Trail Impacts and Their Management in Huascarán National Park, Andes Mountains, Peru

by

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Introduction

Park and protected area managers around the world are often faced with the conflicting mandate of providing park users access while preserving the flora, fauna, and natural ecological systems within the park for future generations. This mandate becomes problematic when visitation within the park boundaries by tourists or use by local populations results in adverse natural resource impacts. As a result, managers must develop systems to monitor user impacts and strategies to mitigate them when they are deemed unacceptable.

Tourism is the world's largest and one of its fastest growing industries. In 1998, world tourism receipts came to 445 billion dollars (WTO, 1999). It has been estimated that 15-20% of the tourism industry, or $66-90 billion per year, is tourism in mountain regions (Mountain Agenda, 1999). Tourism to mountain areas often entails outdoor recreational activities such as hiking, backpacking, climbing, skiing, and mountaineering. This growing number of visitors to fragile mountain parks and protected areas is of importance to managers concerned with visitor impacts.

Ecotourism and protected areas often are promoted by developing country governments to attract international visitation and associated revenues while avoiding environmental degradation from resource extraction industries. However, protected area visitation can cause soil erosion along trails, campsite proliferation, vegetation damage, wildlife disturbance and water pollution (Marion & Farrell, 1998; Obua & Harding, 1997).

Trail impacts are particularly important because trail-related recreation activities such as hiking and wildlife viewing are popular ecotourism activities, and because trails receive some of the most intensive visitor use within protected areas (Backman & Potts, 1993; Wight, 1996). Trails provide access to protected area attractions and facilities, facilitate recreation opportunities, and protect natural resources by concentrating visitor use (Leung & Marion, 1996). Trail deterioration is a concern for protected area managers because trails may become difficult or unsafe, aesthetic aspects of protected areas may be diminished, and because substantial funding or staffing may be required to repair or maintain trails (Cole, 1987).

Visitor impacts in Central and South America have been largely addressed through carrying capacity approaches, where visitor numbers are limited (Giongo, Bosco-Nizeye, & Wallace, 1994). However, reducing the amount of use may not be a highly effective or desirable management strategy for managing trail impacts. Use reduction only addresses one potential factor contributing to trail impacts, when other factors such as trail location and design may be of equal or greater importance (Cole, 1983). For example, trails may lack design, construction or maintenance features that can prevent or mitigate many forms of trail impact. Research has also shown that the majority of impact occurs with trail development and low levels of use, reducing the effectiveness of use limitation as a management tool (Hammitt & Cole, 1998; Leung & Marion, 2000). Finally, use limits are difficult to implement administratively, visitors dislike regulatory management approaches, and use limitations diminish economic benefits and land preservation motives (Lucas, 1990; Lindberg, Epler-Wood, & Engeldrum, 1998). Managers need to understand the relative importance of multiple factors that contribute to trail impacts to effectively minimize trail degradation.

This research was conducted to evaluate trail impact assessment and monitoring techniques, identify and characterize trail impacts, and to improve understanding of trail degradation processes at Huascaran National Park, in the central Andes Mountains of Peru. Trail impacts studied included the number of informal trails, the number of secondary trails, trail width, and two measures of trail incision.

The findings from this research are useful for other protected area managers in Central and South America who are concerned about trail impacts, are interested in learning more about the factors that influence trail impacts, are exploring developing trail impact monitoring programs, or are interested in learning more about potential strategies used to minimize trail impacts.

Trail Impacts and Influential Factors

Common trail impacts include soil erosion, trail wetness or muddiness, creation of parallel secondary treads and informal side-trails, vegetation cover loss or composition change, soil compaction and trail widening (Cole, 1983; Hall & Kuss, 1989; Leung & Marion, 1996, 2000). Trail impact assessment surveys have documented these impacts and how they change over time. For example, trampling of vegetation in the Andes of central Chile resulted in soil compaction and a decrease in the number and density of plant species (Hoffman & Alliende, 1982). In another study, overall path width, extent of bare ground and number of secondary trails increased between two measurement periods in the Mourne Mountains in Ireland (Ferris, Lowther, & Smith, 1993).

Trail impacts may be caused or influenced by use-related, environmental or managerial factors. Understanding how these factors contribute to trail impacts permits selection of the most effective impact management strategies and actions.

Use-Related Factors

Use-related factors include the amount and distribution of use, type of use and user behavior (Hammitt & Cole, 1998; Leung & Marion 2000; Wilson & Seney, 1994). Of these factors, protected area managers often focus on limiting use to control resource degradation. However, reducing use is most effective if there is a strong and linear relationship between trail impacts and amount of use. In fact, research findings frequently show this not to be the case. For example, most studies reveal that many trail impact indicators, including vegetation cover loss, altered species composition, soil compaction (bulk density and penetration resistance) and trail width are curvilinearly related to the amount of use, indicating that use level is most strongly related to trail degradation at initial and low levels of use (Bayfield & Lloyd, 1973; Dale & Weaver, 1974; Cole, 1987; Boucher et al., 1991). An important implication of this finding is that use levels would need to be kept extremely low to effectively minimize impact. Such levels would be difficult and perhaps undesirable from the perspective of protected area managers and visitors. Additionally, further increases in use result in incrementally smaller amounts of impact, reducing the effectiveness of use reductions to minimize impacts at higher use levels. Some studies have also found that trail erosion and frequency of problems like tread muddiness are unrelated to amount of use (Dale & Weaver, 1974; Cole, 1983).

Environmental Factors

Environmental factors include vegetation type, soil type, topographic characteristics, ecosystem characteristics, and phenological state (Hammitt & Cole, 1998). Resistance is the ability of vegetation and soils to withstand visitor use without being altered or otherwise disturbed. Resilience is the ability of vegetation and soils to recover from disturbance. Research has shown that vegetation and soil types differ significantly in their resistance and resilience to trail impacts (Cole, 1995a, 1995b; Leung & Marion, 2000). For example, plant species that are highly resistant to impact, such as those in dry grasslands, can minimize impacts like trail proliferation and trail widening. Conversely, trail degradation occurs more rapidly in less resistant vegetation types (Lance, Thaxton, & Watson, 1991). Some vegetation types also have low resilience, and require lengthy recovery periods following trampling disturbance (Cole, 1995b). Short growing seasons (e.g., high elevations or latitudes) and inhospitable climates (e.g., deserts) also lengthen recovery periods.

Soil characteristics affecting impact susceptibility include texture, organic matter content, moisture, and presence/thickness of surface litter (Graefe, Kuss, & Vaske, 1990). Generally, damp non-organic soils composed of equal amounts of sand, silt and clay (e.g., loams) are most prone to compaction; homogeneous-textured soils high in silt and fine sands and low in organic matter are most prone to erosion by water and wind (Hammitt & Cole, 1998).

Vegetation and soil resistance varies by season of year. Plants and their root systems are more easily disturbed during wet seasons while trampling during dormant periods has little lasting effect. Topographic characteristics can also be an important determinant of impact susceptibility. Soils on steep slopes are easily eroded and valley bottom soils are frequently wet and prone to persistent muddiness. The management implications of these findings are that resource impacts can be minimized by locating trails in the most resistant and/or resilient environments and by avoiding sensitive environments or employing site hardening measures to increase resource resistance (Marion, 1998).

Managerial Factors

Managerial factors that affect trail conditions include visitor and site management techniques. The curvilinear use-impact relationship indicates that limiting the amount of use will not effectively minimize most trail impacts. Additionally, dispersing use to previously unaffected areas will increase cumulative disturbance unless visitation is kept at extremely low levels that avoid permanent impact (Cole, 1995a). Area closures can be used to protect sensitive or rare species or to relocate use to more resistant environments (Leung & Marion, 2000). Regulations that prohibit higher-impact activities (e.g., motorized travel) or practices (off-trail travel) are other options. However, these actions restrict visitor freedom and may be difficult to implement due to open access issues. Visitor education, such as promoting low impact hiking practices (e.g., Leave No Trace), offer non-regulatory alternatives (see www.lnt.org).

Site management techniques include trail location, design, construction, and maintenance (Hesselbarth & Vachowski, 1999; Birchard & Proudman, 2000). Trail locations must avoid sensitive environments and focus trampling pressures on the most resistant surfaces. Proper design and construction limits trail grades to reduce tread erosion and includes adequate bridges and tread reinforcement to avoid impacts at stream crossings and in wet soils. A sustained program of trail maintenance can prevent impacts by managing surface water flows and focusing use onto the middle of tread surfaces. For example, a study that investigated soil erosion at Kilimanjaro National Park in Africa recommended that park staff install water diversion features along the trail to minimize tread erosion (Newmark & Nguye, 1991). Other studies have also reported that trail location, design and maintenance, as well as climatic factors such as wind and rainfall intensity, are the most important determinants of certain trail impacts like tread erosion (Helgath, 1975; Cole, 1983; Cole, Petersen, & Lucas, 1987).

Study Area

Huascarán National Park (HNP) is a 3,400 km^2 protected area in the Cordillera Blanca of north-central Peru. The park was established in 1975 and is administered by the National Institute of Natural Resources (INRENA), through the Ministry of Agriculture. The park forms the nucleus of a UNESCO Biosphere Reserve established in 1977, and was declared a World Natural Heritage Site in 1985.

HNP contains almost the entirety of the Cordillera Blanca which extends 180 Km NN-W to SS-E and does not exceed 20 Km in width at any one point. Over twenty peaks within the park are 6000 meters or higher in elevation, with Huascarán at 6,768 meters being the highest peak in Peru. Within the park boundary there are 779 plan, 112 bird, 10 mammal, and 8 orchid species (Instituto de Montaña, 1996). There are forty-four glacial valleys leading into the park from the east and west and a roadway on the western side of the park in the Callejon de Huaylas where the cities of Huaraz (90,000 residents), Caraz (15,000 residents), and numerous small villages are located. This arrangement provides easy access into the park for trekkers, mountaineers, and the local campesinos.

Only a limited number of people live within the park's boundaries but many of the Quechua people living in the region rely upon the resources in the park for subsistence grazing, hunting, and harvest of native products. Subsistence grazing, which is largely unregulated, has perhaps one of the largest impacts on the park, with cattle being found all the way up to the permanently glaciated zone below the high peaks in the park.

Study Objectives

The objectives of this study are three-fold. First, to characterize the type, frequency and extent of trail impacts on selected trails in Huascaran National Park. Second, to assess the relative effect on trail impacts of trail design and layout. Third, to experimentally apply and evaluate trail impact monitoring procedures. The implications of study findings for trail management are discussed.

Methods

A monitoring manual was developed to standardize procedures for conducting a comprehensive inventory and assessment of resource conditions on selected trail segments. Procedures were designed to obtain quantifiable measures of vegetation and soil disturbance. Data were gathered by the authors of this paper with the assistance of U.S. college students enrolled in an ecotourism management field course. Data collection took place from late May to early June, 1999.

A stratified sampling design was used to select three 1500-meter trail segments in varying topographical positions along the Santa Cruz - Llanganuco trekking route, one of the most heavily used trails in Huascaran National Park. Trail segment one was located in a gradually sloping valley bottom (labeled Valley Bottom in Results) along the Santa Cruz Trail between Cashapampa and Punta Union a 10 minute walk up the valley from the Llamacorral Camp. Segment two steeply descended from Punta Union, a high mountain pass, (labeled Upper Slope) along the Huaripampa Trail close to Tutubaba (starting at UTM: E0218266, S9013238). Segment three, also along the Huaripampa Trail, descended a valley along the lower slope of a valley wall inside the park boundary above the town of Colcabamba (labeled Valley Wall) (starting at UTM: E0219251 S9008094). Trails and trail segments were purposively sampled as part of a student exercise so results apply only to the segments studied and are not representative of the park's larger trail system.

Use levels are similar between the three trail segments, estimated by park staff at approximately 40-50 people/day during the use season. Trails also receive an unknown amount of use by animals, including grazing livestock, packstock associated with local commerce, and recreational packstock. Both are relatively common and may contribute greater impact to the study trails than human visitors. The valley bottom and upper slope trail segments were located in open grassland vegetation, the valley wall segment was primarily located in open shrub vegetation.

Two trail assessment methods were selected for application because each method represents a different survey approach, and they are commonly used in previous studies. The *point sampling method* is perhaps the most common survey approach which utilizes a systematic sample scheme to determine the number and locations of measurements to be taken at a fixed interval on a trail (Leung & Marion, 1999b). The *problem assessment method*, on the other hand, employs a census approach, in which a continuous search for indicators of pre-defined impact problems is performed on a trail (Leung & Marion, 1999a).

The Point Sampling Method

A measuring wheel (122 cm circumference) was pushed along each of the three trail segments. Measurements were taken at a systematic sampling interval of 100 meters. At each sampling point a transect was established perpendicular to the trail tread to assess a series of inventory and impact indicators (Table 1). The number of informal trails leaving the survey trail was counted and recorded between sampling points. Trail tread width, number of treads, tread condition characteristics, and a measure of trail erosion were evaluated. A maximum incision measure within the current tread boundaries provided a relatively efficient and precise measure of soil erosion. Trail tread condition characteristics (Table 1) were defined to be mutually exclusive and were assessed in 10% categories (5% where necessary). These indicators were evaluated along a linear transect oriented perpendicular to the trail at each sample point. Transect endpoints were defined by pronounced changes in ground vegetation height, cover composition, or organic litter.

Table 1. Survey indicators included in the point sampling method as applied to Huascaran National Park.

Indicator	**Description**
Tread Width (m)	Tread width between boundaries defined by pronounced changes in ground vegetation height, cover, composition, or organic litter
Maximum Incision (cm)	Max. distance between tread surface and a line connecting tread boundaries
Informal Trails (#)	Count of the number of informal trails
Secondary Treads (#)	Count the number of separate or multiple trail treads that parallel the main tread at the sample point
Tread Condition Characteristics (%)	Percentage of the trail width transect by tread surface category:
Exposed Soil	Exposed soil of all types, excluding rock and organic litter
Rock	Naturally-occurring rock surfaces (bedrock, rocks, and gravel)
Running Water	Running water on tread surface
Muddy Soil	Seasonal or permanently wet and muddy soils
Vegetation Cover	Vegetative cover rooted within the tread boundaries
Gravel	Natural gravel on tread surface

The Problem Assessment Method

The same trail segments were also assessed with problem assessment procedures. Three impact indicators were documented, including excessively muddy soil, running water on the tread, and excessive erosion (Table 2). A measuring wheel (122 cm circumference) was used to identify the cumulative distance from the starting point to the beginning/ending distances of each tread problem that exceeded a length of 10 ft. For example, a trail segment eroded between one and two feet below the estimated post-construction tread surface would be recorded if it extended along the trail for more than ten feet.

Table 2. Survey indicators included in the problem assessment method as applied to Huascaran National Park.

Impact Indicator	**Description**
Soil Erosion: 15-30 cm 30.1-45 cm 45.1-60 cm ... (15 cm categories)	Segment has eroded below the estimated original, post-construction, tread surface by the amount specified
Wet Soil	Segment has wet muddy soil over more than half of the tread width, including muddy soils or mud holes with standing water
Running Water on Trail	Segment has running water on the tread

Results and Discussion

Trail Conditions

Data are reviewed in this section to characterize the type, frequency and extent of trail impacts on selected trails in Huascaran National Park. Survey data reveal that the selected trail segments are generally in fair condition, with one significant exception (soil erosion). We attribute these conditions to relatively low use levels and to the exceptionally trampling resistant grassy groundcover common throughout the park. For example, median vegetation cover on the surveyed trails was 30% (Table 3), with vegetation cover of at least 60% at 40% of the sample points. Even the herbaceous species seen along trails have adapted in response to the high levels of historic animal trampling and grazing, to be highly resistant and resilient to the trampling effects associated with trail use.

Table 3. Median and range values for tread characteristics and impact indicators, point sampling data.

Indicators	Median	Range
Tread Characteristics (%)		
Vegetation	30	0-100
Soil	40	0-100
Rock	0	0-100
Muddy Soil	0	0-50
Running Water	0	0-20
Gravel	0	0-20
Impacts		
Informal Trails (#)	0	0-2
Secondary Trails (#)	1	0-4
Tread Width (m)	2.9	0.5-7.8
Maximum Incision (cm)	12.7	0-85.1
Trail Grade (%)	8	3-33

Table 4. Number of occurrences and lineal distance for three trail impact indicators, problem assessment data.

Indicator	Occurrences		Lineal Distance	
	#	#/km	m	%
Soil Erosion (cm)				
	27	6.0	204	4.5
	23	5.1	459	10.2
	5	1.1	8	0.2
	3	0.6	11	0.2
Muddy Soil	6	1.3	58	1.3
Running Water	1	0.2	13	0.3

However, a variety of trail impacts were documented, including some visitor-created informal trails and secondary trails, excessive tread width, muddiness and soil erosion (Tables 3&4). Very few informal trails, often created to access attraction features, water sources, or viewpoints, were found. Secondary trails that paralleled the main tread were somewhat more numerous. These may have been created by livestock or packstock that also use the trails. In some instances there was no readily apparent "main path," so trail users simply select different alternative routes from those present.

Tread widths ranged from 0.5 to 7.8 meters (Table 3) with a median width of 2.9 meters. These trails are somewhat wide in comparison to other protected areas. Hiking trails are generally constructed to be less than one meter in width, horse trails are generally less than two meters in width. Muddiness was not a common problem, though the survey was conducted during the dry season. The problem assessment survey found only six occurrences of wet muddy soil for a total lineal extent of only 58 meters (Table 4). Only one occurrence of running water on trail treads was found.

The most significant problem identified by the trail survey was soil erosion from trail treads. Median maximum tread incision was 12.7 centimeters with a range of 0 to 85.1 centimeters (Table 4). Fifty-eight occurrences of tread erosion of more than 15 centimeters were located, affecting 682 meters of the 4,500 meters sampled (15%)(Table 4). Thirty-one of the occurrences were more than 30 centimeters deep and 8 were more than 45 centimeters in depth.

The substantial trail erosion documented on the study trails may be attributed to a combination of steep trail grades, lack of proper trail design, insufficient trail maintenance, high rainfall and heavy animal use. Very few of the park trails were ever formally designed or constructed by trained trail crews; most were created by local campesinos and have long use histories. The median trail grade for the study segments was 8%, with a range of 3 to 33% (Table 3). Thirteen of 45 sampling points (29%) had trail grades of 18% or greater, which are generally considered to be too steep to sustain visitor traffic without substantial stonework to reinforce trail treads, a technique not evidenced in the park. In addition to steep slopes, poor trail design is evidenced by poor trail alignments. For example, trail alignments were close to being parallel to mountain slopes at seven of the 45 sample points. Trails configured this way cannot easily be drained of water once they become incised because the land on both sides of the trail is equivalent in height (discussed further in the following section).

Communication with local campesinos and park staff reveled that trail maintenance is conducted on a sporadic basis by the local residents. The local campesinos, as the primary users and beneficiaries of the trail system, are expected to maintain this system with little to no support or compensation from park officials. The condition of the trails within the park indicate that the quantity and quality of this maintenance is insufficient to prevent soil erosion on park trails. There are also no trail maintenance training courses offered to the local population or trail maintenance manuals in the Spanish language. Further, the tools available to local residents for effective trail maintenance are often inadequate for the task. Trails in the park ascend to elevations of 4,800 meters and the high tropical rainfall at these elevations quickly erode soils on vulnerable trail surfaces. Finally, heavy use by livestock and recreational packstock may also contribute to the high erosional levels measured on the study trails. Studies in other areas have shown that animal hooves substantially increase erosional rates by churning up trail substrates and making more soil available for erosion by both water and wind (DeLuca et al., 1998; Wilson & Seney, 1994; Cole & Spildie, 1998).

Trail Design

Trail segments were selected to characterize and permit evaluations of trail conditions located at three topographic positions: valley bottom, upper slope, and valley wall. Tread characteristics and trail impacts varied substantially by trail position. For example, median vegetation cover on treads ranged from 70% on the valley bottom trail to 35% on the upper slope trail to 20% on the valley wall trail (Table 5). These were mirrored by the percentages of exposed soil on treads for these three trail positions: 15%, 40%, and 70%, respectively. Differences in exposed soil were statistically significant (p=.008) based on a non-parametric one-way ANOVA test (Table 5). We attribute these differences to a combination of factors. The valley bottom trail segment was nearly three times wider than the valley wall segment (Table 6), allowing a greater dispersal of use over the highly trampling resistant vegetation. The much steeper slopes and shrub cover along the sides of the valley wall segment prevented such wide trail widths from developing. Furthermore, the shrub cover along much of the valley wall segment frequently shaded out ground vegetation, particularly the trampling resistant but shade-intolerant grass species. The upper slope trail segment was bordered by resistant grass cover but substantial erosion on this section (Tables 6 and 7) prevented extensive vegetation cover on the trail tread.

Table 5. Median and range values for tread characteristics stratified by trail segments at three topographic positions, point sampling data.

	Tread Characteristics (% of tread width)					
Topographic Position	**Vegetation**	**Soil**	**Rock**	**Muddy Soil**	**Running Water**	**Gravel**
Valley Bottom						
Median[1]	70	15	0	0	0	0
Range	0-100	0-100	0-100	0-50	0-20	0
Upper Slope						
Median	35	40	15	0	0	0
Range	0-95	0-90	0-100	0	0	0
Valley Wall						
Median	20	70	5	0	0	0
Range	0-100	0-100	0-50	0	0	0-20
Chi-Square statistic	4.4	9.8	3.2	2.0	2.0	4.1
p value[2]	.109	**.008**	.207	.368	.368	.129

1 - Medians are presented because data were not normally distributed.

2 - Statistical testing based on the non-parametric Kruskal-Wallis test, p values ≤ .05 (bolded) are considered significant.

Table 6. Median and range values for trail impact indicators stratified by trail segments at three topographic positions, point sampling data.

	Impact Indicators				
Topographic Position	**Informal Trails (#)**	**Secondary Trails (#)**	**Tread Width (m)**	**Maximum Incision (cm)**	**Trail Grade (%)**
Valley Bottom					
Median[1]	0	1	3	7.6	3
Range	0-2	0-3	1.8-7.8	0-16.5	3-13
Upper Slope					
Median	0	1	3.9	49.5	23
Range	0	0-4	1.6-6.0	17.8-85.1	8-33
Valley Wall					
Median	0	0	1.2	8.9	8
Range	0	0-2	0.5-3.0	2.5-16.5	3-33
Chi-Square statistic	4.1	12.5	25.5	29.6	22.9
p value[2]	.129	**.002**	**.000**	**.000**	**.000**

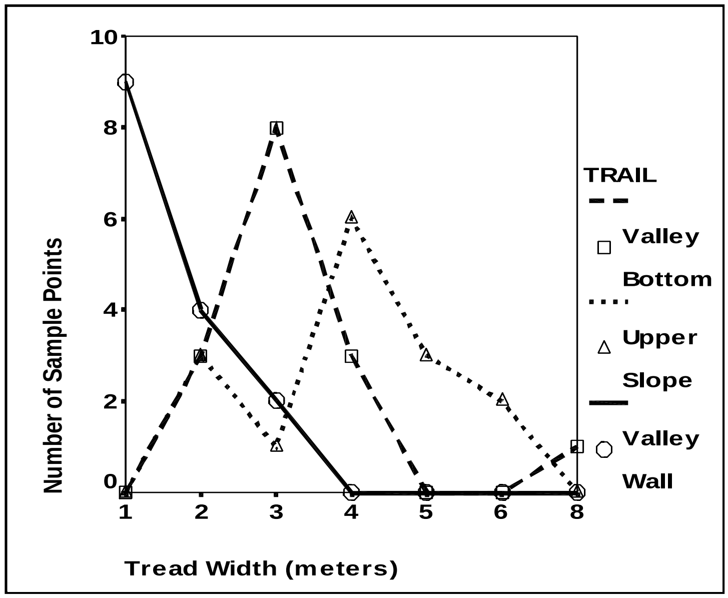
1 - Medians are presented because data were not normally distributed.

2 - Statistical testing based on the non-parametric Kruskal-Wallis test, p values ≤ .05 (bolded) are considered significant.

Table 7. Number of occurrences and lineal distance for three trail impact indicators, problem assessment data.

Indicator	**Occurrences (#)**			**Lineal Distance (m)**		
	Valley Bottom	**Upper Slope**	**Valley Wall**	**Valley Bottom**	**Upper Slope**	**Valley Wall**
Soil Erosion						
15-30 cm	5	20	2	56	131	17
30.1-45 cm		23			459	
45.1-60 cm		5			8	
60.1-75 cm		3			11	
Muddy Soil		5	1		51	7
Running Water			1			13

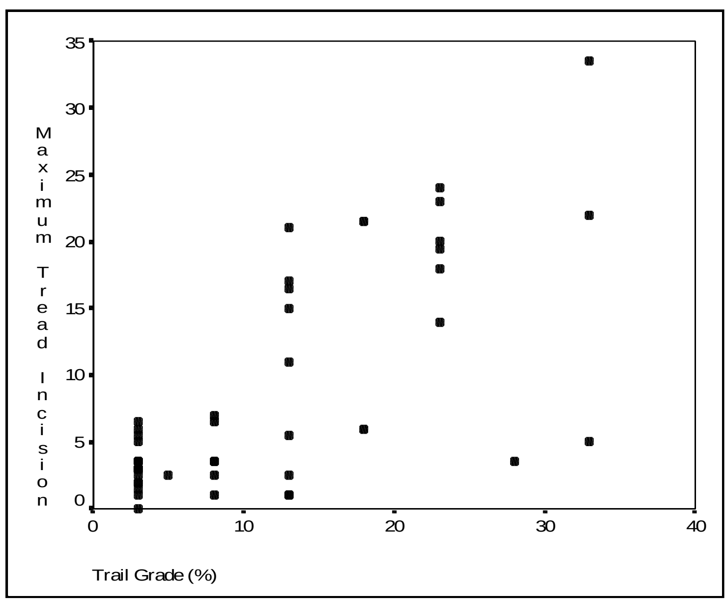
Tread width also varied significantly (p=.000) with trail position (Table 6). These differences in tread width are illustrated in Figure 1. The valley wall segment was the narrowest (median = 1.2 m) due to the steeper slopes and shrub cover in adjacent off-trail areas. The wider valley bottom segment (median = 3.0 m) can be attributed to the flatter terrain and lack of shrubs or other barriers to trail expansion. The upper slope segment was the widest (median = 3.9 m) due to the extensive erosion, which caused trail users to widen the trail in their attempts to avoid deep ruts and exposed rocks. Variation in median maximum incision values was also substantial and statistically significant (p=.000) (Table 6). Erosion was relatively minimal on valley bottom and valley wall segments, 7.6 and 8.9 cm, respectively. Erosion rates are low in the flatter terrain of valley bottoms and the roots and cover of the resistant vegetation largely prevents the removal of soil by water or wind. Erosion was low on the valley wall segment because, while the valley wall was steep, ranging from 10-35%, the trail grade was generally 8% or less. Water coming down the valley wall could pass over the trail tread, or if captured by the trail, was diverted across and off the tread by natural or trail drainage features before traveling very far.



1Figure 1. Tread width in one meter categories by trail.

Erosion on the steeper upper slope segment was substantial, ranging from 18 to 85 cm with a median of 50 cm (Table 6). Trail grades for this segment ranged from 8 to 33% with a median of 23%. The relationship between maximum tread incision and trail grade is illustrated in Figure 2. A regression analysis revealed a statistically significant relationship (T-value = .000) with trail grade explaining 50% of the variation in maximum tread incision.

A few tread drainage features (drainage dips) were located on the upper slope trail segment, yet they were inadequate in reducing continuing tread erosion on this deeply entrenched trail. This is largely because the drainage features observed were not in sufficient quantity or of substantial enough construction to effectively remove running water from the trail tread. The problem assessment data (Table 7) provides a more complete illustration of the erosion along this segment. Most of the eroded portions were in the range of 15 to 45 cm deep, 43 occurrences accounting for 590 m in length.



2Figure 2. Scatterplot of maximum tread incision (cm) by trail grade (%).

Monitoring Options

The third objective of this study was to experimentally apply and evaluate two alternative trail impact monitoring procedures. Results from this comparison of trail condition assessment approaches reveal that the point sampling and problem assessment survey methods provide distinctly different types of quantitative information. Point sampling surveys provide the best information for characterizing typical trail conditions, such as trail width, tread incision, and tread composition. Replication of these procedures would yield the most appropriate data for monitoring trends in trail conditions or for evaluating the influence of use-related, environmental, or managerial factors. For example, in this study a number of trail impacts were significantly correlated with trail topographic position. This method is also efficient, requiring a one or two trail surveyors pushing a measuring wheel and covering approximately one mile of trail per hour.

In contrast, the problem assessment method focuses on documenting specific pre-defined trail impact problems. This method provides many different measures for characterizing all occurrences of impact indicators, including frequency of occurrence (#, #/km), lineal extent (m, % of segment), and location of each occurrence (begin/end distance from the survey starting point). The problem assessment method could also provide information on a variety of inventory indicators, such as the number, location, and relative effectiveness of tread drainage features (e.g., drainage dips). This method also requires only one or two trail surveyors pushing a measuring wheel. Assessment times are similar to the point survey method, though much longer for trails in very poor condition.

We may conclude that these two methods assess trail conditions in distinctly different ways, one applies systematic sampling to characterize typical conditions, the other applies census assessments to document all occurrences of predefined trail problems. These different approaches underlie the limitations of each method. For example, the point sampling method may miss occurrences of uncommon trail problems, particularly at larger sampling intervals. Further discussion on this topic and guidance in selecting an appropriate sampling interval is provided elsewhere (Leung & Marion, 1999a).

The point sampling method also provides incomplete and potentially inaccurate information on the frequency, lineal extent, and location of specific trail problems. Some of these statistics can be estimated from point sampling data. For example, the frequency of occurrence and lineal extent of soil erosion in excess of 15 cm could be estimated for a trail segment by examining and extrapolating the ratio of sample points with and without tread incision that exceeds 15 cm. Information on the location of trail problems is only available from sample points, substantially limiting the utility of this data for planning and directing trail maintenance work.

Recommendations

The trail segments that we evaluated, along with many others that we hiked, were generally in fair condition. We attribute this primarily to a relatively low level of use and to the highly resistant and resilient ground vegetation. Among the study segments, only the valley wall segment appeared to have characteristics indicating that it was professionally designed and constructed. The most exemplary trail from a design perspective was the trail up to Lake 69, which employed carefully laid out switchbacks and a constant grade, along with excellent sidehill construction work for a tread that is largely self-draining. This is one of a handful of professionally constructed trails leading to high glacial lakes within the park which were established in the 1950's as part of an effort to mitigate disasters associated with glacial lake outburst. However, most trails along the standard trekking route were not professionally designed or constructed. Segments with excessively steep trail grades (>15%) were common, as were segments that directly ascended mountain slopes. Outside the study segments we also observed many trail segments that had problems with multiple treads and trail widening, and segments that were excessively wet and muddy.

Trail maintenance on the study segments and elsewhere was quite variable, ranging from fair to nonexistent. We saw good use of rockwork to border small stream crossings and some good drainage ditches to reduce tread muddiness. However, we rarely saw tread drainage features (e.g., waterbars or drainage dips) and most were too small, infrequent, or full of deposited silt and debris to be effective. We also saw few examples of outsloped trail treads which allow water to cross and flow off, rather than down, tread surfaces. A result of steep trail grades and poor tread drainage, was erosion excessive in those areas where the rock and gravel content of soils was low. The upper slope study segment provides a good example of such settings. In some locations, trail maintainers had dug soil from trailside locations and filled in trail ruts but had done nothing to drain subsequent water runoff from the tread surface. In the absence of effective tread drainage features this fill material will also be washed away, much more rapidly than the original soil.

In our opinion, the impacts documented in this study are primarily related to an inadequate quality and quantity of trail design, construction, and maintenance rather than to amount of use. While precise data concerning the number of trail users within the park is unavailable, the estimates given by the park staff are fairly low compared to many parks in other countries. Type of use, mainly the burros and livestock that also use these trails, could also be a significant contributing factor. The hooves of these animals loosen soil and increase subsequent erosional rates by water and wind. In particular, because burros are herded down trails rather than tied and led in pack strings. As a result, they are prone to create numerous multiple treads and contribute to trail widening.

Based on this research and our observations, our specific recommendations are as follows:

1) Conduct a comprehensive survey of park trails to evaluate their design and construction characteristics. Evaluate the capabilities of existing trails to support the intended types and amounts of use. Evaluate current trail conditions to provide a baseline for future monitoring,

permit analyses to further explore trail degradation processes and factors, and provide information on those segments most in need of relocation and trail maintenance.

2) Hire or train one permanent park staff member in trail design, construction, and maintenance. Develop and implement a permanent program of trail maintenance. Acquire a library of trail maintenance manuals and have the best translated into Spanish. Develop and offer courses in trail maintenance targeted toward the donkey driver associations and local community members that perform the maintenance. Provide economic incentives for accomplishing this work and develop assessment procedures to evaluate and quantity and quality of their trail maintenance work. Obtain and distribute proper trail maintenance equipment.

3) Institute an educational program such as Leave No Trace (No Deje Rastro) which informs park visitors and local residents about proper techniques for minimum impact travel and packstock use (such as the use of pack strings).

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