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Hiker, horse and llama trampling effects on native vegetation in Montana, USA

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Intensity of trampling disturbance varies with type of recreation traffic. The purpose of this study was to assess the relative impact of hiker, horse and llama traffic on vegetation and groundcover conditions. Hiker, horse and llama traffic were applied at two trampling intensities (25 and 150 passes at one time) to two previously undisturbed forested vegetation types (one with an understory dominated by erect forbs, the other dominated by low shrubs). Trampling effects were assessed immediately after traffic application and 1 year later. For most impact parameters, intensity of trampling impact varied with type of user. For all parameters that varied with type of user: (1) horse traffic caused the most disturbance; and (2) hiker and llama impacts could not be differentiated statistically. The forb-dominated vegetation type was highly vulnerable to vegetation impact but recovered rapidly. The shrub-dominated type was more resistant but lacked resilience. Higher trampling intensities caused more disturbance but the relationship between trampling intensity and disturbance intensity was non-linear.

Keywords: ecotourism, natural areas, packstock, recreation impact, recreation management, recreation users, trampling, visitor management.

Introduction

Recreation impacts are a concern to managers of National Parks, wildernesses and other protected areas. Trampling impacts are particularly problematic because they are largely inevitable wherever recreation use occurs. Trampling impacts are dependent on five primary explanatory variables: type of use; amount of intensity of use; user behavior; time of use; and durability of the trampled environment (Cole, 1994). Most trampling research has focused on the influence of amount of use (e.g. Bell and Bliss, 1973; Coleman, 1981; Cole 1995a) and environmental durability (e.g. Liddle, 1975; Bayfield, 1979; Cole, 1995b) on the intensity of disturbance. Relatively little is known about how trampling disturbance varies with type of use. This lack of knowledge limits managers' ability to apply differential restrictions dependent on the types and intensities of impact that different user groups cause.

In National Park backcountry and wilderness, where motorised travel is prohibited, the two primary user groups are hiking groups and groups that travel with packstock. Traditionally, the animals used as packstock have been horses, mules and occasionally donkeys. Over the past few decades, however, use of non-traditional packstock, particularly llamas, has increased markedly in many areas. For example, by 1990, 57% of the wilderness areas in the United States with packstock use had llama use (McClaran and Cole, 1993). Proponents of llama use claim that llamas cause less ecological impact than traditional packstock (Harmon and Rubin, 1992).

Trampling impacts occur on campsites, on trails, while traveling off-trail and, in the case of packstock, while grazing. Most trampling research has either examined the effect of human traffic or not attempted to differentiate between types of use. A few studies have specifically examined the impacts of horse traffic on trails (Whinam and Comfort, 1996) or compared trail impacts caused by hiking and horse groups (Dale and Weaver, 1974; McQuaid-Cook, 1978; Summer, 1980,

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1986; Wilson and Seney, 1994). Generally, these studies found that horses affect trails more profoundly than hikers. The only study (DeLuca *et al.*, 1998) that compared the trail impacts of horses, hikers and llamas, found that horse traffic caused more impact than either llama or hiker traffic but that llama traffic caused no more impact than hiker traffic.

The effects of different types of traffic on vegetation has received even less attention than trail impacts. Whinam *et al.* (1994) studied horse trampling impacts on vegetation in the Tasmanian Wilderness World Heritage Area. Nagy and Scotter (1974) and Weaver and his colleagues (Weaver and Dale, 1978; Weaver *et al.*, 1979) compared impacts of horse and hiker traffic on vegetation in Alberta (Canada) and Montana (USA), respectively. Again, these studies generally found that horse impacts are more severe than hiker impacts. The impact of non-traditional packstock, such as llamas, on vegetation has not been studied.

The primary objective of this research is to assess the relative impact of horses, llamas and hikers on the vegetation and groundcover conditions of two vegetation types in Montana, USA. The research is intended to complement earlier research on trail impacts of horses, llamas and hikers (Deluca *et al.*, 1998) and visitor reactions to meeting horses, llamas or hikers (Blahma *et al.*, 1995), as well as ongoing research on grazing impacts of horses and llamas. Together the results of these studies should suggest how to incorporate the differential impact potential of various types of use into park and wilderness management programs.

Methods

Study sites

Two forested vegetation types were selected for study using the following criteria: (1) they are widespread in the northern Rocky Mountains; (2) they are likely to be widely divergent in their response to trampling; and (3) they are not highly resistant to trampling disturbance. Both types were located in the Lolo National Forest, adjacent to the Bob Marshall Wilderness, about 70 km NNE of Missoula, Montana. At the nearby Seeley Lake weather station, annual precipitation averages 536 mm, with about 40 mm in August—the month when trampling occurred. January temperatures average −8°C and July temperatures average 17°C.

Both vegetation types were located in the flat bottoms of narrow mountain valleys. One type, the *Equisetum* type (denoted by the genus of the most abundant understory species), is located at an elevation of 1250 m. It has an overstory dominated by large *Picea engelmannii*, with occasional *Abies lasiocarpa*, *Pinus contorta* and *Pseudotsuga menziesii*. Total canopy cover is about 80%. All of the tree regeneration is *P. engelmannii*. The understory is highly diverse (Appendix 1), with *Equisetum arvense*, *Cornus canadensis*, *Bromus vulgaris* and *Clintonia uniflora* most abundant. Species nomenclature follows Hitchcock and Cronquist (1973). Previous research suggests that this type, because it has an understory dominated by erect forbs, should have low resistance to trampling disturbance but it should have high resilience (Cole, 1995b). As it has thick soil organic-horizons (typically >10 cm), it should be resistant to mineral soil exposure.

The *Vaccinium* type, located at an elevation of 1550 m, differs in its predicted response to trampling. This type has a more open overstory (25% canopy cover) entirely of *P. contorta*. Most of the tree regeneration is *A. lasiocarpa*. The understory is highly dominated by the low shrub, *Vaccinium scoparium*. The most abundant associates are *Vaccinium globulare* and species of moss (mostly species of *Brachythecium* and *Dicranum*) and lichen (mainly *Cladonia* sp.) (Appendix 1). Previous research suggests that this type, because the understory is dominated by low shrubs, should have moderate resistance but low resilience (Cole, 1995b). As it has thin soil organic-horizons (typically <2 cm), it should be susceptible to mineral soil exposure.

Field methods

The methods used were a modified version of the standard experimental trampling protocols recommended by Cole and Bayfield (1993). Four replicate sets of seven experimental trampling lanes were established in each of the two vegetation types. Each lane was 0·5 m wide and 3 m long and had no slope.

Treatments were randomly assigned to lanes and administered during 1 day in August 1994. One treatment, the control, received no traffic. The other treatment lanes received either 25 or 150 passes by either a hiker, a horse or a llama. A pass was a one-way walk, at a natural gait, along the lane. Hikers weighed 75–80 kg and wore lug-soled boots. Horses and llamas weighed 450–500 kg and 140–155 kg, respectively. Horses wore non-cleated shoes. None of the user types carried packs. Horses and llamas were led (not ridden) by lead ropes attached to a halter.

Measurements were taken prior to and after trampling (within 2 weeks), as well as 1 year after trampling. Measurements were taken in two 3 × 5-dm subplots placed—in the center of each lane—0·5 m from each end of the lane. Both vegetation cover and height were measured with a point quadrat frame, with five pins (3 mm in diameter) located 5 cm apart. The frame was placed systematically 10 times in each subplot and pins were slowly dropped to the ground surface. When pins hit live vegetation, the height of the hit was recorded to the nearest cm. When pins reached the ground surface without hitting vegetation, vegetation height was recorded as zero and groundcover was recorded as either organic soil (O horizon) or mineral soil.

Data analysis

Vegetation cover was estimated, for each experimental lane, as the proportion of the 100 pins (50 in each of two subplots) that hit live vegetation. Mineral soil cover, which was absent before trampling and rare after trampling, was estimated in a similar manner. Vegetation height was estimated as the mean height for those pins that hit vegetation.

To assess whether or not trampling had an effect on vegetation cover and vegetation height, post-treatment conditions were expressed as a percentage of pre-treatment conditions. The null hypothesis that treatments had no effect on vegetation cover or height was tested, by t-test ($\alpha = 0{\cdot}05$), comparing control lanes with trampled lanes.

To more precisely quantify trampling disturbance of vegetation, relative cover (RC) and relative height (RH) were calculated. In both cases, conditions after trampling were expressed as a proportion of initial conditions, with a correction factor (cf) applied to account for changes on the control plots that reflect influences other than trampling. Relative cover was calculated as:

$$\frac{\text{surviving cover on trampled lanes}}{\text{initial cover on trampled lanes}} \times \text{cf} \times 100 \qquad (1)$$

where:

$$\text{cf} = \frac{\begin{array}{c}\text{mean initial cover on four}\\ \text{control replicates}\end{array}}{\begin{array}{c}\text{mean surviving cover on four}\\ \text{control replicates}\end{array}} \qquad (2)$$

Relative height was calculated in an identical manner, substituting height for cover. Relative cover and height would be 100% in the absence of any change caused by trampling. Deviations from 100% provide an estimate of trampling effects. Differences in relative cover and height immediately after (within 2 weeks) and 1 year after trampling provide estimates of short-term recovery following trampling.

The effects of user type (horse, llama, hiker), trampling intensity (25, 150 passes) and vegetation types (*Equisetum* erect forb, *Vaccinium* low shrub) on relative cover and relative height after trampling were tested with ANOVA. With few exceptions, assumptions of normality and homogeneity of variance were met; consequently, data were not transformed. Scheffe's tests and t-tests were used to assess the significance of differences between means for main factors ($\alpha = 0{\cdot}05$). Given the large number of zero values for mineral soil cover, inferential statistics were not used in their analysis.

Results

The correction factors used to calculate relative cover and relative height (measures of changes on control plots) were close to unity. This suggests that variation over the period of the experiment, attributable to 'natural'

Table 1. Analysis of variance for the effect of user type, trampling intensity and vegetation type on vegetation cover and vegetation height immediately after trampling

		Relative cover		Relative height	
Source of variation	df	Mean square	*F*	Mean square	*F*
User type	2	6641	33·1[b]	491	0·6
Trampling intensity	1	3863	19·2[b]	10413	12·6[b]
Vegetation type	1	2798	13·9[b]	29164	35·3[b]
User × intensity	2	2137	10·6[b]	707	0·9
User × vegetation	2	757	3·8[a]	382	0·5
Intensity × vegetation	1	5	<0·1	8	<0·1
User × intensity × vegetation	2	187	0·9	343	0·4
Error	36	200		825	

Significance: [a]≤0·05; [b]≤0·01.

causes, was small compared with the variation attributable to trampling. Correction factors for vegetation cover immediately after trampling were 1·02 in the *Vaccinium* type and 0·98 in the *Equisetum* type. Numbers greater than one indicate increased cover at the later measurement period. One year after trampling, correction factors for vegetation cover were 1·04 in *Vaccinium* and 1·02 in *Equisetum*. Increases in vegetation height, over time, were more pronounced. Correction factors for vegetation height immediately after trampling were 1·13 in *Vaccinium* and 1·31 in *Equisetum*. One year after trampling, correction factors were 1·00 in *Vaccinium* and 1·15 in *Equisetum*.

Immediate effects of trampling on vegetation cover

Vegetation cover after treatment (expressed as a percentage of pre-treatment cover) was significantly less (P<0·001) on lanes that were trampled (mean = 78%; SE = 2%) than on the control lanes (mean = 100%; SE = 2%). However, the intensity of trampling disturbance varied significantly with each of the three main factors (Table 1). User type had the most pronounced effect on relative cover after trampling, but interacted with both vegetation type and trampling intensity. Consequently, each main factor was analysed separately.

In both vegetation types, relative cover after horse traffic was significantly lower than after llama or hiker traffic. Relative cover following llama and hiker traffic was not significantly different. Horse traffic also caused more vegetation cover loss than llama or hiker traffic at both trampling intensities, but the difference between horse traffic and other traffic was not statistically significant (P = 0·16) on the 25-pass lanes. When each combination of vegetation type and trampling intensity was isolated, horse traffic caused substantially more vegetation loss than llama or hiker traffic in each situation other than 25 passes in *Vaccinium*—the lower trampling intensity in the more resistant vegetation type (Figure 1). In none of these situations was there a significant difference between the effects of llama and hiker traffic.

As originally predicted, trampling effects were initially more pronounced in the *Equisetum* erect forb type (61% mean relative cover; SE = 5%) than in the *Vaccinium* low shrub type (75% mean relative cover; SE = 4%). However, this difference between vegetation types was more pronounced (and statistically significant) following horse and llama traffic than following hiker traffic (where P = 0·80 for the significance of differences between vegetation types). As expected, the effect of 150 passes (60% mean relative cover; SE = 3%) was more pronounced than the effect of 25 passes (75% mean relative cover; SE = 5%), but this difference was more pronounced (and statistically significant) following horse traffic than following either hiker (P = 0·33) or llama traffic (P = 0·16).

Immediate effects of traffic on vegetation height

Vegetation height after treatment (expressed as a percentage of pre-treatment height) was

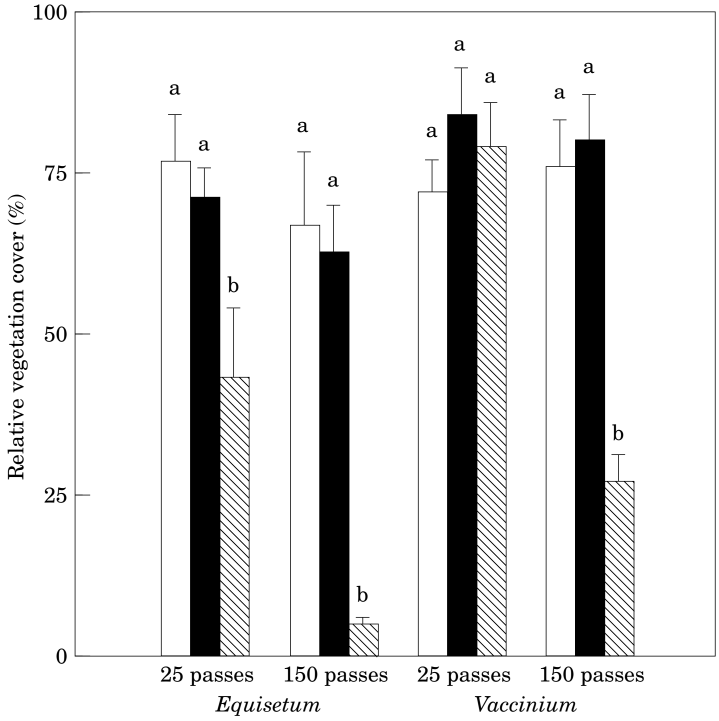

Figure 1. Relative vegetation cover (mean and 1 standard error) immediately after hiker, llama and horse traffic applied at two trampling intensities in two vegetation types. Means with similar superscripts are not significantly different ($\alpha = 0{\cdot}05$). □, hiker; ■, llama; ▧, horse.

significantly less ($P < 0{\cdot}001$) on lanes that were trampled (mean = 52%; SE = 5%) than on the control lanes (mean = 90%; SE = 5%). Relative height after trampling varied significantly with vegetation type and trampling intensity, but not with user type (Table 1). Moreover, no interactions were significant. As was the case with vegetation cover, trampling effects were much more pronounced in the *Equisetum* type (32% mean relative height; SE = 4%) than in the *Vaccinium* type (86% mean relative height; SE = 6%). The immediate effect of 150 passes (46% mean relative height; SE = 7%) was more pronounced than the effect of 25 passes (72% mean relative height; SE = 7%). Differences following hiker traffic (65% mean relative height; SE = 9%), llama traffic (54% mean relative height; SE = 10%) and horse traffic (56% relative height; SE = 11%) were not statistically significant.

Immediate effects of traffic on mineral soil exposure

Prior to trampling, no measurable quantities of mineral soil were exposed on any of the treatment lanes in either of the vegetation types. Exposure of mineral soil following trampling varied with vegetation type, trampling intensity and user type. After trampling, no mineral soil was exposed on any of the treatment lanes in the *Equisetum* type. Soil organic-horizon thickness (typically >10 cm) exceeded the depth to which traffic churned the surface soil. In the *Vaccinium* type, however, where soil organic-horizon thickness seldom exceeded 2 cm, trampling did expose mineral soil under certain circumstances.

In the *Vaccinium* type, no mineral soil was exposed on any of the lanes trampled by hikers or llamas. In contrast, mineral soil was exposed on five of the eight lanes trampled by horses. Trampling intensity strongly influenced the extent to which horse traffic exposed mineral soil. Twenty-five passes by horses exposed mineral soil on only one of the four replicates; mean soil exposure on 25-pass horse lanes was 0·3% (SE = 0·2%). One-hundred and fifty passes exposed mineral soil on all four replicates; mean soil exposure on 150-pass horse lanes was 9% (SE = 2%).

Table 2. Analysis of variance for the effect of user type, trampling intensity and vegetation type on vegetation cover and vegetation height 1 year after trampling

		Relative cover		Relative height	
Source of variation	df	Mean square	*F*	Mean square	*F*
User type	2	1999	10·4^{c}	2235	5·1^{b}
Trampling intensity	1	2119	11·0^{c}	13044	29·5^{c}
Vegetation type	1	6239	32·3^{c}	5053	11·4^{c}
User × intensity	2	541	2·8^{a}	950	2·2
User × vegetation	2	98	0·5	47	0·1
Intensity × vegetation	1	688	3·6^{a}	1735	3·9^{a}
User × intensity × vegetation	2	84	0·4	1249	2·8^{a}
Error	36	193		442	

Significance: $^{a}\leq 0{\cdot}1$; $^{b}\leq 0{\cdot}05$; $^{c}\leq 0{\cdot}01$.

Vegetation cover 1 year after trampling

One year after trampling, vegetation cover (expressed as a percentage of pre-treatment cover) was still significantly less ($P=0{\cdot}02$) on lanes that were trampled (mean = 84%; SE = 3%) than on control lanes (mean = 98%; SE = 4%). Relative cover still varied significantly with each of the three main factors (Table 2). However, user type no longer had the most pronounced effect and the strength of interactions was considerably diminished.

As was the case immediately after trampling, relative cover on the lanes trampled by horses (mean = 69%; SE = 6%) was significantly lower than on the lanes trampled by hikers (mean = 86%; SE = 4%) or llamas (mean = 90%; SE = 4%). In fact, 1 year after trampling, it is difficult to confidently conclude that vegetation cover on lanes trampled by hikers or llamas is significantly less than on control lanes ($P=0{\cdot}18$ and 0·07, respectively). Relative cover on lanes trampled by hikers and llamas did not differ significantly. Although this ordinal relationship was consistent across both vegetation types and trampling intensities, there was a moderately strong interaction effect ($P=0{\cdot}07$) between user type and trampling intensity. The magnitude of difference between horses and the other user types was greater on the lanes trampled 150 times (Figure 2).

In contrast to the situation immediately after trampling, relative cover 1 year after trampling was lower in the *Vaccinium* type than in the *Equisetum* type. This ordinal relationship was consistent across all user types and both trampling intensities, but there was a moderately strong interaction effect ($P=0{\cdot}07$) between vegetation type and trampling intensity. The magnitude of difference between vegetation types was greater on the lanes trampled 150 times.

In the *Equisetum* type, vegetation recovered substantially once trampling was curtailed; mean relative cover increased from 61% (SE = 5%) immediately after trampling to 91% (SE = 3%) 1 year later. One year after treatment, relative cover on trampled lanes in the *Equisetum* type was no longer significantly lower than on the control lanes ($P=0{\cdot}30$). In the *Vaccinium* type, however, vegetation cover continued to decline even after trampling stopped; relative cover declined from 75% (SE = 4%) immediately after trampling to 71% (SE = 4%) 1 year later.

Finally, relative cover 1 year after 150 passes (mean = 74%; SE = 5%) was significantly lower than relative cover after 25 passes (mean = 89%; SE = 3%). One year after trampling, it is difficult to conclude confidently that relative cover on lanes trampled 25 times is significantly less than on control lanes ($P=0{\cdot}06$).

There appear to be moderately strong interactions between trampling intensity and both user type and vegetation type (Table 2), however. Consequently, each of these main factors was analysed separately. Although relative cover 1 year after 150 passes was always lower than it was after 25 passes, this difference was only statistically significant for horse traffic—the most damaging of the user types. Similarly, relative cover after 150 passes was lower than it was after 25 passes

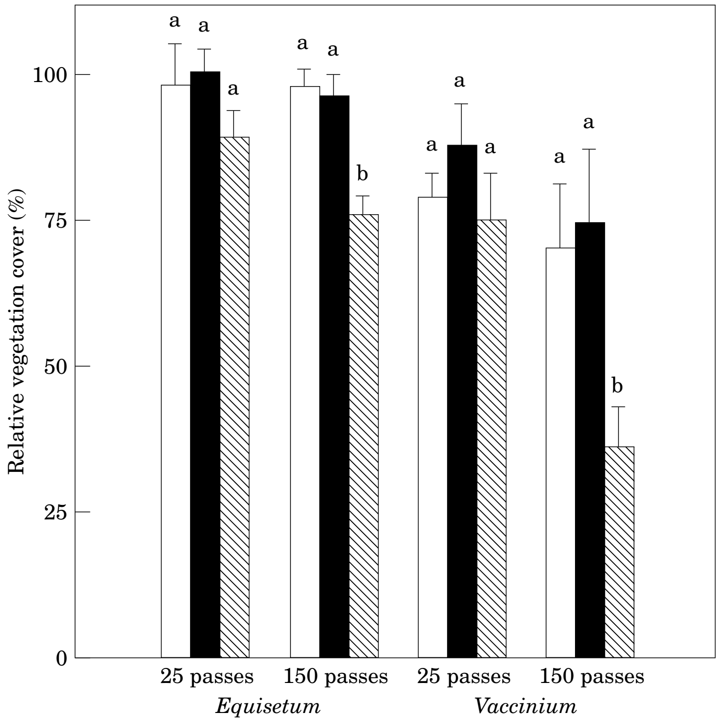

Figure 2. Relative vegetation cover (mean and 1 standard error) 1 year after hiker, llama and horse traffic applied at two trampling intensities in two vegetation types. Means with similar superscripts are not significantly different ($\alpha = 0{\cdot}05$). □, hiker; ■, llama; ▨, horse.

in both vegetation types, but the difference was only statistically significant in *Vaccinium*—the less resilient vegetation type.

Vegetation height 1 year after trampling

One year after trampling, vegetation height (expressed as a percentage of pre-treatment height) was still significantly less ($P = 0{\cdot}05$) on lanes that were trampled (mean = 75%; SE = 4%) than on the control lanes (mean = 108%; SE = 15%). Relative height 1 year after trampling varied significantly with vegetation type and trampling intensity (as was the case immediately after trampling), but also with user type (Table 2). Relative height 1 year after trampling was significantly lower on lanes trampled by horses (mean = 57%; SE = 8%) than on lanes trampled by hikers (mean = 75%; SE = 8%) or llamas (mean = 79%; SE = 5%).

Trampling intensity was the independent variable with the most pronounced effect on vegetation height 1 year after trampling. Mean relative height 1 year after 150 passes was 60% (SE = 6%) compared with mean relative height of 84% (SE = 4%) 1 year after 25 passes. However, the effect of trampling intensity interacted ($P = 0{\cdot}05$) with that of vegetation type. Higher trampling intensities (150 passes) caused more substantial reductions in vegetation height that lower intensities (25 passes) in both vegetation types; however, differences were more pronounced in the non-resilient *Vaccinium* type than in the resilient *Equisetum* type. Mean relative height 1 year after trampling was greater in the *Equisetum* type (mean = 83%; SE = 5%) than in the *Vaccinium* type (mean = 62%; SE = 6%), but differences were only statistically significant on the lanes that received 150 passes.

Mineral soil exposure 1 year after trampling

Exposure of mineral soil 1 year after trampling varied with vegetation type, trampling intensity and user type. Mineral soil was only exposed in the *Vaccinium* vegetation type, on lanes that received 150 passes of horse traffic. Three of the four 150-pass horse replicates in the *Vaccinium* type still had exposed mineral soil (mean = 5%; SE = 2%) 1 year after trampling.

Discussion

These results clearly indicate that horse traffic has more potential to disturb vegetation and groundcover than llama or hiker traffic. For all impact indicators, horses had more pronounced effects than either llamas or hikers and, with the exception of immediate effects on vegetation height, differences were statistically significant. In contrast, none of the effects of llama and hiker traffic differed significantly from each other. This result is identical to that for user effects on established trails where DeLuca *et al.* (1998) found that horse traffic results in more sediment yield from trails than llama or hiker traffic, which result in equivalent amounts of sediment yield. Differences between horse impacts and those caused by llamas or hikers persisted for at least a year.

Horses caused more vegetation impact than llamas or hikers in both vegetation types, despite the fact that these vegetation types contrasted greatly in their response to trampling. Differences in intensity of impact, between horses and other user types, were greater on the less resistant vegetation type (*Equisetum*) immediately after trampling, on the less resilient vegetation type (*Vaccinium*) 1 year after trampling, and at the higher trampling intensity. This suggests that differences between horses and other user groups would have been even more pronounced in less durable vegetation types or at trampling intensities higher than the modest intensities (150 passes) administered during the experiment. Conversely, differences between horses and other user groups are likely to be less pronounced in more durable vegetation types or at lower trampling intensities (<25 passes).

The effects of trampling on vegetation cover and on vegetation height are generally similar. Trampling reduced vegetation height more than it reduced vegetation cover, but the differential effects of users were more pronounced for vegetation cover. Effects on mineral soil exposure were qualitatively different, however. Under the experimental conditions that were imposed, only horse use caused mineral soil exposure.

The interaction between user type and other influential variables and the non-linearity of interrelationships make it impossible to provide a single estimate of the magnitude of difference between horse impact and that caused by llamas or hikers. However, for the range of conditions included in the experiment, it is posible to identify a range of differences.

Perhaps the best way to quantify differences in impact potential is in terms of the amount of trampling it takes to cause a given amount of impact. In the *Vaccinium* vegetation type, the magnitude of vegetation cover loss caused by 25 horse passes was equivalent to that caused by 150 llama or hiker passes, both immediately after trampling (Figure 1) and 1 year after trampling (Figure 2). In the *Equisetum* type, however, 25 horse passes caused much more cover loss than 150 llama or hiker passes. This suggests a six- to 10-fold difference in the amount of use these vegetation types can sustain before a given amount of vegetation cover loss occurs.

Two earlier studies of trampling impacts on vegetation suggest four- to eight-fold differences in the impacts caused by horses and hikers. Nagy and Scotter (1974) studied a prairie grassland which was substantially more resistant that either the *Equisetum* or *Vaccinium* vegetation types; *Festuca scabrella* was the most abundant species. Depending on when trampling occurred, 100–200 passes by a horse resulted in vegetation cover loss equivalent to that caused by 800 passes by a hiker. Weaver and Dale (1978) studied an even more resistant vegetation type (a *Poa pratensis–Festuca idahoensis* grassland), as well as a *Pinus albicaulis–V. scoparium* forest, with an understory very similar to the *Vaccinium* type. In both types, 400–500 passes by hikers resulted in bare ground exposure (loss of vegetation cover) equivalent to that caused by 100 horse passes.

The difference in intensity of impact between horses and hikers can be largely accounted for by variation in the vertical pressure (weight per unit area) exerted by each type. The weight of the horses used was roughly six times that of the hikers. Although the weight of the horses was simultaneously born on more than one foot, the surface area of each hoof was approximately one-half the area of a boot. Horses also are more likely to shear vegetation than hikers (Whinam *et al.*, 1994).

Other variables are needed, however, to explain why llamas did not cause more impact than hikers and why they caused so much less impact than horses. Field observations suggest that, compared to horses and hikers, there is less horizontal movement when llama's feet come into contact with the ground; consequently, the forces llamas exert may cause less shearing of vegetation.

This study corroborated some of the conclusions of other experimental trampling studies. As predicted by Cole (1995b), the vegetation type dominated by erect forbs (the *Equisetum* type) was much less resistant than the vegetation type dominated by low shrubs (the *Vaccinium* type). Also as predicted, the type dominated by hemicryptophytes (forbs) was much more resilient than the type dominated by chamaephytes (shrubs). As expected, the site with thin soil organic-horizons experienced more mineral soil exposure than the site with thick organic-horizons. Finally, as has been reported elsewhere (Cole, 1995a; Marion and Cole, 1996), the relationship between trampling intensity and trampling disturbance is non-linear. On average, a six-fold increase in trampling intensity (from 25 to 150 passes) caused an approximate doubling of vegetation cover loss and height reduction.

Management implications

In attempting to minimise recreation impact in protected areas, managers need to be aware that users differ in their potential to cause impact. The most pronounced difference among non-motorised users appears to be not between packstock and humans but between horses (probably including mules) and other users (both llamas and hikers). Evidence for this conclusion comes from the data reported here, on impacts to vegetation, studies of impacts on established trails (DeLuca *et al.*, 1998), as well as research on the social acceptability of different types of use (Blahna *et al.*, 1995).

Managers can utilise this information in several ways. They can zone protected areas to separate different types of users or to confine the more damaging user types to certain areas, preferably more durable areas. Available data suggest that in separating users, llamas are more closely allied with hikers (in terms of potential to adversely affect the physical environment and other users) than with horses and mules.

In many places, managers attempt to control impacts by limiting and rationing amount of use. Several scientists have suggested that managers should attempt to ration the environmental 'expense' of different user groups (Hendee, 1974; Stankey and Baden, 1977; Weaver *et al.*, 1979). This would be implemented by making the difficulty of obtaining a permit proportional to the environmental impact one's group is likely to cause. The experimental data presented here are useful for this purpose, although they can only be applied to the vegetation types and trampling intensities included in the experiment. Under these conditions, the impact of a horse was about six to 10 times that of a llama or hiker. Even though this specific estimate of magnitude of difference will vary under other circumstances, it illustrates how impact potential increases greatly as type of use shifts from backpacking and llama packing to packing with horses and mules. Managers might want to factor this differential into their management programs.

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Appendix 1. Initial frequency and mean percentage cover of understory species in each vegetation type

Species	*Vaccinium* Frequency (%)	*Vaccinium* Cover (%)	*Equisetum* Frequency (%)	*Equisetum* Cover (%)
Shrubs and subshrubs				
Vaccinium scoparium	100	46		
Vaccinium globulare	36	4	11	+
Spiraea betulifolia	5	+	17	1
Rubus parviflorus			19	4
Symphoricarpos albus			39	2
Linnaea borealis			31	2
Rubus idaeus			11	+
Rosa gymnocarpa			11	+
Vaccinium caespitosum			11	+
Berberis repens			8	+
Graminoids				
Carex concinnoides	27	1		
Calamagrostis rubescens	14	1	47	2
Bromus vulgaris			83	13
Forbs				
Xerophyllum tenax	32	1		
Hieracium albiflorum	9	+		
Equisetum arvense			94	25
Cornus canadensis			97	18
Clintonia uniflora			81	6
Smilacina stellata			58	4
Osmorhiza chilensis			67	2
Senecio pseudaureus			36	1
Fragaria virginiania			33	1
Galium triflorum			33	1
Viola adunca			19	1
Thalictrum occidentale			17	1
Aster conspicuus			14	1
Pyrola secunda			14	+
Aster foliaceus			11	+
Galium boreale			11	+
Viola orbiculata			11	+
Adenocaulon bicolor			6	+
Goodyera oblongifolia			3	+
Mosses	81	11		
Lichens	86	8		

Frequency is percent of subplots 30 × 50 cm in which species was found.
+, mean cover <0·05%. Nomenclature follows Hitchcock and Cronquist (1973).