosional condition: (Check one or more)
___ No erosion (i.e. stabilized with plants) ___ Erosion evident
___ Soil compacted throughout site
Comments:

Estimate percent of area that is bare:
___ <5% ___ 6-25% ___ 26-50% ___ 51-75% ___ 76-95% ___ 96-100%
Is loss continuing? ___ Y ___ N
Comments:

Evidence of prior trail or rehabilitation work?
___ Transplants ___ Jute netting ___ Water bars ___ Others