Effects of Three Seasons of Experimental Trampling on Five Montane Forest Communities and a Grassland in Western Montana, USA

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ABSTRACT

Six vegetation types, one grassland and five forest communities, were experimentally trampled for three successive summers. The relationships between amount of trampling and vegetation cover loss, species loss, and increase in penetration resistance were strongly curvilinear, approximating an asymptotic model in most cases. The relationship between amount of trampling and increase in mineral soil exposure was linear, beyond the level of trampling required to expose mineral soil. The relative vulnerability of each vegetation type was assessed, as was the number of years of trampling required before damage levelled off. Implications for management of recreation sites and design of trampling experiments are discussed.

INTRODUCTION

Vast areas in the mountains of the Western United States have been designated as wilderness, to be managed for the dual objectives of preserving nature and providing opportunities for 'primitive and unconfined recreation'. The most common problem that results from attempts to meet these conflicting objectives is trampling damage of vegetation and soil on trails and campsites (Washburne & Cole, 1983), particularly loss of vegetation cover, loss of organic horizons, and compaction of the mineral soil.

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Managers have implemented a variety of programmes to minimise these impacts. Beyond the imposition of a code of appropriate behaviour, either through regulation or education, most management involves influencing the amount, timing, and location of use. Specific actions include limiting use, requiring use of designated campsites, discouraging use of heavily impacted campsites or trails, locating trails in durable places, and closing campsites or trails to permit recovery. Generally, these actions have been taken without much understanding of how the amount, timing, or location of use influences impact. Several studies have related amount of campsite or trail impact to amount of use (e.g. Dale & Weaver, 1974; Cole & Fichtler, 1983); others have related impact to site characteristics (e.g. Helgath, 1975; Summer, 1980; Cole, 1981). While such studies have improved our understanding of relationships between trampling effects and independent variables, the conclusiveness of results is limited by the confounding of variables, such as amount and types of use, and the inadequacy of visitor use data.

The most common solution to these methodological problems has been to study the effects of carefully controlled amounts of trampling (Liddle, 1975). Models relating amount of use to concomitant impacts can be derived and the relative vulnerability of different sites can be assessed. Unfortunately, most experimental trampling studies have examined the effects of no more than one season of trampling. Because it should generally take several years for the effects of a given level of use to equilibrate, it may be misleading to apply the effects of one season of trampling to management of areas receiving sustained recreation use.

This paper reports the results of experiments in which trampling was applied to six different vegetation types for three successive summers. Objectives of these experiments were to (1) examine relationships between amount of trampling and vegetation cover loss, organic horizon loss, and soil compaction; (2) determine the relative vulnerability of six different vegetation types and the magnitude of differences among types; (3) determine the number of seasons of trampling required before additional trampling seasons cause no further impact; and (4) examine recovery during the seasons that followed each of the three successive summers of trampling.

A better understanding of the relationship between amount of use and amount of impact will be useful to managers attempting to control impact through manipulation of use levels and distributions. Knowledge about the vulnerability of different vegetation types can be useful in promoting use of more durable sites and protecting plant communities that are particularly sensitive to disturbance. Knowledge about how long it takes for the effects of a given level of use to equilibrate will improve our ability to simulate recreation use in trampling experiments. An assessment of overwinter recovery and whether or not the ability to recover diminishes over time or with increased trampling will be useful in evaluating the likely effectiveness of minimising impact through site rotation or closure.

METHODS

The sites

The six vegetation types selected for study were those most commonly used for camping at low to mid elevations (1200–2000 m) in the Bob Marshall Wilderness complex, a 650 000-ha area in the Northern Rocky Mountains of western Montana. There were five forested vegetation types and one grassland type. The forested experimental sites were located outside the Wilderness, in the Seeley Lake Ranger District of the Lolo National Forest; the grassland site was in the Blackfoot–Clearwater Game Range. All sites were at elevations of 1260–1320 m. At the nearby Seeley Lake weather station, annual precipitation averages 536 mm, with 75 mm in July and August—the months when plots were trampled; January temperatures average −8°C and July temperatures 17°C.

The forest types (denoted by the genus of an understorey indicator) and growth forms characteristic of the understorey of each were: (1) the *Symphoricarpos* type—medium-sized (0·3–1 m tall) shrubs and a rhizomatous grass; (2) the *Clintonia* type—caulescent broad-leaved herbs; (3) the *Clintonia–Vaccinium* type—short and prostrate shrubs and caulescent broad-leaved herbs; (4) the *Vaccinium* type—short and prostrate shrubs; and (5) the *Xerophyllum* type—short shrubs and a forb with linear, tufted leaves. The *Festuca* grassland is characterised by tufted grasses. Additional information on each type is presented in Table 1 and in Cole (1985).

Field methods

Two replicate sets of experimental trampling lanes were established in each vegetation type, except in the *Clintonia* and *Clintonia–Vaccinium* types, in which only one set was established. Each set consisted of 17 treatment lanes, each 0·3 m wide and about 5 m long. Where there was any slope, lanes were oriented parallel to contours.

Treatments were randomly assigned to lanes. One treatment lane was a control; the 16 other lanes received trampling. Both the total number of passes per season and the number of days per season when trampling was applied varied. One lane each received 5, 15, 25, 40, 75, 80, 100, 200, 400, 600, 800, 900, 1200, or 1600 total passes per season and two lanes received 300

TABLE 1
Site Descriptions for Each Vegetation Type[a]

Vegetation type (Habitat type)	*Soil type*	*Mean organic horizon thickness (cm)*	*Mean A and B horizon thickness (cm)*	*Slope (%)*	*Overstorey mean canopy cover and species present*	*Understorey mean total vegetation cover and dominant species*
Grassland type						
Festuca (*Festuca scabrella-F. idahoensis*)	Typic Haploboroll	3·0	27	0–2	None	94% *Festuca scabrella*, *F. idahoensis*, *Lupinus sericeus*, and *Achillea millefolium*
Forest types						
Symphoricarpos (*Pseudotsuga menziesii/Symphoricarpos albus*)	Eutric Glossoboralf	6·0	42	20–25	80% *Pseudotsuga menziesii*, *Pinus contorta*, and *Larix occidentalis*	81% *Calamagrostis rubescens*, *Berberis repens*, *Arnica cordifolia*, and *Spiraea betulifolia*
Clintonia (*Abies lasiocarpa/Clintonia uniflora*)	Eutric Glossoboralf	11·0	75	0–4	90% *Larix occidentalis* and *Picea engelmannii*	93% *Thalictrum occidentale*, *Arnica cordifolia*, *Berberis repens*, and *Smilacina stellata*

Clintonia–Vaccinium (*Abies lasiocarpa*/ *Clintonia uniflora*- *Vaccinium caespitosum*)	Typic Udorthent	6·0	10	0–3	90% *Larix occidentalis*, *Pseudotsuga menziesii*, and *Pinus contorta*	92% *Linnaea borealis*, *Berberis repens*, *Calamagrostis rubescens*, and *Spiraea betulifolia*
Vaccinium (*Abies lasiocarpa*/ *Vaccinium caespitosum*)	Andic Dystrochrept	3·5	31	0–7	75% *Pinus contorta* and *Larix occidentalis*	90% *Vaccinium caespitosum*, mosses, *Xerophyllum tenax*, and *Calamagrostis rubescens*
Xerophyllum (*Abies lasiocarpa*/ *Xerophyllum tenax*)	Andic Dystrochrept	0·7	28	0–2	70% *Pinus contorta*, *Pseudotsuga menziesii*, *Abies lasiocarpa*, and *Larix occidentalis*	93% *Vaccinium scoparium*, mosses, lichens, and *Xerophyllum tenax*

[a] Vegetation types are denoted, in this paper, by the genus of an understorey indicator species; habitat types are a classification system based on potential climax tree species and indicator understorey species (Pfister *et al.*, 1977; Mueggler & Stewart, 1980). Soil types are based on the 7th Approximation (USDA Soil Survey Staff, 1960). Species nomenclature follows Hitchcock & Cronquist (1973). Tree species and understorey dominants are listed in order of decreasing mean cover.

passes. The number of days per season when trampling was applied varied from once during the 8-week trampling season to 16 times (twice per week). Whether trampling was concentrated at one time or spread out over the summer had no consistent effect, so in the following analysis all treatments were considered as a simple incremental series. A pass was a one-way walk, at a natural gait, along the lane. The weight of tramplers varied from about 60 to 90 kg; all tramplers wore lug-soled boots.

Trampling treatments were administered between late June and mid-August in 1981, 1982, and 1983. Initial measurements were taken in mid-June 1981, prior to any trampling. Follow-up measurements were taken in late August 1981, after the cessation of trampling, as well as in mid-June and late August 1982 and 1983, and mid-June 1984.

Measurements were taken in four 2 × 5-dm subplots placed—in the centre of each lane—1, 2, 3, and 4 m from one end of each lane. In each subplot the cover of total vegetation, exposed mineral soil (without overlying vegetation or organic horizons), each vascular plant species, all mosses and all lichens, was estimated to the nearest percent if under 10% or in 10% coverage classes between 10 and 100%. Soil compaction was measured below the unconsolidated surface organic litter horizon, once in each subplot, with a pocket soil penetrometer.

Data analysis

The four measures of trampling impact used were relative vegetation loss (RVL), a modification of the relative cover measure first suggested by Bayfield (1979); percent of species lost (SPL); increase in mineral soil exposure (MSI); and increase in penetration resistance (PRI). Formulas were as follow:

(1) $$\mathrm{RVL} = \left[1 - \left(\frac{\text{surviving cover on trampled subplot}}{\text{initial cover on trampled subplot}} \times \mathrm{cf}\right)\right] \times 100\%$$

where $$\mathrm{cf} = \frac{\text{initial cover on control subplots}}{\text{surviving cover on control subplots}}$$

and cover is the sum of the percent covers of all vascular species, mosses and lichens.

(2) $$\mathrm{SPL} = \frac{\text{initial number of species} - \text{number after trampling}}{\text{initial number of species}} \times 100\%$$

(3) MSI = percent mineral soil cover after trampling − initial cover.

(4) PRI = penetration resistance (PR) on trampled subplot − PR on control.

All initial measures refer to those taken in mid-June 1981 prior to treatment. Increases in mineral soil exposure were not corrected by a factor related to change on controls, as other measures were, because there was no exposed mineral soil on controls. Increases in penetration resistance were not pre- and post-treatment comparisons, as other measures were, because resistance varies with soil moisture and moisture varied greatly both between early and late summer and between years. Instead, change was inferred by comparing trampled lanes to controls.

EFFECTS OF THREE SEASONS OF TRAMPLING

Loss of vegetation cover

In all vegetation types, vegetation cover loss increased with an increase in number of passes, rapidly at low levels of trampling and more slowly at high levels (Fig. 1). The *Symphoricarpos*, *Vaccinium*, and *Clintonia* types, not shown in Fig. 1, were similar to the *Clintonia–Vaccinium* type (Fig. 1*a*) in response. An asymptotic regression model of the general form

$$Y = A - B\exp(-CX),$$

where Y is vegetation cover loss (%) and X is number of passes/year, provides a close fit to the data for all vegetation types. For the *Clintonia* type, $Y = 97 - 66\exp(-0{\cdot}013X)$. An asymptotic relationship between trampling and vegetation loss has been a consistent finding of experimental trampling studies (Cole, 1985). The major distinction among vegetation types is in how rapidly the asymptote is approached. Curvilinearity decreases as resistance increases.

Differences among vegetation types, in susceptibility to cover loss, were sizeable. For example, the number of passes/year required to eliminate more than 50% of the cover varied from 400 in the *Festuca* grassland to 40 in the *Clintonia–Vaccinium* and *Symphoricarpos* types (Table 2). Compared to the most fragile types, then, the grassland can be trampled 10 times as frequently and still maintain a 50% cover. The magnitude of differences in susceptibility varied with trampling intensity. Overall, differences among vegetation types were most pronounced at trampling levels of 100–200 passes/year (Table 2).

The high resistance of the *Festuca* grassland type appears to be attributable to the resistance of the bunchgrasses that are abundant in this type. The moderate resistance of the *Xerophyllum* type is largely attributable to the resistance of mosses (primarily *Brachythecium* and *Dicranum*) and of *Xerophyllum tenax*, a perennial, rhizomatous monocotyledon, with tough,

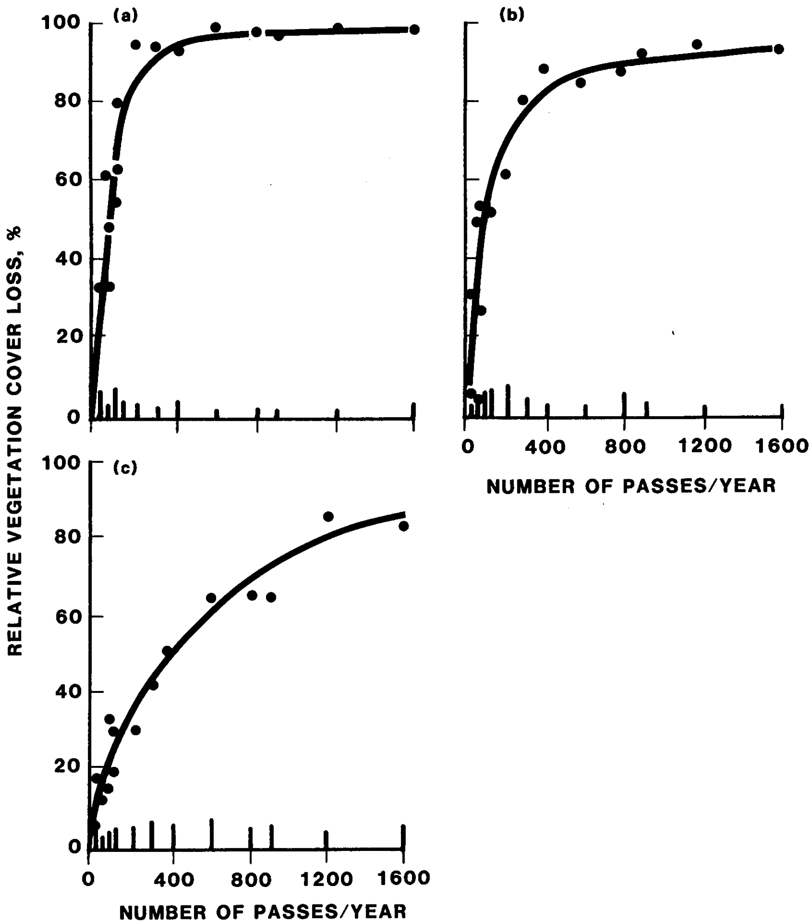

Fig. 1. The relationship between number of passes/year and relative vegetation cover loss after three seasons of trampling in the (a) *Clintonia–Vaccinium*, (b) *Xerophyllum*, and (c) *Festuca* grassland vegetation types. Mean values are plotted; bars at bottom are one standard error. The curves were fitted by hand.

wiry leaves, arranged in large basal tufts. The most abundant plants in the most fragile types are short shrubs with brittle stems and branches and tall, caulescent forbs. Several studies have found grasses and mosses to be highly and moderately resistant, respectively (Holmes & Dobson, 1976; Rogova, 1976; Studlar, 1980), although Schreiner (1974) found mosses to be quite fragile. Tough, wiry leaves and a tufted growth form are common characteristics of species reported to be tolerant of trampling by Speight (1973) and Holmes & Dobson (1976). Holmes & Dobson (1976) also report that the most sensitive species in a subalpine meadow in Yosemite National Park, California, were short woody plants and tall herbaceous plants with caulescent shoot systems.

TABLE 2
Differences among Vegetation Types in Vegetation Cover Loss (RVL) after Three Seasons of Trampling[a]

Number of passes	*Vegetation type*						*All vegetation types*
	Festuca	Xerophyllum	Vaccinium	Clintonia-Vaccinium	Symphoricarpos	Clintonia	
				Percent			
5	6a	9a	19ab	33bc	14ab	42c	17
15	13a	15a	24ab	33ab	31ab	41b	24
25	18a	35ab	43b	48b	45b	47b	38
40	15a	35b	48bc	61c	63c	50bc	43
75	9a	55b	63b	62b	68b	73b	53
80	33a	61b	66b	54b	59b	78b	57
100	30a	56b	60b	79c	80c	83c	61
200	31a	69b	93c	95c	95c	94c	77
300	42a	82b	89b	95b	87b	91b	79
400	51a	89b	88b	94b	95b	97b	84
600	65a	85b	90b	100b	91b	96b	86
800	66a	90b	96b	99b	99b	98b	90
900	65a	92b	95b	98b	97b	97b	90
1 200	86a	93b	98b	100b	98b	99b	95
1 600	84a	93b	96b	100b	99b	100b	95
Mean of all treatments	38a	61b	68c	73c	71c	75c	63

[a] Any two cover loss values in the same row followed by the same letter are not significantly different (Duncan's multiple range test, $p = 0{\cdot}05$).

There is also a tendency for resistance to increase as tree canopy cover decreases. A dense overstorey discourages the growth of resistant graminoids and encourages adaptations to low light intensities—such as large leaf areas, thin cuticles, cell walls and stems—that make plants particularly susceptible to trampling damage. This result adds further support to Grime's (1979) observation that no plants are well adapted to environments characterised as both high in stress (in this case low light intensity) and in disturbance.

Loss of species

As with cover loss, the percent of species lost (decrease in species richness) increases with number of passes, rapidly at low levels of trampling and more slowly at higher levels. Data for the *Vaccinium* type (Fig. 2*a*) are typical of the other forested types. The relationship approximates an asymptotic model. Again the curve for the grassland is less curvilinear; the asymptote is approached less rapidly and is located at a lower percentage of species loss (Fig. 2*b*). About 20% of the grassland species on controls were absent by the mid-August measurement period; they had wilted and disintegrated. This natural seasonal loss caused the erratic results at trampling intensities of less than 400 passes/year.

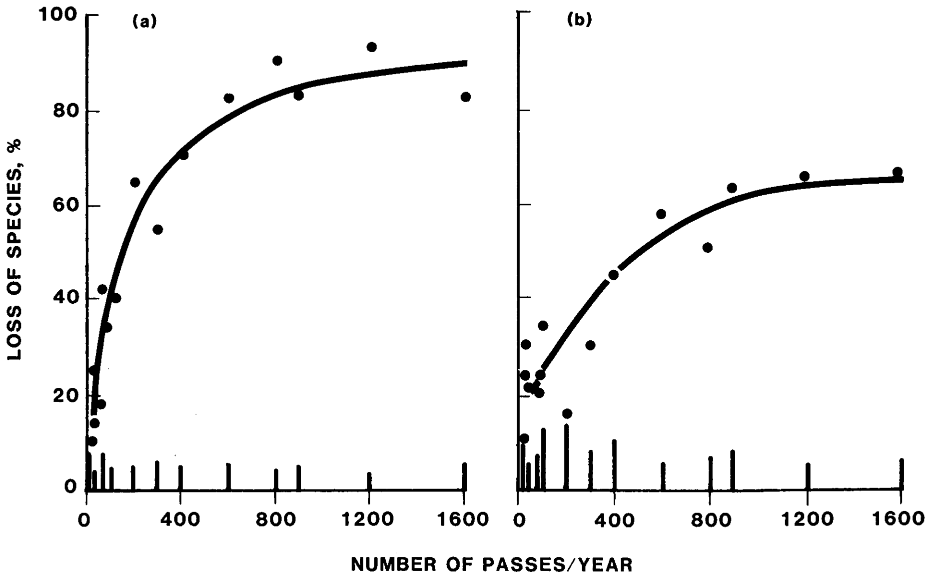

Fig. 2. The relationship between number of passes/year and loss of species after three seasons of trampling in the (a) *Vaccinium* and (b) *Festuca* grassland vegetation types. Mean values are plotted; bars at bottom are one standard error. The curves were fitted by hand.

The relative vulnerability of each vegetation type to species loss is quite similar to its vulnerability to vegetation cover loss. Differences among types are less pronounced, however. The number of passes/year required to eliminate 50% of the species varied from 600 in *Festuca* grassland to 200 in all of the forested types other than the *Xerophyllum* type. The *Xerophyllum* type generally retained a larger proportion of species than other forested types. Differences in susceptibility to species loss were most pronounced at trampling levels between 600 and 900 passes/year.

Loss of organic horizons

In contrast to loss of species and vegetation cover, loss of organic horizons sufficient to expose the underlying mineral soil only occurred at relatively high levels of trampling. Below trampling intensities of 100 passes/year, exposure is negligible. Above this intensity, a linear regression model provides a close fit to the data, although in the most resistant types the slope of the regression line is quite flat (Fig. 3). For the *Vaccinium* type, $Y = 0{\cdot}9 + 0{\cdot}000\,85X$, where Y is increase in mineral soil exposure (%) and X is passes/year; $r^2 = 0{\cdot}25$. For the *Xerophyllum* type, $Y = 3{\cdot}5 + 0{\cdot}008\,25X$; $r^2 = 0{\cdot}44$. A similar response has been reported in studies of campsites.

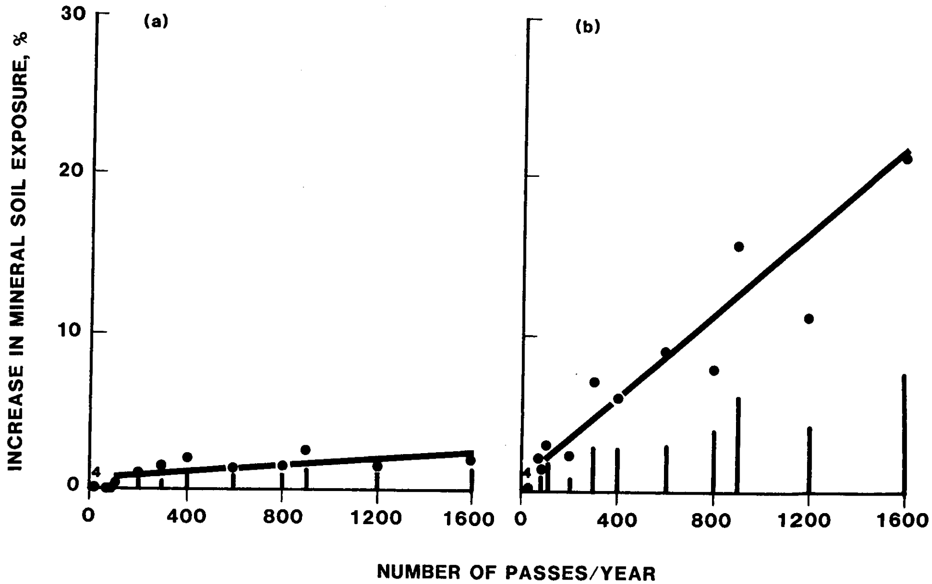

Fig. 3. The relationship between number of passes/year and increase in mineral soil exposure after three seasons of trampling in the (a) *Vaccinium* and (b) *Xerophyllum* vegetation types. Mean values are plotted; bars at bottom are one standard error. The curves were fitted by hand; values <100 passes/year were excluded.

Mineral soil exposure is one of the few types of impact that increase substantially, with increasing amount of use, on regularly used campsites (Cole & Fichtler, 1983; Marion & Merriam, 1985*a*).

There were sizeable differences among vegetation type in susceptibility to loss of organic horizons. In contrast to vegetation loss, differences were most pronounced at the highest trampling levels. Mean exposure after 1600 passes/year was 2% in *Vaccinium*, 8% in *Clintonia–Vaccinium*, 11% in *Symphoricarpos*, 17% in *Festuca* grassland, and 22% in *Xerophyllum*. No mineral soil was exposed on any of the lanes in the *Clintonia* type. Generally, more mineral soil was exposed on the types that either had thin organic horizons or were located on steeper slopes (Table 1).

Increase in penetration resistance

Penetration resistance increased with an increase in number of passes—rapidly at low levels of trampling and more slowly at higher levels (Fig. 4). A similar response was reported by Liddle & Greig-Smith (1975). In their study of trampling effects on sand dune soils, bulk density and penetration resistance were linearly related to the log of the number of walkers. In this study, a logarithmic model provides a close fit for all vegetation types but the *Clintonia*. For the *Vaccinium* type, $Y = 1{\cdot}01\ (\log X + 1)$; $r^2 = 0{\cdot}71$.

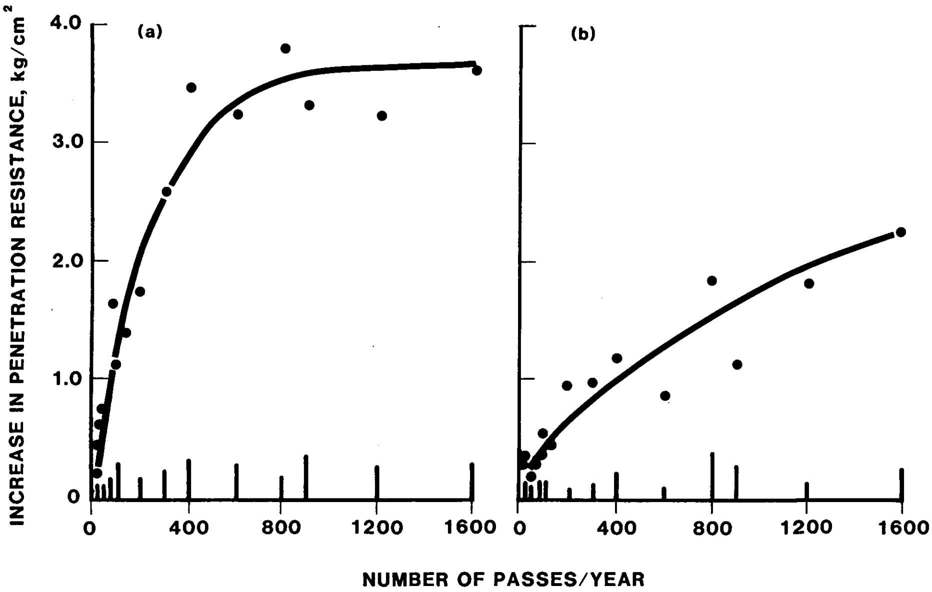

Fig. 4. The relationship between number of passes/year and increase in penetration resistance in the (a) *Vaccinium* and (b) *Clintonia* vegetation types. Mean values are plotted; bars at bottom are one standard error. The curves were fitted by hand.

As with the use/impact relationships for loss of species and vegetation cover, curvilinearity of the penetration resistance response curve decreases in the more resistant vegetation types. The type most resistant to compaction, the *Clintonia*, had the thickest organic horizons prior to trampling. Mineral soil was never exposed in this type. A strong negative correlation between organic horizon thickness and increase in bulk density has also been observed on established backcountry campsites (Marion & Merriam 1985*b*). Persistent thick organic horizons cushion the mineral soil and limit the compaction caused by trampling. The type most susceptible to compaction was *Vaccinium*. Other types were intermediate in response. Differences among vegetation types were most pronounced at intensities of 400–900 passes/year.

The sensitivity of different parameters

Even low levels of trampling cause a substantial loss of vegetation cover and species and an increase in penetration resistance. For these parameters, the initial increment of trampling causes the most change; additional increments have less effect. For example, using the mean for all vegetation types as a measure of typical response, it took only 15 passes/year to cause a 20% loss of vegetation cover. Additional 20% increments of vegetation loss occurred after about 40, 100, and 300 passes/year (Table 3). Higher trampling intensities were required to cause similar proportional decreases in number of species and increases in penetration resistance (Table 3). Sites resisted these types of change longer than vegetation loss. The type of impact that responded least rapidly to increased trampling was mineral soil exposure. Generally, several hundred passes/year were required to expose any mineral

TABLE 3

The Number of Passes/Year Required to Cause Proportional Increase in Impact[a]

Impact parameter	*Percent of maximum recorded impact*				
	20	*40*	*60*	*80*	*100*
	Number of passes/year				
Vegetation cover loss	15	40	100	300	1 200
Loss of species	40	100	300	600	1 200
Increase in mineral soil	300	600	900	1 200	1 600
Increase in penetration resistance	40	100	300	600	1 600

[a] The mean for all vegetation types was used. Values are the number of passes/year administered to the most lightly trampled lane that experienced proportions of the maximum level of impact recorded on any lane.

soil at all; above this use intensity, each increment of use had approximately the same effect.

Deterioration in successive seasons

The number of seasons of trampling required before additional seasons of trampling caused no further vegetation loss differed among vegetation types and trampling intensities. At trampling intensities above 200 passes/year vegetation loss in the *Clintonia* type after two seasons of trampling was similar to the loss after just one season (Fig. 5*a*). Maximum levels of deterioration occurred after just one season of trampling. At lower trampling intensities and at all intensities in the other forested types, the second season of trampling caused substantially more vegetation loss but the third season did not (Fig. 5*b*). In these types, deterioration continued for two seasons before stabilising. In the *Festuca* grassland type, maximum deterioration occurred in two seasons on lanes that received less than 300 passes/year. At higher trampling intensities, however, vegetation loss after three seasons was substantially greater than loss after two seasons (Fig. 5*c*); deterioration was continuing.

In most situations, loss of vegetation cover reached a maximum after two seasons of trampling. Only moderate and heavy trampling (>200 passes/year) in the type that resisted cover loss most (*Festuca* grassland) caused substantial loss beyond the second season. Only moderate and heavy trampling (>200 passes/year) in the type that resisted cover loss least (*Clintonia*) eliminated so much cover in just one season that the second season of trampling caused no further loss.

At trampling intensities of less than 100 passes/year, species loss in most vegetation types did not increase significantly after the first season of trampling. At higher trampling intensities, maximum levels of species loss occurred after the second season of trampling. In the *Festuca* grassland, *Symphoricarpos* and *Clintonia* types, more species were present after the third trampling season than after the second.

At low to moderate trampling intensities (<600 passes/year), mineral soil exposure reached a maximum after two seasons of trampling. At higher levels of trampling, however, exposure increased substantially during the third season of trampling, particularly in the *Festuca* grassland, *Xerophyllum* and *Clintonia–Vaccinium* types.

With the exception of the *Clintonia* type, penetration resistance peaked after the second season of trampling. This was the case regardless of trampling intensity. In the *Clintonia* type, compaction levels increased during the third trampling season as well. The mineral soil on this site was still completely covered with an organic horizon, even after the third

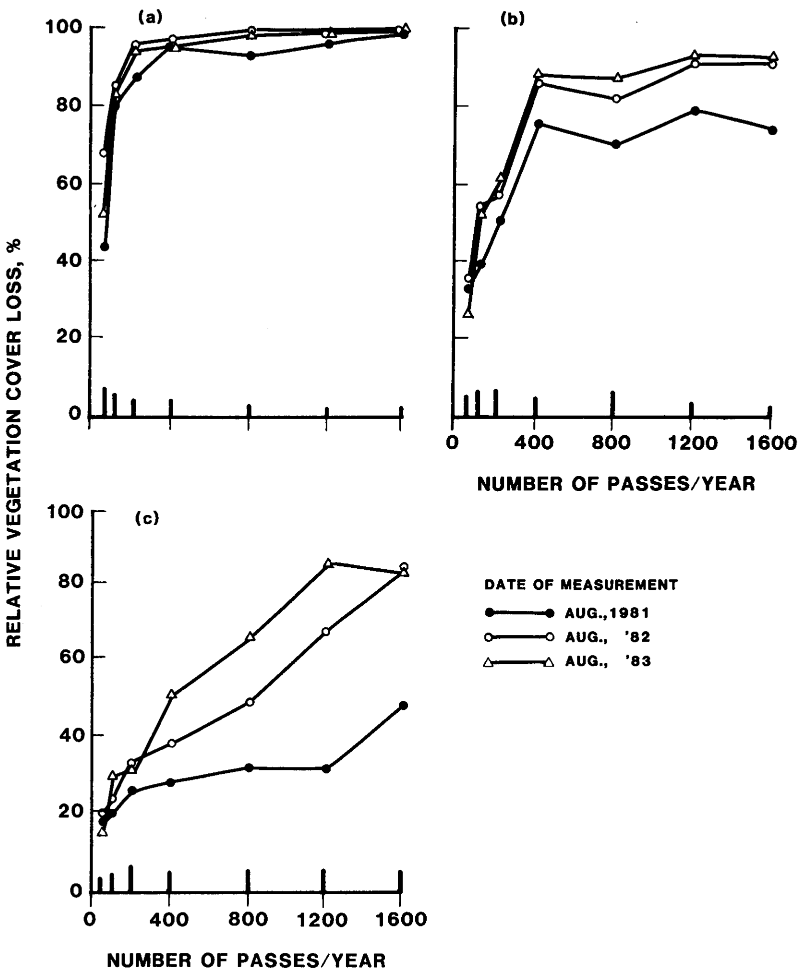

Fig. 5. The relationship between number of passes/year and relative vegetation loss after one (August 1981), two (August 1982), and three (August 1983) trampling seasons in the (a) *Clintonia*, (b) *Xerophyllum*, and (c) *Festuca* grassland types. Selected mean values are plotted; bars at bottom show the median standard error for the three trampling seasons.

trampling season. Assuming that this horizon was gradually thinning, its ability to inhibit compaction was probably diminishing each year. If so, stabilisation of compaction should not be expected in this type until thinning of the organic horizon stops. In all other types, penetration resistance after the third trampling season was lower than after the second season. This decline in resistance from the second to third trampling season is more likely a reflection of different soil moisture levels than evidence of a decrease in compaction.

SEASONAL RECOVERY

Vegetation cover

Examination of overwinter recovery provides information on the short-term resilience of these vegetation types and how resilience is affected by both the intensity of trampling and the number of years trampling occurs. All vegetation types, except for *Vaccinium* and *Clintonia–Vaccinium*, experienced substantial overwinter recovery between late August 1981 (immediately after the first season of trampling) and June 1982. In the *Clintonia–Vaccinium* type, cover actually declined over this period. Most of the decline can be attributed to a decrease in the cover of the dominant shrub, *Linnaea borealis*. This may represent another example of the delayed damage noted by Bayfield (1979) in a number of ericaceous shrubs. No delayed damage was evident in ericaceous shrubs, however.

Amount of recovery, expressed as the difference in cover between the start of the recovery period in August (immediately after trampling) and the following June, varied greatly among vegetation types. For the first recovery period, the *Clintonia–Vaccinium* type experienced the least recovery (Fig. 6*a*) and the *Clintonia* type experienced the most (Fig. 6*b*). Variation among types diminished after successive seasons of trampling. Compared to recovery after the first trampling season, the amount of overwinter recovery after the second and third seasons decreased substantially in the *Clintonia* type (Fig. 6*b*), increased substantially in the *Clintonia–Vaccinium* (Fig. 6*a*), and remained relatively constant in the other types. Only in the type that was initially most resilient (*Clintonia*) is there evidence that successive years of trampling substantially reduce the amount of overwinter recovery.

Conclusive explanations for differences in resilience are lacking, but observations suggest that both environment and growth form characteristics play a role. After one season of trampling, most recovery occurred on the site that was both relatively warm and moist and dominated by broad-leaved herbs (*Clintonia*); least recovery occurred on sites that were subject to cold air drainage and frequent frosts and dominated by low shrubs (*Clintonia–Vaccinium* and *Xerophyllum*). These latter sites continued to be least resilient after subsequent seasons of trampling. The resilience of broad-leaved herbs declined substantially after the first year. The most resilient sites, after several seasons of trampling, were those with the longest growing season and the most sizeable grass component (*Festuca* grassland and *Symphoricarpos*).

Although one might hypothesise that lightly trampled lanes would experience the most overwinter recovery, this was not the case.

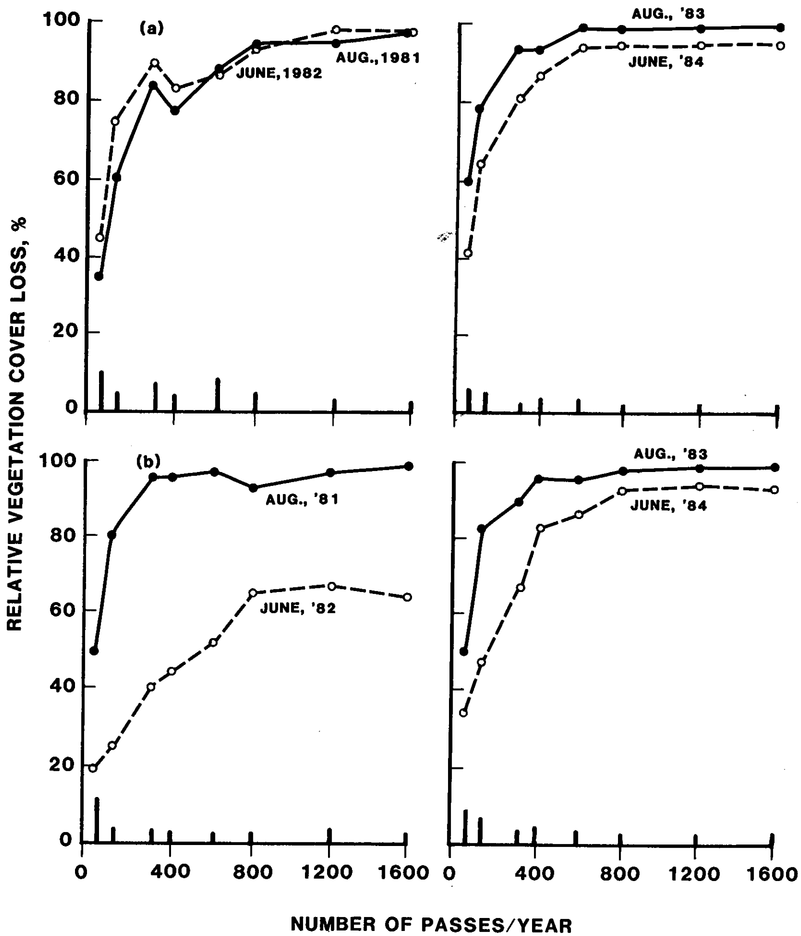

Fig. 6. Recovery after the first and third seasons of trampling in the (a) *Clintonia-Vaccinium* and (b) *Clintonia* vegetation types. August measurements immediately followed trampling; June measurements preceded trampling. The difference provides a measure of recovery. Selected mean values are plotted; bars at bottom show the median standard error for the two measurement periods.

Recovery during the first overwinter period was usually greatest on the lanes that received 100–600 passes. In the *Festuca* grassland recovery was greatest on the lanes that received the highest levels of trampling (> 600 passes/year). Maximum recovery after the second and third trampling seasons generally occurred on lanes receiving less trampling (40–300 passes/year after the third trampling season). See, for example, Figure 6*b*.

Similar results were reported in an experimental trampling study in Waterton Lakes National Park, Alberta (Nagy & Scotter, 1974; Douglas *et al.*, 1975). In several forested vegetation types containing many of the same species found on the Montana sites, maximum amounts of recovery usually occurred on lanes trampled 100–300 times. In a *Festuca scabrella* grassland, maximum recovery occurred on lanes trampled 400–800 times. Apparently recovery is usually greatest after a moderate level of vegetation loss.

Management often has an objective to keep impacts to levels at which complete recovery can occur within one year. By assuming that recovery is complete where percent cover is not substantially different from cover on the control, the maximum trampling intensity that each vegetation type can endure and still recover completely can be determined. The maximum number of passes administered to a lane that recovered completely between August 1981 and June 1982 was 800 in *Festuca* grassland and 25 or less in the forested types. In all types, the amount of trampling vegetation can tolerate and still recover completely either declined or stayed the same with successive years of trampling.

Species richness

Differences among vegetation types in overwinter recovery of species richness were less pronounced than differences in cover loss. However, the types that experienced the greatest overwinter increase in vegetation cover also experienced the largest proportional overwinter increase in number of species. In almost every case, more than one-half of the species lost after trampling reappeared the following year. This considerable resilience was maintained even after three seasons of heavy trampling, although recovery after the third season was less than after the second season.

Organic horizons

Overwinter decreases in mineral soil exposure were substantial in all of the forested vegetation types; exposure after each winter was often less than 50% of what it had been immediately after trampling. Recovery was minimal in the *Festuca* grassland, however. After the second and third recovery periods, mean exposure there was still 91% and 93% of what it had been immediately after trampling. Recovery was greatest in the *Xerophyllum* and *Symphoricarpos* types, those forested types that experienced the most exposure following trampling.

Lanes that received heavy trampling had much more soil exposure after recovery periods than lanes receiving light or moderate trampling. The difference in exposure between the heavily trampled lanes and the more lightly trampled ones increased after each successive period of trampling and recovery (Fig. 7). This response differs from that of the other impact parameters; it reflects the linear increase in exposure with number of passes/

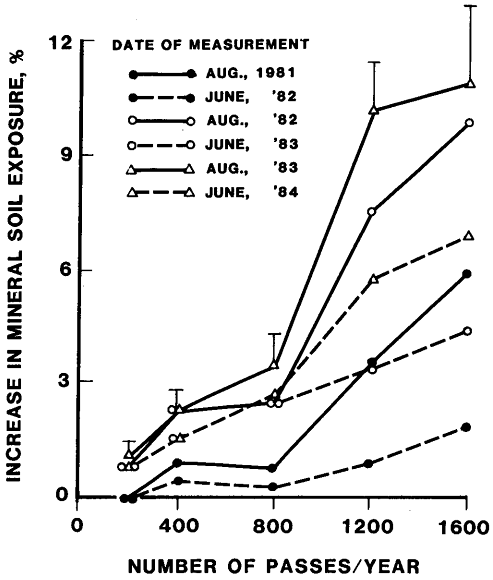

Fig. 7. The relationship between number of passes/year and mean increase in mineral soil exposure after one, two, and three trampling seasons and the recovery periods that followed. August measurements immediately followed trampling; June measurements followed the recovery period and preceded trampling. Data are for all six vegetation types combined. Bars above mean values show the median standard error for the six measurements.

year and the continued increase in exposure, at high trampling intensities, even after three seasons of trampling. Despite pronounced overwinter recovery, soil exposure will be substantial on sites that have received heavy trampling for many years (Cole & Marion, 1986).

Penetration resistance

Overwinter decreases in penetration resistance were pronounced in all vegetation types. The most pronounced recovery occurred in the *Vaccinium*, *Clintonia–Vaccinium*, and *Festuca* grassland types. Recovery was greatest after the second season of trampling and at the highest trampling intensities. This reflects, in part, the tendency for amount of recovery to be roughly proportional to compaction levels. There is some indication that the ability to recover from compaction declined after the third season of trampling, however.

METHODOLOGICAL IMPLICATIONS

This study found that experimental trampling studies must be conducted over several seasons if they are to realistically simulate long-term recreation impact. Usually two seasons of trampling should be adequate. On more resistant sites, and when examining impact parameters that deteriorate slowly, such as soil exposure, more than two seasons of trampling may be necessary. If this had been a single-season study it would have underestimated amount of impact, particularly on the more resistant sites. It would have exaggerated differences among sites in susceptibility to vegetation impact and underestimated differences in susceptibility to soil exposure and increase in penetration resistance.

Although the number of seasons trampling was administered was important, the number of days within the 8-week trampling season that trampling was administered (this varied from 1 to 16) had no consistent effect. Bayfield (1979) also found that trampling frequency had little effect. Although trampling frequency may be an influential factor on some sites, and a few studies have reported an effect (e.g. Hylgaard & Liddle, 1981), its importance is probably so insubstantial that it can be ignored in study design.

One factor that cannot be ignored is delayed damage. If post-trampling measurements are taken only immediately after trampling, they will often underestimate vegetation impact. This study, and those of Bayfield (1979) and Hylgaard & Liddle (1981) found that some species lose cover within a few weeks after trampling, after wilting occurs, while others lose cover during the following winter, perhaps as a result of increased susceptibility to frost damage or loss of carbohydrate reserves. Ideally, post-trampling measurements should be taken immediately after trampling, within a few months (e.g. 2 months) after trampling, and 1 year later. To increase comparability of results, a standard sequence of measurement periods should be adopted.

Given the inconsistent effect of trampling frequency, the design employed in this study could have been improved by decreasing the number of treatments and increasing the number of replications. The range of trampling intensities was close to ideal, however. To examine vegetation response, the highest trampling intensities were unnecessary; to examine soil exposure, higher trampling intensities would have been desirable. It would also have been desirable to continue the trampling beyond three seasons to see how many seasons soil exposure would increase.

Translating experimental passes into managerially relevant units of use

Perhaps the major limitation of experimental trampling studies is the difficulty of comparing number of passes to managerially relevant units of use, such as number of visitors. Trail use should be readily comparable to number of passes. Each person walking along a trail should be directly comparable to a pass. For example, the effect of 400 people/year walking along a path should be roughly comparable to the effects of 400 passes/year. The major complication is the effect of people spreading out laterally. Where this occurs, the effect of a given number of people/year will be less pronounced than that of the same number of passes/year. On most trails, however, it is doubtful that lateral spreading would dilute the amount of use on the central part of the trail by a factor of more than about two.

The complication caused by people spreading out becomes most problematic where trail systems are lacking and visitors can wander where they will. In these situations, the best managers can do is estimate trampling intensities on different portions of the area from visitor use figures and observations of user distribution patterns. Such estimates will obviously be imprecise, but in some cases it may be possible to relate these estimates to environmental responses identified in trampling experiments.

It is also difficult to compare nights of use on campsites to number of passes/year. Such a comparison could never be precise because many of the environmental stresses caused by camping are very different from those caused by walking. Much of the impact on campsites is caused by trampling, however, and this should be generally comparable to the effects of experimental trampling. Through observations of camping behaviour and a series of assumptions described in Cole (1985), it was estimated that 75–150 passes/year simulates the amount of trampling that occurs in the central part of a campsite during one night of use by a typical party of three backpackers. The validity of this estimate was confirmed by comparing the effects of one night on camping in two of these vegetation types to the effect of 75–150 passes. Vegetational responses were quite similar.

Obviously more research is needed to calibrate campsite use measures with experimental trampling, but the value in increased applicability of results is high.

MANAGEMENT IMPLICATIONS

The results of this study have implications for three issues of concern to managers attempting to minimise site impacts in wilderness and other recreation areas with nature preservation goals. The first issue is the likely effectiveness of use limitations and whether concentration of use or use dispersal is more appropriate. The second is site durability—which sites are most resistant and how sizeable are differences in durability. The third issue is site deterioration and recovery—how rapidly deterioration occurs and under what conditions resilience is greatest.

Concentration vs dispersal

The asymptotic nature of most use/impact relationships permits the identification of use thresholds, located at the trampling intensity where the response curves first approach the asymptote. Above these thresholds, use limitation has little effect; amount of impact is not strongly influenced by amount of trampling. Below these thresholds, amount of impact is determined, to a great extent, by amount of trampling and use reductions can effectively reduce impact. Moreover, the reduction in impact that occurs with an incremental reduction in trampling intensity increases as trampling intensities are lowered. Consequently, where use levels can be kept substantially below thresholds, dispersing use among many sites—so the trampling intensity on all sites is as low as possible—is a worthwhile management strategy. Dispersal can be accomplished by asking visitors to camp on apparently undisturbed sites and to spread out, rather than walk single-file, when walking off constructed trails. At use levels close to and above thresholds, concentration of use on as few sites as possible is a better strategy. Near-maximum levels of impact will occur, regardless of trampling intensity, so the most effective way to minimise impact is to keep the number of impacted sites to a minimum. Visitors should be asked to camp on well-impacted sites, to use existing trails, and to walk single-file on the most obvious tread.

Use thresholds vary with impact parameter and vegetation type. There were no thresholds for mineral soil exposure, which increased linearly with increases in trampling intensity. For each of the other impact parameters, use thresholds are presented for each vegetation type (Table 4). These can be roughly converted to nights of camping using the conversion estimate of 1 night equalling 75–150 passes. Thresholds were lower for vegetation cover loss than for species loss or increase in penetration resistance. Only in the *Festuca* grassland can use levels exceed several hundred passes/year (or a few nights of camping/year) without reaching near-maximum levels in at least one of these types of impact. As was concluded in studies of existing campsites, dispersal will only be effective where use levels are very low and/or sites are highly resistant (Cole & Fichtler, 1983).

Concentration of use tends to aggravate problems with mineral soil exposure because soil exposure continues to increase as use increases, at least under the trampling intensities administered in this study. This problem is likely to be a particular concern on campsites, where studies of existing sites have found much more pronounced loss of organic horizons on heavily used sites than on lightly used ones (Cole & Fichtler, 1983; Marion & Merriam, 1985*a*). Above thresholds, managers' only choice is between a small number of devegetated, compacted sites, with little organic matter, and a larger

TABLE 4
Trampling Intensities, for Each Vegetation Type, Below Which Reductions in Intensity Reduce Impact

Vegetation type	*Impact parameter*		
	Vegetation cover loss	*Species loss*	*Increase in penetration resistance*
		Number of passes/year	
Grassland			
Festuca	1 200	>1 600	>1 600
Forest			
Xerophyllum	400	1 200	600
Symphoricarpos	200	800	1 200
Vaccinium	200	600	400
Clintonia	200	400	>1 600
Clintonia–Vaccinium	200	600	1 200

number of devegetated, compacted sites, with more organic matter. The linear relationship between trampling intensities and soil exposure suggests that the trade-off between number of sites and soil exposure is roughly proportional. Decisions on the appropriateness of either dispersal or concentration must be guided by management objectives which must be concerned with recreational experiences as well as ecological impacts.

Site durability

The effectiveness of either dispersing or concentrating use can be increased by promoting use of durable sites. The durability of different vegetation types varies with impact parameter. The relative susceptibility of each type is presented in Table 5.

The importance of differences among types varies with both impact parameter and trampling intensity. Differences in susceptibility to vegetation cover loss and mineral soil exposure were more pronounced than differences for the other impact parameters. The vegetation type least susceptible to cover loss tolerated 10 times as much trampling as the most susceptible type before losing 50% of its cover. The type least susceptible to soil exposure never experienced any exposure. With loss of species and increase in penetration resistance, the least susceptible type only tolerated about five times as much trampling as the most susceptible type before moderate levels of impact occurred.

Differences in susceptibility to cover loss were most pronounced at

TABLE 5
The Relative Susceptibility of Each Vegetation Type to Each Type of Impact

Vegetation type	*Impact parameter*			
	Vegetation cover loss	*Species loss*	*Mineral soil exposure*	*Increase in penetration resistance*
Grassland				
Festuca	Low	Low	High	Moderate
Forest				
Xerophyllum	Moderate	Moderate	Very high	High
Symphoricarpos	Very high	Very high	High	High
Vaccinium	High	High	Low	Very high
Clintonia	Very high	Very high	Low	Low
Clintonia–Vaccinium	Very high	Very high	Moderate	Moderate

trampling intensities of 100–200 passes/year (or a night or two of camping/year). Above 1200 passes/year, differences among vegetation types in susceptibility to cover loss were minor. Differences in susceptibility to species loss and soil compaction were most pronounced at trampling intensities of 400–900 passes/year. Differences in susceptibility to soil exposure were most pronounced at the highest trampling intensities.

At low use levels, only differences among vegetation types in susceptibility to cover loss were pronounced. This suggests that where dispersal is practised, visitors should be encouraged to use the sites least susceptible to vegetation cover loss, the *Festuca* grassland and *Xerophyllum* types in this study. At high use levels, only differences in susceptibility to soil exposure were pronounced. Where concentration is practised, visitors should be encouraged to use the sites least susceptible to soil exposure, generally those with thick organic horizons, such as the *Clintonia* type.

Rates of deterioration and recovery

Vegetation and soil impact are inevitable except where use levels are very low. This is evident given the extremely low trampling intensities sites can tolerate and still recover completely in one season. Cover loss is particularly difficult to avoid; only on the *Festuca* grassland type is overwinter recovery complete at use intensities that exceed 15 passes/year. Only soil exposure can be avoided without reducing use almost to nil.

Although impact is inevitable, the period of time during which deterioration increases is short. Maximum levels of impact are usually reached after just two seasons of trampling. Only soil exposure increased substantially during the third season of trampling and then only at the highest trampling intensities.

These results suggest that there is little opportunity to minimise impact through managing the temporal distribution of use, such as by alternately opening and closing sites. Maximum impact occurs too rapidly and there is too little benefit, in increased resilience, from avoiding the use of sites for prolonged periods of time. Rotation of use among a large number of sites will only effectively limit impact where use levels are so low that sites are never allowed to deteriorate substantially. Such a rotation system is identical to the dispersal strategy discussed previously.

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