

Experimental trampling of vegetation. I. Relationship between trampling intensity and vegetation response*

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Summary

1. Experimental trampling was conducted in 18 vegetation types in five separate mountain regions in the United States. Each type was trampled 0–500 times. Response to trampling was assessed by determining vegetation cover 2 weeks after trampling and 1 year after trampling.
2. Response varied significantly with trampling intensity and vegetation type. Trampling intensity and vegetation type explained more of the variation in vegetation cover 2 weeks after trampling than they did 1 year after trampling.
3. For most vegetation types, the relationship between vegetation cover after trampling and trampling intensity was best approximated by a second order polynomial of the form $Y = A - BX + CX^2$. The relationship was linear in a few vegetation types.
4. The curvilinearity of the relationship between trampling intensity and surviving vegetation cover decreased with increases in resistance, tolerance and species diversity of the vegetation type.

Key-words: recreation impact, regression analysis, vegetation impact.

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Introduction

Over the past few decades, concerns about adverse impacts associated with outdoor recreation have increased greatly. In national parks, wilderness areas and other natural areas, managing agencies are asked simultaneously to preserve natural conditions and allow for recreational use. To find optimal balances between these competing goals, land managers need better information about recreational impacts on the environment. This need has spurred development of the science of recreation ecology (Cole 1987b; Liddle 1991).

Students of recreation ecology have been particularly interested in the effects of human trampling on natural vegetation and many studies have documented deleterious effects of trampling. One common research approach has been to use experimental designs to separate the effects of trampling intensity on vegetation response from other confounding variables. This approach makes it possible to model the relationship between trampling intensity and vegetation response. It is also possible to assess

variation in response among different vegetation types.

The results of most previous experimental trampling studies suggest a curvilinear relationship between trampling intensity and vegetation response (e.g. Bayfield 1971; Bell & Bliss 1973; Liddle & Thyer 1986). In only two studies was this relationship described mathematically. For an *Empetrum nigrum* sand dune ecosystem in Denmark, Hylgaard & Liddle (1981) approximated the relationship with a logistic model of the general form

$$Y = \frac{A + B}{1 + \exp(C + DZ)} \quad \text{eqn 1}$$

where $Z = \log(X + 1)$ and X = number of passes. For six different vegetation types in Montana, USA, Cole (1987a) approximated the relationship with an asymptotic model of the general form

$$Y = A - B \exp(-CX) \quad \text{eqn 2}$$

where X = number of passes. He also reported that degree of curvilinearity appeared to decrease as vegetation resistance increased. No explanation for these relationships was offered.

The research reported in this paper expands on previous trampling research by applying a standard

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experimental procedure in 18 different vegetation types. This provides a unique opportunity to evaluate the consistency of response and differences between vegetation types. The primary objectives of this paper are (i) to describe vegetational response to different levels of trampling, and (ii) to assess variation in response between vegetation types. A subsequent paper (Cole 1995) will evaluate the extent to which variation in response can be explained by characteristics of plant morphology.

Materials and methods

Eighteen experimental study sites were established in five different mountainous regions of the United States, namely the Cascade Mountains (Washington), the northern Rocky Mountains (Montana), the central Rocky Mountains (Colorado), the northern Appalachian Mountains (New Hampshire) and the

southern Appalachian Mountains (North Carolina). Four different vegetation types were studied in each location except Montana, where only two types were studied. Common vegetation types, at various elevations and of differing physiognomy, were selected for study (Table 1). For discussion purposes, these types will be referred to by the name of the most abundant groundcover species. The Appendix gives more details on floristic composition.

Four replicate sets of experimental trampling lanes were established in each vegetation type. Each set consisted of five lanes, each 0.5 m wide and 1.5 m long. Where the lanes occurred on a slope, they were oriented parallel to contours. Treatments were randomly assigned to lanes. One lane was a control and received no trampling, the other lanes usually received 25, 75, 200 and 500 passes. A pass was a one-way walk, at a natural gait, along the lane. The weight of trampers was about 70 kg and trampers

Table 1. Classification of the 18 vegetation types based on schemes developed by Mueller-Dombois & Ellenberg (1974) and Vankat (1990) and on dominant life forms of the groundcover vegetation. Locations and floras are **WA**, (Washington, Hitchcock & Cronquist 1973); **MT**, (Montana, Hitchcock & Cronquist 1973); **CO**, (Colorado, Weber 1976); **NH**, (New Hampshire, Gleason & Cronquist 1963); and **NC**, (North Carolina, Radford, Ahles & Bell 1968)

Closed forests

Evergreen coniferous forests

Picea rubens–*Abies* subalpine forest

Picea–*Abies balsamea*/*Lycopodium lucidulum* (clubmoss-forb-fern), **NH**

Picea–*Abies fraseri*/*Dryopteris campyloptera* (erect fern-forb), **NC**

Picea engelmannii–*Abies lasiocarpa* subalpine forest

Picea–*Abies*/*Vaccinium scoparium* A (matted shrub), **CO**

Picea–*Abies*/*Cornus canadensis* (erect forb), **MT**

Pinus contorta/*Vaccinium scoparium* B (matted shrub), **MT**

Pseudotsuga menziesii–mixed conifer upper montane forest

Pseudotsuga/*Pachistima myrsinites* (erect shrub), **WA**

Cold-deciduous forest with evergreen trees admixed

Acer saccharum–*Fagus grandifolia*–*Betula alleghaniensis* forest

Northern hardwood/*Leersia oryzoides* (erect forb–fern–grass), **NH**

Northern hardwood/*Maianthemum canadensis* (erect forb–fern), **NH**

Gray beech/*Carex pensylvanica* (erect graminoid), **NC**

Populus tremuloides forest

Populus/*Geranium richardsonii* (erect forb), **CO**

Cold-deciduous forest without evergreen trees

Cove hardwood/*Amphicarpa bracteata* (erect and trailing forb), **NC**

Dwarf-scrub communities

Evergreen dwarf scrub

Phyllodoce empetriformis subalpine heath (matted shrub), **WA***

Terrestrial herbaceous communities

Meadow and grasslands

Below timberline (man-induced)

Potentilla simplex old-field (erect forb–graminoid), **NC***

Above timberline

Carex bigelowii meadow (matted graminoid), **NH**

Carex nigricans turf (matted graminoid), **WA**

Kobresia myosuroides turf (caespitose graminoid), **CO**

Trifolium parryi meadow (matted forb–caespitose graminoid), **CO**

Perennial forb communities

Valeriana sitchensis subalpine meadow (erect forb), **WA***

* Some of the plots in the *Phyllodoce* and *Valeriana* types have an open overstorey of *Picea engelmannii* and *Abies lasiocarpa*. The *Potentilla* old-field is reverting to a deciduous forest.

wore boots with incised treads (lug soles). In two resistant vegetation types, *Carex nigricans*¹ and *Kobresia myosuroides*, 500 passes caused relatively little vegetation loss, so the 25-pass lane was replaced by a 700-pass lane. For these two vegetation types, only the data from the 75-, 200- and 500-pass lanes were included in the analyses reported here. The two types in Montana, *Vaccinium scoparium* B and *Cornus canadensis*, used a different progression of treatments, namely 10, 50, 100, 250 and 500 passes.

Measurements were taken on each lane in two adjacent 30 × 50-cm subplots. In each subplot, the cover of each vascular plant species, and of mosses and lichens, was estimated. Trampling treatments were administered in early summer, after vegetative cover approached its annual peak. Initial measurements were taken immediately before trampling occurred. Follow-up measurements were taken about 2 weeks after trampling and 1 year after trampling.

The primary response variable for each vegetation type was relative vegetation cover (Bayfield 1979), a measure of the fraction of the original vegetation that survives trampling, adjusted for changes in the controls. Application of a correction factor (*F*) for changes in controls separates the effects of trampling from other factors that affect change. It was calculated by (i) summing the covers of all individual species to obtain total cover, and then (ii) calculating relative vegetation cover as

$$\frac{\text{surviving cover on trampled subplots}}{\text{initial cover on trampled subplots}} \times F \times 100\%,$$

eqn 3

$$\text{where } F = \frac{\text{initial cover on control subplots}}{\text{surviving cover on control subplots}}.$$

Relative vegetation cover 2 weeks after trampling and after 1 year of recovery was calculated for each trampling treatment. Analyses were based on plot means to avoid pseudoreplication.

Results

VARIATION IN VEGETATION RESPONSE TO TRAMPLING

Analyses of variance were used to test the effect of trampling intensity and vegetation type on relative vegetation cover. Relative vegetation cover was transformed to ranks in order to meet assumptions of normality and homogeneity of variance. Results from the two vegetation types in Montana were excluded from the analysis of variance because they received a unique set of trampling treatments.

Relative vegetation cover 2 weeks after trampling

varied significantly with both trampling intensity and vegetation type (Table 2). The interaction between these two main effects was also highly significant. Consequently, analysis of the effect of different trampling intensities was done separately for each vegetation type. Relative cover 1 year after trampling also varied significantly with both trampling intensity and vegetation type (Table 2). The interaction was significant again. One year after trampling, variation in relative cover was less pronounced than it was 2 weeks after trampling, and trampling intensity and vegetation type explained less of the variation in relative cover.

Vegetation types varied greatly in their immediate response to trampling and in the amount of recovery that occurred during the year that followed trampling (Fig. 1). In the vegetation type that lost the least cover, *Carex nigricans* (alpine sedge turf), relative cover after 500 passes exceeded 60%. In the type that lost the most cover, *Dryopteris campyloptera* (subalpine forest with erect fern understorey), relative cover was 33% after just 25 passes and only 2% cover survived after 500 passes. The vegetation type that recovered the most during the year following trampling was *Geranium richardsonii* (montane forest with erect forb understorey). In this type, relative cover 2 weeks after 200 passes was 10%; 1 year after 200 passes, relative cover was 89%. In the type that recovered least, *Vaccinium scoparium* A (subalpine forest with matted shrub understorey in Colorado), relative cover on 200-pass lanes declined from 51% 2 weeks after trampling to 35% 1 year later.

The magnitude of differences in response can be quantified in various ways. Liddle (1975) has suggested the number of passes needed to effect a 50% reduction in vegetation cover as an index of relative vulnerability. This index would be about 600 passes in *Carex nigricans* and about 20 passes in *Dryopteris campyloptera*, suggesting a 30-fold difference in vulnerability. Pronounced differences in vulnerability can occur over short distances. For example, the *Phyllodoce empetrififormis* vegetation type is about 10 times less vulnerable than the *Valeriana sitchensis* type, with which it is typically intermixed.

One year after trampling, fewer vegetation types differed significantly in relative cover. In many of the vegetation types that lost substantial cover 2 weeks after trampling, cover increased to levels found in types that were never severely affected by trampling. A few of the vegetation types did not recover, however, and a few lost cover over the year. Consequently, the magnitude of difference between the most and least vulnerable vegetation types remained as great 1 year after trampling as 2 weeks after trampling.

The vegetation type that was least affected by trampling 1 year after the trampling treatments was

¹ Scientific names conform with those in the Appendix and Table 1.

Table 2. Analysis of variance in relative vegetation cover (rank-transformed) 2 weeks after trampling and 1 year after trampling

Source of variation	df	2 weeks after trampling			1 year after trampling		
		Mean square	F	P	Mean square	F	P
Number of passes	3	546 050	306.5	<0.001	242 249	59.6	<0.001
Vegetation type	15	113 512	63.7	<0.001	79 654	19.6	<0.001
Passes $\times$ vegetation	43	3968	2.2	<0.001	9892	2.4	<0.001
Error	266	1782			4063		

Trifolium parryi (alpine meadow of matted forbs and caespitose graminoids). In this type, vegetation loss after trampling was moderate, but subsequent recovery was near complete. In the vegetation types *Vaccinium scoparium* A and B that remained most affected 1 year after trampling, vegetation loss was also moderate; however, the matted shrubs that dominate in this type continued to lose cover during the year following trampling. This suggests that the ability of a vegetation type to tolerate recurrent trampling disturbance may be more a function of its ability to recover from damage than its ability to resist being damaged.

MODELS OF VEGETATION RESPONSE TO DIFFERENT LEVELS OF TRAMPLING

Immediate effects of trampling

Linear and curvilinear regression analyses were performed to identify the mathematical models that best approximate the relationship between trampling intensity and relative vegetation cover. Alternative

models were evaluated on the basis of their adjusted coefficient of determination (r^2) and the distribution of residuals. Second-order polynomials of the form

$$Y = A - BX + CX^2 \quad \text{eqn 4}$$

generally provided the best fit (Table 3, Fig. 2). The only exception was the *Carex nigricans* type, where the model was a second-order polynomial of the form

$$Y = A - BX - CX^2 \quad \text{eqn 5}$$

However, for four vegetation types (*Carex nigricans*, *Pachistima myrsinites*, *Kobresia myosuroides* and *Carex bigelowii*) a linear model provided as good an approximation as the polynomial. For five other types (*Trifolium parryi*, the two *Vaccinium scoparium* types, *Carex pensylvanica*, and *Phyllodoce empetri-formis*), a linear model provided a good fit to the data ($r^2 = 0.74 - 0.86$), although the fit to a polynomial was marginally better. For the remaining nine vegetation types, the straight-line approximation was poor. Second-order polynomials provided a substantially better fit and r^2 for linear models was

Table 3. Regression models that approximate the relationship between trampling intensity ($X = 0-500$ passes) and relative vegetation cover (Y). Separate models are provided for cover 2 weeks after trampling and 1 year after trampling

Vegetation type	2 weeks after trampling		1 year after trampling	
	Regression model	r^2	Regression model	r^2
<i>Pachistima myrsinites</i>	$Y = 99 - 0.2X + 0.00022X^2$	0.31	$Y = 97 - 0.25X + 0.00025X^2$	0.57
<i>Phyllodoce empetriiformis</i>	$Y = 94 - 0.36X + 0.00036X^2$	0.84	$Y = 95 - 0.38X + 0.00046X^2$	0.85
<i>Valeriana sitchensis</i>	$Y = 83 - 0.55X + 0.0008X^2$	0.81	$Y = 97 - 0.1X + 0.00012X^2$	0.09
<i>Carex nigricans</i>	$Y = 102 - 0.05X - 0.00005X^2$	0.65	NS	
<i>Cornus canadensis</i>	$Y = 88 - 0.47X + 0.00068X^2$	0.85	$Y = 98 - 0.16X + 0.00019X^2$	0.54
<i>Vaccinium scoparium</i> B	$Y = 94 - 0.41X + 0.00047X^2$	0.87	$Y = 93 - 0.41X + 0.00053X^2$	0.86
<i>Geranium richardsonii</i>	$Y = 91 - 0.57X + 0.00079X^2$	0.93	NS	
<i>Vaccinium scoparium</i> A	$Y = 100 - 0.34X + 0.00036X^2$	0.93	$Y = 99 - 0.54X + 0.00073X^2$	0.92
<i>Trifolium parryi</i>	$Y = 104 - 0.28X + 0.00025X^2$	0.90	NS	
<i>Kobresia myosuroides</i>	$Y = 99 - 0.17X + 0.00007X^2$	0.85	$Y = 99 - 0.04X + 0.00004X^2$	0.87
<i>Maianthemum canadensis</i>	$Y = 80 - 0.54X + 0.00077X^2$	0.66	$Y = 98 - 0.3X + 0.00045X^2$	0.39
<i>Leersia oryzoides</i>	$Y = 88 - 0.57X + 0.00081X^2$	0.80	$Y = 98 - 0.13X + 0.00004X^2$	0.83
<i>Lycopodium lucidulum</i>	$Y = 82 - 0.5X + 0.0007X^2$	0.76	$Y = 85 - 0.29X + 0.00035X^2$	0.68
<i>Carex bigelowii</i>	$Y = 92 - 0.22X + 0.00015X^2$	0.78	$Y = 90 - 0.22X + 0.00018X^2$	0.77
<i>Potentilla simplex</i>	$Y = 87 - 0.56X + 0.00081X^2$	0.87	NS	
<i>Amphicarpa bracteata</i>	$Y = 81 - 0.56X + 0.00083X^2$	0.74	$Y = 94 - 0.23X + 0.00028X^2$	0.40
<i>Carex pensylvanica</i>	$Y = 95 - 0.36X + 0.00042X^2$	0.84	$Y = 103 - 0.28X + 0.00033X^2$	0.57
<i>Dryopteris campyloptera</i>	$Y = 71 - 0.58X + 0.0009X^2$	0.65	$Y = 104 - 0.24X + 0.00034X^2$	0.54

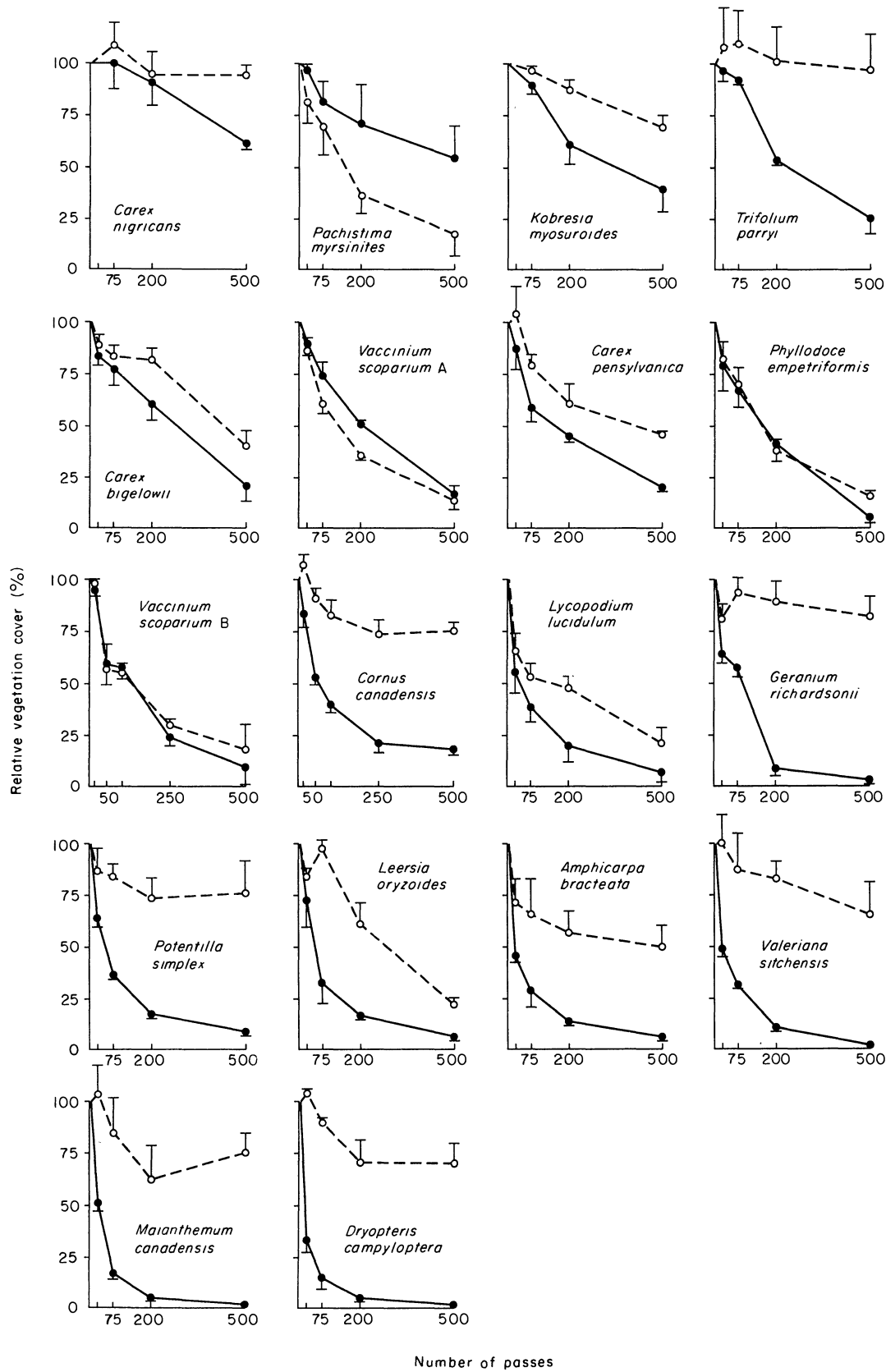


Fig. 1. Relationship between trampling intensity and relative cover, 2 weeks after trampling (●) and 1 year after trampling (○) for each of the 18 vegetation types, referred to by the name of the most abundant groundcover species. Types are arranged from those that lost the least cover after trampling to those that lost the most. Vertical bars denote 1 SE.

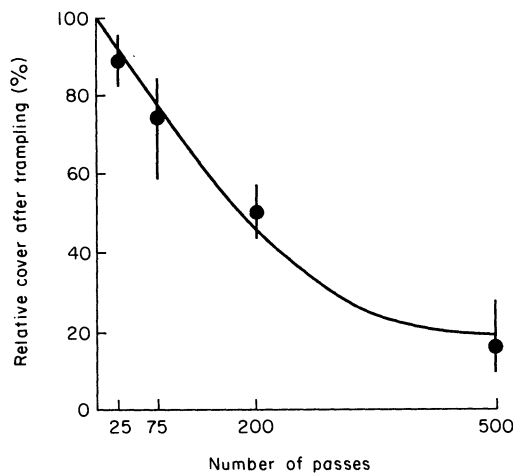


Fig. 2. Relative vegetation cover after trampling in relation to number of passes for the *Vaccinium scoparium* A vegetation type in Colorado. The best fit equation was $Y = 100 - 0.339X + 0.00036X^2$, $r^2 = 0.93$. Mean and range of four replications shown.

less than 0.69. Neither the logistic model suggested by Hylgaard & Liddle (1981) nor the asymptotic model suggested by Cole (1987a) provided such good fits for any of these vegetation types as the models chosen here.

For the seven vegetation types that lost the most cover when trampled, the curvilinearity of the relationship was partially an artifact of the research design. In *Dryopteris campyloptera* and *Maianthemum canadensis*, relative cover was less than 20% after 75 passes. Consequently, the amount of cover these types could lose as trampling intensity increased to 500 passes was low. In *Valeriana sitchensis*, *Amphicarpa bracteata*, *Leersia oryzoides*, *Potentilla simplex* and *Geranium richardsonii*, relative cover was less than 20% after 200 passes.

For these seven types, piecewise regression was used to determine whether curves would best be considered to consist of two separate parts, differentiated at the point where there is no longer much cover to lose (<20%). For all of these types, with the exception of *Geranium richardsonii*, these piecewise regressions provided a better fit to the data ($r^2 = 0.77 - 0.94$) than a single second-order polynomial. However, only in the *Maianthemum canadensis* and *Dryopteris campyloptera* types was the increase in r^2 substantial (>0.08).

For the six types with curves that are best treated as two separate curves, linear and curvilinear regression models were fitted to that portion of the curve where relative cover exceeded 20%. In all cases, second-order polynomials provided the best fit ($r^2 = 0.81 - 0.95$).

Influences that may affect the general form of these models are first, a decline in potential for vegetation loss as cover decreases; secondly, variation in vulnerability between different species

within the same vegetation type; and thirdly variation in vulnerability within the same species or individual.

The rate of change in vegetation cover with increased trampling should be a function of the vegetation loss per unit of trampling pressure and of the effective pressure exerted by each trampling pass. The effective pressure exerted by a trampling pass should decline at a constant rate as surviving cover declines, because fewer tramples then fall on intact plant tissue. If the susceptibility of plant tissue remains constant as trampling intensity changes, the rate of cover loss should decrease at a constant rate as trampling intensity increases. Therefore, the model that describes the relationship between vegetation cover and trampling intensity should have a first derivative that is a negative linear function of number of passes. The models that possess this attribute are second-order polynomials.

For the relationship between vegetation cover and trampling intensity to deviate from this expected model, susceptibility of the vegetation must vary with trampling intensity. If a vegetation type comprises both resistant and non-resistant species, susceptibility should decline as trampling intensity increases, because most of the fragile species will have been eliminated. This suggests that for vegetation types with species that vary greatly in vulnerability, the curvilinearity of models should be even greater than in the predicted second-order polynomials. It also suggests the testable hypothesis that curvilinearity should increase as vegetation diversity increases.

For curvilinearity to be less than in the predicted second-order polynomials, as it was in at least four of the vegetation types, the vulnerability of plants must increase as trampling intensity increases. This might occur in highly resistant plants that are capable of resisting low levels of trampling, but are damaged by high levels of trampling. This suggests a second testable hypothesis, namely that curvilinearity of the model should decrease as resistance to trampling increases.

These two hypotheses were tested with a multiple regression analysis, with degree of curvilinearity as the dependent variable, and resistance index and Simpson's (1949) index of species diversity as independent variables. Degree of curvilinearity was estimated using the absolute value of the coefficient associated with the quadratic term in the polynomial equations for each vegetation type. Curvilinearity decreases as this coefficient approaches zero. Resistance index is defined as mean relative cover 2 weeks after trampling for all levels of trampling between 0 and 500 passes (Cole 1995). The two vegetation types in which curvilinearity was substantially accentuated by the research design, *Maianthemum canadensis* and *Dryopteris campyloptera*, were excluded from the analysis.

The multiple regression analysis supported both

hypotheses (Table 4). Curvilinearity decreased as resistance index increased and as species diversity decreased. These two variables explained 92% of the variation in linearity of the data.

Effects of trampling after 1 year

In most vegetation types, the magnitude of relative cover differences between trampling intensities were less pronounced 1 year after trampling than 2 weeks after trampling. For four vegetation types (*Trifolium parryi*, *Carex nigricans*, *Geranium richardsonii* and *Potentilla simplex*), the relationship between trampling intensity and relative cover was not significant. With the exception of the last, these types had essentially recovered, regardless of trampling intensity. For the 14 other vegetation types, a second-order polynomial generally provided the closest fit to the data, although r^2 values varied between 0.92 and 0.09. Again, linear functions provided equally good fits in some vegetation types and relatively poor fits in others.

Related to these models, two hypotheses were advanced: first, that curvilinearity of the data should decrease as vegetation tolerance increase and, secondly, that curvilinearity should increase as species diversity increases. Curvilinearity and species diversity were operationalized as before. Tolerance was assessed as the mean relative cover 1 year after trampling for all intensities between 0 and 500 passes (Cole 1995). One year after trampling, species diversity was not significantly correlated with curvilinearity of the data ($P = 0.72$) and was deleted from the model. Tolerance was significantly and negatively correlated with curvilinearity, but explained only 40% of the variation in linearity (Table 5).

Discussion

Both the rate of change in vegetation cover with increased trampling and the consistency of this

Table 4. Relationship between curvilinearity of the trampling intensity-vegetation cover model and the resistance and species diversity of the vegetation, 2 weeks after trampling. Curvilinearity is the coefficient of the quadratic term in the model $\times 10^4$. Species diversity is based on Simpson's (1949) index

Source of variation	df	Mean square	F	P	r^2
Regression model	2	62.5	92.1	<0.001	0.92
Error	13	0.7			

Variable	Coefficient	SE	t ratio	P
Intercept	8.10	1.20	6.7	<0.001
Resistance index	-0.12	0.01	-8.4	<0.001
Species diversity	2.39	1.15	2.1	0.05

Table 5. Relationship between curvilinearity of the trampling intensity/vegetation cover model and tolerance of the vegetation, 1 year after trampling. Curvilinearity is the coefficient of the quadratic term in the model $\times 10^4$

Source of variation	df	Mean square	F	P	r^2
Regression model	1	21.7	9.6	0.009	0.40
Error	12	2.3			

Variable	Coefficient	SE	t ratio	P
Intercept	7.94	1.66	4.8	<0.001
Tolerance index	-0.08	0.03	-3.1	0.009

rate of change, at different trampling intensities, varied greatly between vegetation types. These two characteristics of response were related. Those vegetation types that changed the least 2 weeks after trampling and 1 year after trampling (e.g. *Kobresia myosuroides*) had the most constant rates of vegetation loss. In contrast, in those vegetation types with low resistance and tolerance (e.g. *Amphicarpa bracteata*), the relationship between vegetation cover and trampling intensity was highly curvilinear.

Most previous experimental trampling research has reported a highly curvilinear relationship between trampling intensity and vegetation response (Bell & Bliss 1973; Hylgaard & Liddle 1981; Cole 1987a; Kuss & Hall 1991). This curvilinearity should be expected, given that the amount of vegetation that can be affected declines as trampling intensity increases. The results of this study indicate, however, that the relationship can be linear, particularly in the most resistant and tolerant vegetation types. This suggests that certain vegetation types have thresholds of vulnerability. They are capable of resisting damage as long as trampling intensity is low. Once trampling intensities exceed these thresholds, damage occurs and increases as trampling increases.

Several of these findings have significant implications for the management of natural vegetation types subjected to recreational use. Vegetation types vary substantially in their vulnerability to trampling damage. Some of the vegetation types examined in this study were at least 30 times more vulnerable than others. This suggests that there is great potential to reduce the impacts of recreational trampling on vegetation by controlling the spatial distribution of use. Traffic can be directed onto more durable vegetation types and away from more vulnerable types.

Vegetation types vary both in their ability to resist being damaged by trampling and in their ability to recover from trampling damage. The appropriateness of management strategies will vary with both of

these properties. In this study, the vegetation types that were least able to tolerate a complete cycle of damage and recovery were those that recovered least, rather than those that were damaged most initially. Some of the most resistant vegetation types can tolerate a certain amount of trampling, as long as trampling intensities do not exceed threshold levels. Managers could maintain trampling impacts at negligible levels by keeping the trampling intensities below these thresholds. Additional research might lead to more precise identification of these thresholds.

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Appendix

Table A1. Initial frequency and mean percentage cover of the more abundant species in each of the four Washington Cascade Mountain vegetation types*

Species	Vegetation type							
	<i>Pachistima</i>		<i>Phyllodoce</i>		<i>Valeriana</i>		<i>Carex nigricans</i>	
	Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover
<i>Pachistima myrsinites</i>	98	46						
<i>Amelanchier alnifolia</i>	70	9						
<i>Phyllodoce empetriformis</i>			100	81				
<i>Vaccinium membranaceum</i>			93	15	5	+		
<i>Ligusticum grayi</i>			38	3	28	6		
<i>Valeriana sitchensis</i>			25	2	96	40		
<i>Lupinus latifolius</i>			18	2	13	3		
<i>Arnica mollis</i>			23	2				
<i>Potentilla flabellifolia</i>			28	2	48	8	45	7
<i>Aster alpigenus</i>			25	2	43	6		
<i>Erigeron peregrinus</i>			35	2	18	2		
<i>Trollius laxus</i>			8	1	58	19		
<i>Mitella breweri</i>					67	16		
<i>Senecio triangularis</i>					57	12		
<i>Thalictrum occidentale</i>					41	11		
<i>Carex spectabilis</i>			8	+	25	5	28	5
<i>Heracleum lanatum</i>					18	5		
<i>Equisetum palustre</i>			3	+	35	5		
<i>Osmorhiza purpurea</i>					26	5		
<i>Luzula hitchcockii</i>					22	5	8	1
<i>Veratrum viride</i>					7	2		
<i>Phleum alpinum</i>			5	+	16	2		
<i>Carex nigricans</i>							100	87
<i>Juncus drummondii</i>							43	9
<i>Veronica cusickii</i>					1	+	55	6
<i>Hieracium gracile</i>							45	4
Mosses	13	+	58	7	74	20	73	9

* Only species with mean cover of at least 2% are included. Frequency is the fraction (%) of 40 subplots of 30 × 50 cm in which the species was found. +, cover less than 0.5%. Nomenclature follows Hitchcock & Cronquist (1973).

Table A2. Initial frequency and mean percentage cover of the more abundant species in each of the two Montana Rocky Mountain vegetation types*

Species	Vegetation type				Species	Vegetation type			
	<i>Vaccinium B</i>		<i>Cornus</i>			<i>Vaccinium B</i>		<i>Cornus</i>	
	Freq.	Cover	Freq.	Cover		Freq.	Cover	Freq.	Cover
<i>Vaccinium scoparium</i>	100	54			<i>Fragaria virginiana</i>			75	5
<i>Carex geyeri</i>	31	4			<i>Equisetum arvense</i>			31	4
<i>Pedicularis racemosa</i>	15	2			<i>Symphoricarpos albus</i>			23	3
<i>Cornus canadensis</i>			90	25	<i>Clintonia uniflora</i>			21	3
<i>Berberis repens</i>			79	19	<i>Senecio pseud aureus</i>			33	3
<i>Bromus vulgaris</i>			60	7	<i>Calamagrostis rubescens</i>			29	2
<i>Smilacina stellata</i>			52	7	<i>Galium triflorum</i>			44	2
<i>Linnaea borealis</i>			60	6	<i>Antennaria racemosa</i>			15	2
<i>Osmorhiza chilensis</i>			83	5	Mosses	67	5	44	12
<i>Viola canadensis</i>			40	5	Lichens	92	13	8	+
<i>Thalictrum occidentale</i>			40	5					

* Only species with mean cover of at least 2% are included. Frequency is the fraction (%) of 48 subplots of 30 × 50 cm in which the species was found. +, cover less than 0.5%. Nomenclature follows Hitchcock & Cronquist (1973).

Table A3. Initial frequency and mean percentage cover of the more abundant species in each of the four Colorado Rocky Mountain vegetation types*

Species	Vegetation type							
	<i>Trifolium</i>		<i>Kobresia</i>		<i>Vaccinium</i> A		<i>Geranium</i>	
	Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover
<i>Trifolium parryi</i>	100	20						
<i>Danthonia intermedia</i>	95	17						
<i>Sibbaldia procumbens</i>	88	12						
<i>Potentilla diversifolia</i>	100	10						
<i>Erigeron melanocephalus</i>	90	7						
<i>Deschampsia caespitosa</i>	30	4						
<i>Kobresia myosuroides</i>			100	65				
<i>Acomastylis rossii</i>			85	7				
<i>Trifolium dasyphyllum</i>			73	5				
<i>Vaccinium scoparium</i>					100	60		
<i>Carex rossii</i>					76	5		
<i>Aster laevis</i>							73	22
<i>Fragaria ovalis</i>							98	17
<i>Geranium richardsonii</i>							100	17
<i>Viola canadensis</i>							90	14
<i>Thermopsis divaricarpa</i>							73	12
<i>Achillea lanulosa</i>							98	10
<i>Galium boreale</i>							95	7
<i>Bromopsis porteri</i>							85	6
<i>Carex norvegica</i>							70	4
<i>Thalictrum fendleri</i>							20	4
<i>Trisetum spicatum</i>	13	1	40	2			23	4
<i>Taraxacum officinale</i>							45	4
<i>Arnica cordifolia</i>							45	3
Mosses	53	5	80	3	36	2		
Lichens	38	1	90	4	59	5		

* Only species with mean cover of at least 2% are included. Frequency is the fraction (%) of 48 subplots of 30 × 50 cm in which the species was found. +, cover less than 0.5%. Nomenclature follows Weber (1976).

Table A4. Initial frequency and mean percentage cover of the more abundant species of the four New Hampshire White Mountain vegetation types*

Species	Vegetation type							
	<i>Carex bigelowii</i>		<i>Leersia</i>		<i>Lycopodium</i>		<i>Maianthemum</i>	
	Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover
<i>Carex bigelowii</i>	100	65						
<i>Arenaria groenlandica</i>	55	14						
<i>Vaccinium uliginosum</i>	35	5						
<i>Juncus trifidus</i>	23	3						
<i>Leersia oryzoides</i>			100	24				
<i>Viola pallens</i>			85	12				
<i>Onoclea sensibilis</i>			35	12				
<i>Aster acuminatus</i>			40	11	40	11	6	1
<i>Rubus pubescens</i>			53	10				
<i>Carex crinita</i>			43	9				
<i>Dryopteris austriaca</i>			20	9	60	14	58	22
<i>Impatiens pallida</i>			43	9				
<i>Osmunda cinnamomea</i>			5	3				
<i>Oxalis acetosella</i> [†]			30	3	98	45	55	18
<i>Scutellaria lateriflora</i>			18	3				
<i>Dryopteris phegopteris</i>			23	3			1	+
<i>Maianthemum canadensis</i>			25	3			100	51
<i>Lycopodium lucidulum</i>					98	47	19	4
<i>Abies balsamea</i>					30	3	13	1
<i>Trientalis borealis</i>			8	+			62	5
<i>Dryopteris disjuncta</i>			10	1			14	3
Lichens	60	20						
Mosses	50	19	45	3	8	+	24	4

* Only species with mean cover of at least 2% are included. Frequency is the fraction (%) of 40 subplots of 30 × 50 cm in which the species was found. +, cover less than 0.5%. Nomenclature follows Gleason & Cronquist (1963).

[†] *Oxalis acetosella* is named *O. montana* in the flora by Radford *et al.* (1968) in the Great Smoky Mountains.

Table A5. Initial frequency and mean percentage cover of the more abundant species of the four North Carolina Great Smoky Mountain vegetation types*

Species	Vegetation type							
	<i>Carex pensyl.</i>		<i>Potentilla</i>		<i>Amphicarpa</i>		<i>Dryopteris</i>	
	Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover
<i>Carex pensylvanica</i>	100	45						
<i>Medeola virginiana</i>	35	4						
<i>Rubus canadensis</i>	18	3	48	6	2	+		
<i>Holcus lanatus</i>			88	17				
<i>Potentilla simplex</i>			93	17	4	+		
<i>Panicum boscii</i>			60	17				
<i>Carex swanii</i>			85	12				
<i>Chrysanthemum leucanthemum</i>			75	7				
<i>Agrimonia parviflora</i>			35	6				
<i>Fragaria virginiana</i>			73	6	2	+		
<i>Luzula echinata</i>			18	5				
<i>Solidago gigantea</i>	3	+	35	5				
<i>Prunella vulgaris</i>			65	5				
<i>Lespedeza procumbens</i>			8	5				
<i>Solidago</i> sp.			25	4				
<i>Parthenocissus quinquefolia</i>			28	4	52	5		
<i>Clematis virginiana</i>			33	3				
<i>Amphicarpa bracteata</i>			28	3	96	28		
<i>Phlox stolonifera</i>					92	16		
<i>Thaspium trifoliata</i>					71	15		
<i>Geranium maculatum</i>					57	12		
<i>Viola papilionacea</i>	15	+	10	+	68	5		
<i>Aster divaricatus</i>	5	+			33	4		
<i>Laportea canadensis</i>					39	4		
<i>Dryopteris campyloptera</i>							98	82
<i>Clintonia borealis</i>					6	+	50	17
<i>Athyrium asplenoides</i>					2	+	23	16
<i>Oxalis montana</i> [†]							78	3
<i>Cacalia rugelii</i>							13	3
Mosses			13	1	43	4	75	9

* Only species with mean cover of at least 2% are included. Frequency is the fraction (%) of 40 subplots 30 × 50 cm in which the species was found. +, cover less than 0.5%. Nomenclature follows Radford *et al.* (1968).

[†] *Oxalis montana* is named *O. acetosella* in the flora by Gleason & Cronquist (1963) in the White Mountains.