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Trampling Effects on Mountain Vegetation in Washington, Colorado, New Hampshire, and North Carolina

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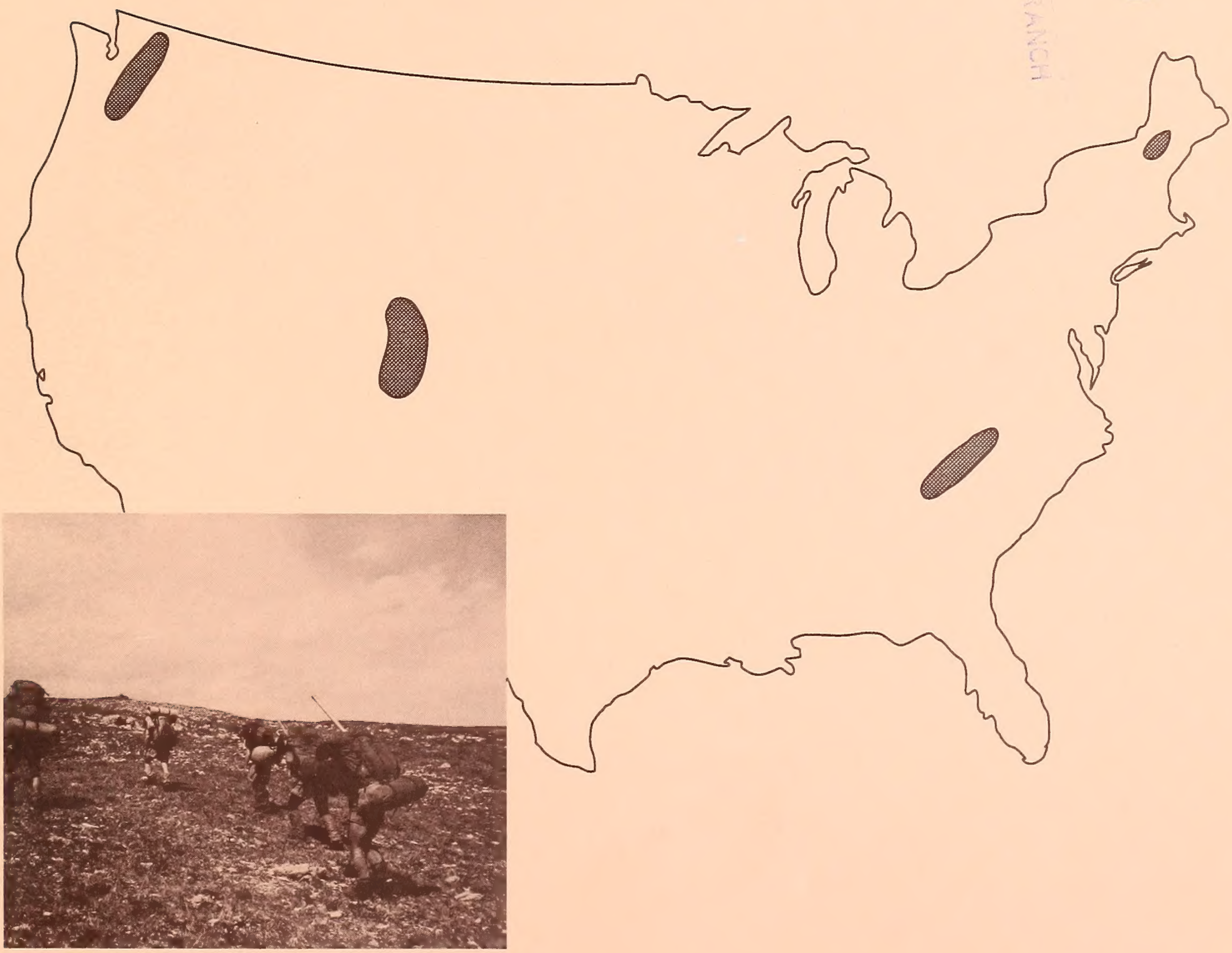

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RESEARCH SUMMARY

This study examined the response of vegetation to experimental trampling that simulated the effects of hiking. A total of 16 different vegetation types were studied in mountainous regions of Washington, Colorado, New Hampshire, and North Carolina. Changes in vegetation cover, vegetation height, species richness (the number of species), and species composition were evaluated. This provided a unique opportunity to compare trampling impacts in different parts of the country and to assess factors that influence the durability of vegetation. The most significant findings were:

1. Most vegetation types had substantially less cover and were substantially shorter after being trampled just 75 times. However, in most types the number of species did not decline, nor did the species composition shift except at higher levels of trampling.
2. Some vegetation types were highly resistant to trampling. The most resistant vegetation type could absorb 25 to 30 times as much trampling as the least resistant type, with no more damage.
3. Differences among the responses of vegetation types were greatest shortly after trampling. However, a few types remained substantially more impacted than others 1 year after trampling.
4. The responses of vegetation types varied more within any part of the country than among regions. Moreover, the types of vegetation that were the most resistant or the most resilient were similar across the country. A larger proportion of the vegetation types in the mountainous Western United States appeared to be more resistant to trampling than vegetation types in the Eastern States.
5. Alpine vegetation, at least the types included in this study, was more resistant to trampling than many vegetation types found at lower elevations.
6. The best predictors of resistance were (a) whether the vegetation was dominated by shrubs, forbs, or graminoids, and (b) whether the vegetation was erect or not. The least resistant plants were erect forbs and ferns. The most resistant plants were caespitose (tuft-forming) and mat-forming graminoids (grasses, sedges, and rushes).
7. The best predictor of resilience was whether or not the vegetation was dominated by chamaephytes—plants that regenerate from tissues (such as buds) above ground. Chamaephytes, most of which were short shrubs, were substantially less resilient than hemicryptophytes—plants with growing points at the soil surface—and cryptophytes—plants with growing points at or below the ground surface.

These results should help managers predict the effects of various levels of wilderness use. They should also help managers assess the relative durability of different vegetation types.

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Trampling Effects on Mountain Vegetation in Washington, Colorado, New Hampshire, and North Carolina

David N. Cole

INTRODUCTION

Recreational use inevitably alters vegetation in natural environments. In wilderness, where maintaining natural conditions is a management objective, the impacts of recreation on vegetation are a serious problem. These impacts can be minimal where visitors stay on constructed trails and campsites that are already heavily impacted. However, impacts occur wherever visitors leave established trails and campsites. In popular destination areas the results are webs of social trails (trails developed by use) and excessive numbers of campsites. In remote, little-used areas the results are trails and campsites that need not have been created.

To mitigate disturbance, managers need a better understanding of (1) the relationship between the amount of use and the amount of impact and (2) the relative durability of different vegetation types. This will allow them to predict the consequences of various levels of use and to choose whether to concentrate or disperse use. The understanding will improve their ability to select durable sites for recreational use. Finally, it will help them tell visitors where they can camp or hike with the least damage to vegetation.

Several research methodologies have been used when studying the durability of sites and the relationship between the level of use and impacts (see Cole 1987 for a review). The most effective way to isolate these variables is through carefully designed experiments. Experimental trampling studies can be traced back to the early work of Bates (1935), although Wagar (1964) was the first to report quantitative results following controlled levels of trampling. Over the years, experimental methods have evolved. The tendency for each researcher to develop a unique methodology has made it difficult to compare results from different studies. Cole and Bayfield (1993) have suggested a standard protocol that, if followed, would greatly increase the comparability of results.

This paper applies the Cole and Bayfield technique in 16 vegetation types around the United States. The objectives are to (1) describe the immediate response of vegetation to different amounts of trampling, (2) describe vegetative recovery within 1 year of trampling, (3) assess the magnitude of difference in response among vegetation types, and (4) evaluate the extent to which variation in response can be explained by regional, environmental, or plant characteristics.

STUDY AREAS

Trampling experiments were conducted in mountainous areas in four regions of the country—the Pacific Northwest, the Central Rocky Mountains, the Northeast, and the Southeast. Each region contains substantial wilderness acreage and receives heavy recreational use. Experiments were conducted in four different vegetation types in each region.

All of the vegetation types were regionally abundant and were selected to represent diverse environmental and botanical characteristics. In each region, vegetation types spanned a range of 800 to 1,200 m elevation. Alpine communities, those above timberline, were studied in the three regions in which mountains extend above timberline, the Pacific Northwest, the Central Rocky Mountains, and the Northeast. Nine of the vegetation types were in closed forest; one was a dwarf-scrub community; and six were open herbaceous communities (table 1). Closed subalpine spruce-fir forests were examined in three of the four study areas; in the fourth area—the Cascade Mountains of the Pacific Northwest—two vegetation types (*Phyllodoce* and *Valeriana*) occurred both within and intermixed with spruce-fir forest. Deciduous forests were examined in three of the four areas.

Ground cover vegetation on the study sites showed considerable diversity in growth forms and habits. Since the ground cover species are subject to most of the disturbance from trampling and camping, their characteristics largely determine the response of the vegetation type. Three of the 16 types had a predominantly shrubby ground cover; six had predominantly forbs (herbaceous plants other than ferns, grasses, rushes, and sedges) or ferns; four had predominantly graminoids (grasses, rushes, and sedges) and three had a mixture of forbs and graminoids. The vegetation types also varied in height and density. For example, the dense *Carex nigricans* turf in the Cascades contrasted with the relatively sparse *Carex pensylvanica*

Table 1—A classification of the 16 vegetation types based on classification schemes developed by Mueller-Dombois and Ellenberg (1974) and Vankat (1990)

Closed Forests

Evergreen coniferous forests

Picea rubens-Abies subalpine forest

Picea-Abies/Lycopodium (White Mountains)

Picea-Abies/Dryopteris (Smoky Mountains)

Picea engelmannii-Abies lasiocarpa subalpine forest

Picea-Abies/Vaccinium (Rocky Mountains)

Pseudotsuga menziesii-mixed conifer upper montane forest

Pseudotsuga/Pachistima (Cascade Mountains)

Cold-deciduous forest with evergreen trees

Acer saccharum-Fagus grandifolia-Betula alleghaniensis forest

Northern hardwood/*Leersia* (White Mountains)

Northern hardwood/*Maianthemum* (White Mountains)

Gray beech/*Carex* (Smoky Mountains)

Populus tremuloides forest

Populus/Geranium (Rocky Mountains)

Cold-deciduous forest without evergreen trees

Cove hardwood/*Amphicarpa* (Smoky Mountains)

Dwarf-Scrub Communities

Evergreen dwarf scrub

Subalpine heath

Phyllodoce (Cascade Mountains)[1]

Terrestrial Herbaceous Communities

Meadow and grasslands

Below timberline (anthropogenic)

Potentilla old-field (Smoky Mountains)[1]

Above timberline

Carex bigelowii (White Mountains)[1]

Carex nigricans (Cascade Mountains)

Kobresia (Rocky Mountains)

Trifolium (Rocky Mountains)

Perennial forb communities

Valeriana (Cascade Mountains)[1]

[1] These vegetation types have similarities to other vegetation types as well. Some of the plots in the *Phyllodoce* and *Valeriana* types have an open overstory of *Picea engelmannii-Abies lasiocarpa*. The *Potentilla* old-field is reverting to a deciduous forest. The *Carex bigelowii* meadow has a minor dwarf-scrub component.

ground cover in the Smoky Mountains gray beech forest. Most of the forb ground covers consisted of species that were erect and caulescent (with a definite leafy stem); however, the forbs that provided most of the cover in the *Trifolium* meadow in the Rockies were prostrate or scapose (without definite leafy stems).

EXPERIMENTAL METHODS

The experimental design follows the standard protocol suggested by Cole and Bayfield (1993). 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 ground was sloped, lanes were oriented parallel to contours. Slopes were never more than 10 percent. Treatments were randomly assigned to lanes. One lane was a control and received no trampling. The other lanes usually received either 25, 75, 200, or 500 passes. Treatments in the highly resistant *C. nigricans* (Cascades) and *Kobresia* (Rockies) types were 75, 200, 500, and 700 passes. A pass was a one-way walk, at a natural gait, along the lane. Tramplers weighed about 70 kg. They wore lug-soled boots.

Measurements were taken on each lane in two adjacent 30- by 50-cm subplots. The following parameters were measured:

1. The cover of each vascular plant species and of lichens and mosses. Visual estimates were recorded as the closest of the following values: 0, 1, 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 90, or 100 percent.
2. The cover of bare ground (ground not covered by live vegetation). Visual estimates used the same values as for individual species.
3. Mean vegetation height. We used a point quadrat frame with five pins, each 5 cm from the next. The frame was placed 10 times, systematically, along the length of the subplot. The pins were dropped to the ground. When the pin hit bare ground, a 0 was recorded. When it hit live vegetation, the height of the pin strike was recorded to the nearest 1 cm.

Trampling treatments were administered in early summer of 1988. Initial measurements were taken before trampling. Followup measurements were taken shortly after trampling and 1 year after trampling. Height measurements were taken immediately after trampling. Cover estimates were taken 2 weeks after trampling. This lag made it easier to distinguish damaged but living vegetation from dead vegetation.

DATA ANALYSIS

The types of vegetation change described are (1) the amount of bare ground, (2) vegetation cover, (3) vegetation height, (4) species richness (the number of species), and (5) species composition. Indices of durability were determined for the vegetation types. The responses of individual species were also described.

Bare Ground

Mean bare ground (the proportion of the measurement plot not covered by live vegetation) is presented, before and after trampling and after 1 year, for each trampling intensity between 0 and 500 or 700 passes. This provides a straightforward measure of changes in vegetation cover after trampling. Bare ground should not be confused with exposed mineral soil.

Relative Vegetation Cover

Vegetation cover after trampling is expressed as a proportion of the initial vegetation cover, with a correction factor (cf) to account for changes occurring on the control plots at the same time. Cover is based on the sum of the coverages of all species, rather than a single estimate of vegetation cover. It is calculated by (1) summing the covers of all individual species to obtain total cover and (2) calculating relative cover (RC) as:

$$RC = \frac{\text{surviving cover on trampled subplots}}{\text{initial cover on trampled subplots}} \times cf \times 100\%$$

where

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

Relative cover after trampling and after 1 year of recovery was calculated for each trampling treatment.

Relative Height

Vegetation height data are also adjusted for changes on controls. Relative height is calculated by (1) summing the heights and dividing the sum by the number of values greater than zero and (2) substituting these mean height values for the cover values in the formula for relative cover given above. Both relative height after trampling and after 1 year of recovery were calculated.

Species Richness

Richness is the number of different species occurring on the two subplots in each lane. Means are presented, before and after trampling and after recovery, for trampling intensities from 0 to 500 or 700 passes.

Species Composition

Changes in composition are described by calculating the floristic similarity of lanes before and after trampling and after recovery. Sorensen's similarity indices, based on cover, were used (Mueller-Dombois and Ellenberg 1974). Similarity indices were calculated, comparing conditions before trampling with (1) conditions after trampling and (2) conditions 1 year later.

Durability Indices

Relative vegetation cover data were used to characterize the relative durability of the vegetation types. The durability of any vegetation type subjected to trampling is affected both by its ability to resist disturbance and its ability to recover. The terminology for these different properties has not been consistent. I use *resistance* when referring to the ability of a vegetation type to resist change when subjected to trampling (Kelly and Harwell 1990; Kuss and Hall 1991; Sun and Liddle 1991); others have referred to this property as inertia (Grime 1979; Orians 1975; Westman 1978). I use *resilience* when referring to the ability of a vegetation type to recover following trampling (Grime 1979; Kelly and Harwell 1990; Kuss and Hall 1991); others have referred to this property as elasticity (Orians 1975; Westman 1978) or recovery (Sun and Liddle 1991). I use *tolerance* when referring to the ability of a vegetation type to both resist and recover from disturbances such as trampling. An index of tolerance provides an overall indication of vegetation durability. It does not indicate, however, whether tolerance results from an ability to resist damage, an ability to recover rapidly, or both.

Indices of resistance, resilience, and tolerance were developed. The index of resistance was the mean expected relative vegetation cover after trampling, for all possible levels of trampling between 0 and 500 passes. Although only five trampling treatments were applied, the responses define a curve of expected relative cover values between 0 and 500 passes. The mean of all these expected cover values (Y axis) provides an index with a number of desirable attributes. It utilizes all the data collected; it provides a single index of response to the range of treatments from 0 to 500 passes; it is weighted to account for the lack of a regular progression of trampling intensities; and it remains relatively constant regardless of trampling intensity. This mean relative cover value is equal to the proportional area below curves that relate trampling intensity to relative cover after trampling. It can be estimated by calculating the area of a series of rectangles underneath the curve and dividing that area by the total area of the graph.

A similar index of tolerance is the mean expected relative cover after 1 year of recovery, for all levels of trampling between 0 and 500 passes. An index of resilience can be obtained by (1) subtracting the mean relative cover after trampling from the mean relative cover after 1 year of recovery (this provides a measure of how much recovery occurred over the year) and (2) dividing this by 100 percent minus relative cover after trampling (this is the amount of recovery that could possibly have occurred).

Similar indices were derived using the relative height data. These help quantify the ability of each vegetation type to resist being flattened by trampling and to recover its height afterward.

Individual Species Responses

For the most abundant individual species we calculated relative cover. Calculations were identical to those for total vegetation cover. For these species, we also calculated indices of resistance, resilience, and tolerance. The responses of most species, however, could only be described in relative terms.

Statistical Inference

The significance of differences between vegetation types and between trampling treatments was tested with analysis of variance. Because variances were heterogeneous, we used a nonparametric procedure, based on ranks rather than original values. Data from 700-pass lanes were excluded from this analysis. Scheffe's test for multiple comparisons was used to identify significantly different treatments and vegetation types. Alpha was set at 0.05.

EFFECTS OF TRAMPLING IN THE CASCADE MOUNTAINS

The study sites in the Northwest were located in the Okanogan National Forest in northern Washington, along or east of the crest of the Cascade Mountains. One site was located at the relatively low elevation of 760 m along the upper Methow River in a Douglas-fir forest (*Pseudotsuga menziesii*). The moderately dense tree canopy (65 percent cover) consisted almost entirely of *Pseudotsuga menziesii*. The ground cover was only moderately dense. The primary species was the medium-sized shrub, *Pachistima myrsinites* (mountain boxwood). Species diversity was low (fig. 1A). This vegetation type is an example of the *Pseudotsuga menziesii/Pachistima myrsinites* association, as defined by Williams and Lillybridge (1983) and Agee and Kertis (1987).

The other vegetation types were located at higher elevations near Harts Pass and Slate Peak. Two types were intermixed with each other in a mosaic of subalpine forest and meadow, at an elevation of about 1,750 m. One type was a lush subalpine herbland, dominated by forbs such as *Valeriana sitchensis* (valerian) and *Trollius laxus* (globeflower) (fig. 1B). It occurred under an open canopy (30 percent cover) of *Abies lasiocarpa* (subalpine fir) and *Picea engelmannii* (Engelmann spruce), as well as in the open. Ground cover was extremely dense, with a number of different layers. Species diversity was high. Forests with similar ground cover vegetation have been termed the *Abies lasiocarpa/Valeriana sitchensis* association by Hemstrom (1982). A variety of lush subalpine herblands, with abundant quantities of

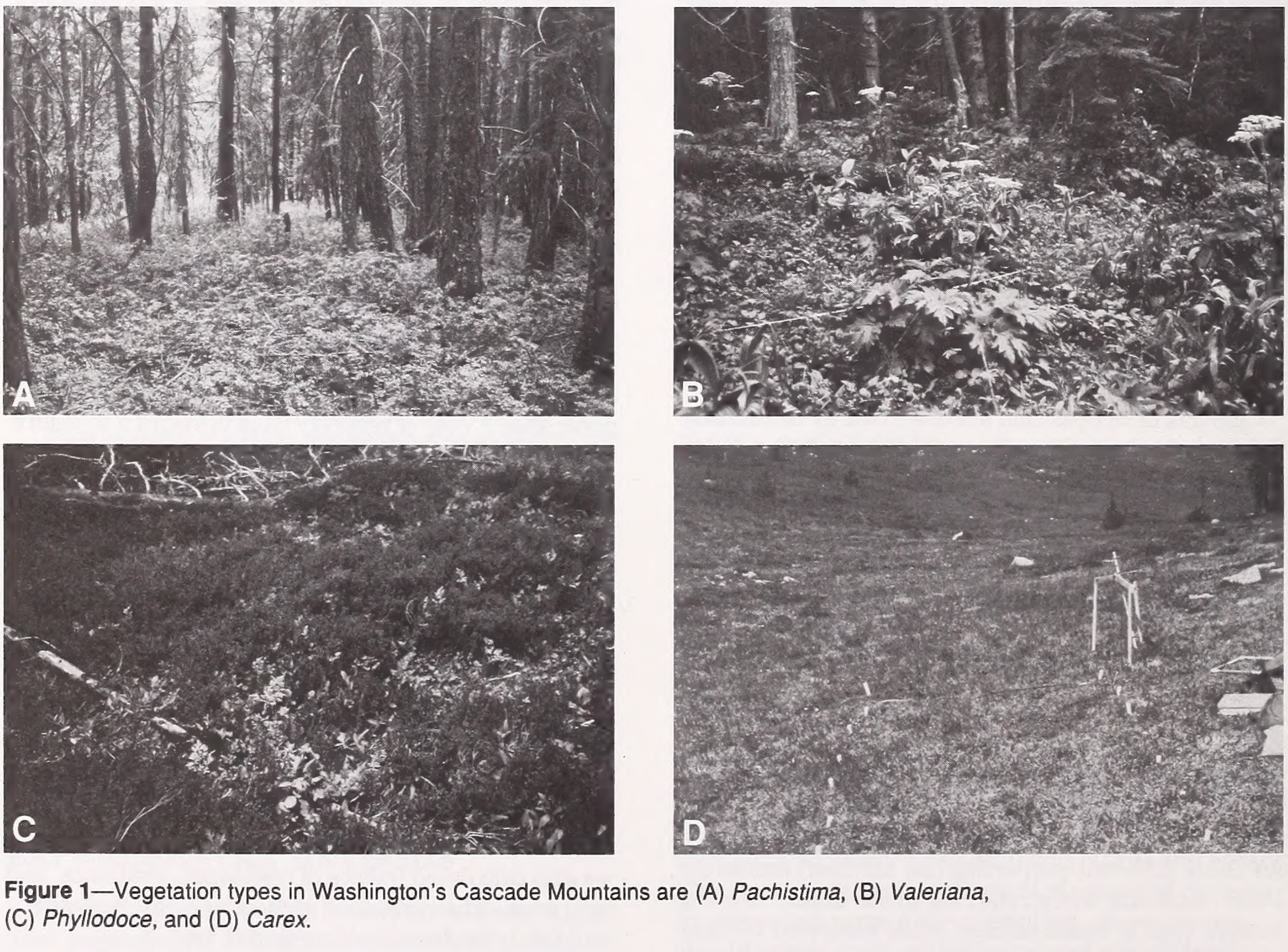

Figure 1—Vegetation types in Washington's Cascade Mountains are (A) *Pachistima*, (B) *Valeriana*, (C) *Phyllodoce*, and (D) *Carex*.

V. sitchensis, have been described in the Cascade Mountains (Franklin and Dyrness 1973).

The other subalpine vegetation type was a heath, dominated by red *Phyllodoce empetriformis* (mountain-heather) (fig. 1C). It also occurred under an open canopy of *A. lasiocarpa* and *P. engelmannii* and in the open. Ground cover was dense. Species diversity was relatively low, given the dominance of *Phyllodoce*. Forests with similar ground cover vegetation have been termed the *Abies lasiocarpa/Phyllodoce empetriformis* association by Williams and Lillybridge (1983) and by Agee and Kertis (1987). *Phyllodoce* heaths are among the most widespread subalpine meadow communities in the Pacific Northwest (Franklin and Dyrness 1973).

The final type occurred above timberline, at an elevation of about 2,000 m, below Slate Peak at the edge of the Pasayten Wilderness. It was a sedge meadow, predominantly *Carex nigricans* (black alpine sedge), located in swales where snowmelt is unusually late (fig. 1D). The ground cover was a dense turf with relatively low species diversity. This vegetation type is widespread in the Pacific Northwest (Franklin and Dyrness 1973).

In sum, the Cascade vegetation types include one type dominated by graminoids (*Carex*), one type dominated by forbs (*Valeriana*), and two types dominated by shrubs (*Pachistima* and *Phyllodoce*). Vegetation types will be referred to by the genus of the most abundant ground cover species. One type is above timberline; two partially forested types are in the subalpine zone; the final type is in closed forest in the montane zone. A list of the most abundant species in each type can be found in the appendix. Nomenclature follows Hitchcock and Cronquist (1973).

Bare Ground and Vegetation Cover

Before trampling, three of the four Cascade Mountain vegetation types were densely vegetated. Although the forested *Pachistima* vegetation type had 17 percent bare ground before trampling, no other type had more than 2 percent bare ground. After trampling, however, substantial amounts of bare ground were exposed on all vegetation types (table 2). In the *Valeriana* subalpine meadow, for example, mean bare ground was 19 percent after 25 passes, 51 percent after 75 passes, and 95 percent after 500 passes. After 500 passes the *Valeriana* meadow and the *Phyllodoce* heath were almost entirely barren, the forested *Pachistima* type was about one-half vegetated, and the *Carex* alpine turf was about two-thirds vegetated.

Measurements taken 1 year after trampling indicate how much the vegetation recovered. Bare ground diminished on two of the vegetation types (*Carex* and *Valeriana*), increased on one type (*Pachistima*), and remained relatively constant on the other (*Phyllodoce*).

Table 2—Percent bare ground before and after trampling and after 1 year of recovery for four vegetation types in Washington's Cascade Mountains[1]

	Number of passes					
	0	25	75	200	500	700
Pachistima myrsinites (montane forest)						
Before trampling	8 (3)[2]	18 (5)	15 (4)	24 (11)	19 (2)	—
After trampling	4 (2)	16 (4)	31 (12)	44 (16)	50 (18)	—
After 1 year	13 (5)	41 (4)	38 (8)	65 (8)	79 (7)	—
Carex nigricans (alpine turf)						
Before trampling	2 (1)	—	1 (+)	1 (1)	1 (1)	2 (1)
After trampling	10 (2)	—	16 (3)	23 (3)	36 (6)	51 (5)
After 1 year	5 (2)	—	5 (2)	10 (2)	8 (2)	10 (3)
Phyllodoce empetriformis (subalpine heath)						
Before trampling	+ (+)	1 (1)	+ (+)	+ (+)	+ (+)	—
After trampling	2 (1)	20 (8)	17 (7)	48 (6)	94 (5)	—
After 1 year	2 (1)	9 (4)	23 (10)	54 (13)	84 (5)	—
Valeriana sitchensis (subalpine forest-meadow)						
Before trampling	+ (+)	2 (1)	5 (1)	2 (2)	1 (1)	—
After trampling	+ (+)	19 (3)	51 (6)	79 (5)	95 (2)	—
After 1 year	5 (2)	13 (4)	16 (7)	23 (2)	15 (7)	—

[1]Percent bare ground is the mean proportion of each quadrat that is not vegetated.
[2]Standard errors are in parentheses. A + indicates mean cover or standard error less than 0.5 percent.

Table 3—Analysis of variance and multiple comparisons for relative cover after trampling and after 1 year of recovery in Washington's Cascade Mountains

Source	After trampling df	After trampling F	After trampling p	After 1 year df	After 1 year F	After 1 year p
Number of passes	3	49.4	0.0001	3	10.7	0.0001
Vegetation type	3	91.2	.0001	3	18.1	.0001
Interaction	8	2.5	.02	8	1.3	.28
	Significantly different treatments					
Number of passes	25,75>200>500			25,75>500		
Vegetation types[1]	C,PA>PH>VA			C,VA>PA,PH		

[1]Vegetation types: C = *Carex*, PA = *Pachistima*, PH = *Phyllodoce*, VA = *Valeriana*.

Calculations of relative vegetation cover are a convenient way to compare changes in vegetation cover after trampling and after a recovery period. The reduction of vegetation cover immediately after trampling differed significantly both with the amount of trampling and the vegetation type (table 3). The interaction between these two main effects (amount of trampling and vegetation type) was also significant, but the magnitude of this interaction was relatively small. After the year of recovery, relative cover still differed significantly between trampling intensities and vegetation types. The magnitude of differences had declined, however, and the interaction between these two main effects was no longer significant.

With only one exception, relative cover declined with each successive increase in the number of passes (fig. 2). The exception was in the *Carex* vegetation type, where relative cover was 100 percent even after trampling intensity reached 75 passes.

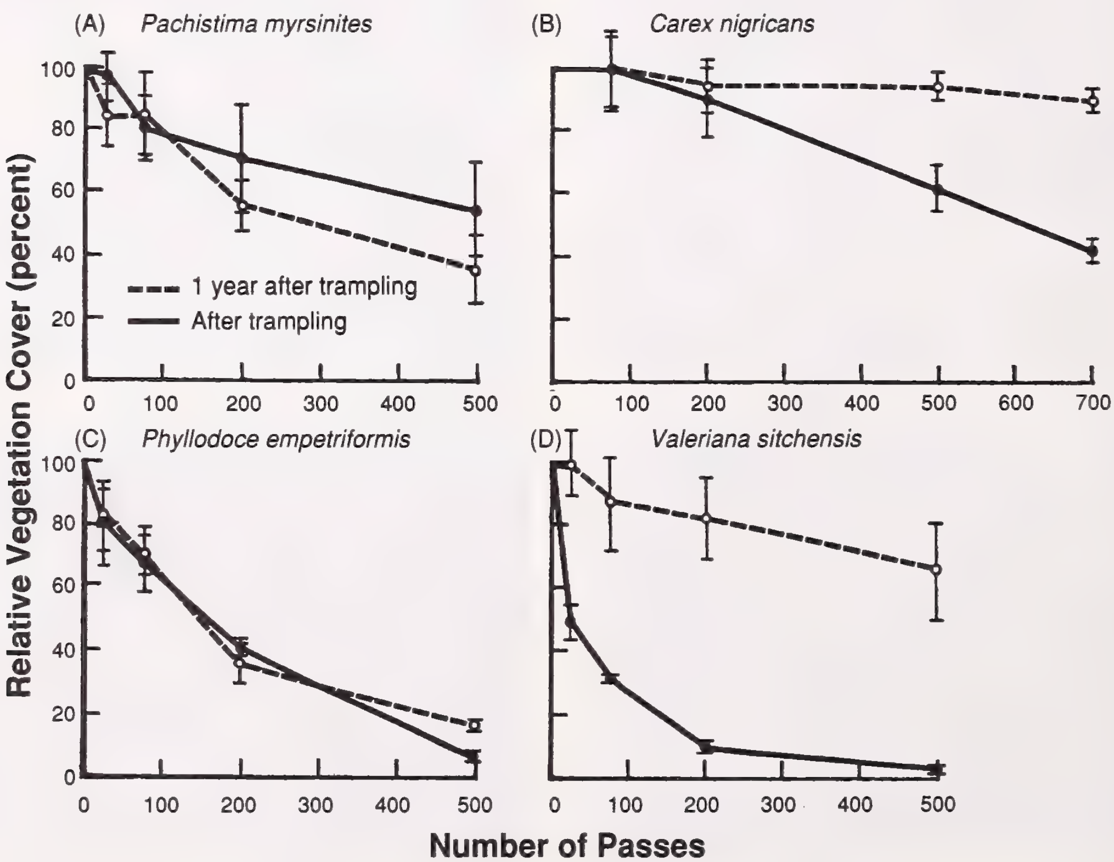

Figure 2—Relative vegetation cover after trampling and after 1 year of recovery in four vegetation types in Washington's Cascade Mountains. Vertical bars represent 1 standard error above and below the mean.

The *Valeriana* vegetation type lost the most cover when trampled. Relative cover was reduced by more than 50 percent after just 25 passes; 500 passes eliminated virtually all the vegetation cover (2 percent relative cover remained). The *Phyllodoce* type was also quite fragile, although it was significantly more resistant than the *Valeriana* type. Just 25 passes reduced cover significantly. After 500 passes relative cover was only 6 percent.

The other two types were significantly more resistant. In the *Carex* type, relative cover after 200 passes was not significantly different from the control. On the paths that received 500 and 700 passes, relative cover after trampling was 62 and 43 percent, respectively. The *Pachistima* type lost cover at lower trampling intensities than the *Carex* type, although differences in relative cover were not significant. Relative cover after 75 passes (81 percent) was significantly different from the control; relative cover had declined to 55 percent after 500 passes.

One year after trampling, disturbance was difficult to detect on all but the most heavily trampled lanes in both the *Carex* and *Valeriana* types. Vegetation cover increased substantially, on both of these types, during the year after trampling. The amount of recovery was particularly pronounced in the *Valeriana* type. Relative cover increased from 2 percent shortly after 500 passes to 66 percent 1 year later. These two vegetation types, the most different in their initial response to trampling, were not significantly different after 1 year of recovery.

The *Phyllodoce* and *Pachistima* types had not recovered a year after trampling. In each of these types, the 25-pass lane was still significantly different from the control. The relative cover of these two types was not significantly different, but their responses over the year of recovery were very different. Cover on the *Phyllodoce* type remained relatively unchanged over the year of recovery. Cover increased more than 5 percent only on the lane trampled 500 times. In the *Pachistima* type, cover actually declined over the year. Relative cover after 500 passes was 55 percent. During the year after trampling, cover declined to 36 percent.

Vegetation Height

Before trampling, ground cover was tallest in the *Pachistima* type, with a mean vegetation height of 25 cm. Ground cover in the *Phyllodoce* and *Valeriana* types had mean vegetation heights of 16 and 14 cm, respectively. In the *Carex* type, mean vegetation height was only 3 cm. Trampling reduced vegetation height in all four types (table 4). Only 25 passes in the *Valeriana* type reduced the mean height dramatically. In the other three types, mean height was reduced substantially only after high levels of trampling (500 passes). Height declined as a result of shortening of stems, flattening of plants, and death of taller plants.

Table 4—Mean vegetation height (cm) before and after trampling and after 1 year of recovery for four vegetation types in Washington's Cascade Mountains[1]

	Number of passes					
	0	25	75	200	500	700
Pachistima myrsinites (montane forest)						
Before trampling	22 (2)[1]	23 (3)	24 (3)	27 (4)	28 (2)	—
After trampling	22 (2)	25 (2)	20 (5)	21 (5)	15 (3)	—
After 1 year	28 (2)	27 (1)	23 (2)	26 (3)	30 (3)	—
Carex nigricans (alpine turf)						
Before trampling	3 (+)	—	3 (+)	3 (1)	3 (+)	3 (1)
After trampling	3 (+)	—	3 (+)	3 (+)	2 (+)	2 (+)
After 1 year	3 (+)	—	3 (+)	2 (+)	2 (+)	2 (+)
Phyllodoce empetriformis (subalpine heath)						
Before trampling	17 (1)	15 (1)	16 (+)	16 (1)	17 (2)	—
After trampling	17 (1)	15 (1)	15 (1)	16 (2)	12 (5)	—
After 1 year	18 (1)	14 (1)	13 (1)	13 (1)	2 (1)	—
Valeriana sitchensis (subalpine forest-meadow)						
Before trampling	13 (2)	12 (1)	13 (2)	15 (1)	19 (5)	—
After trampling	13 (2)	4 (1)	3 (+)	3 (1)	+ (+)	—
After 1 year	13 (3)	10 (1)	9 (2)	8 (1)	8 (2)	—

[1]Values in parentheses are 1 standard error. A + indicates mean height or standard error less than 0.5 cm.

Table 5—Analysis of variance and multiple comparisons for relative height after trampling and after 1 year of recovery in Washington's Cascade Mountains

Source	After trampling df	F	p	After 1 year df	F	p
Number of passes	3	19.6	0.0001	3	5.3	0.002
Vegetation type	3	140.6	.0001	3	2.1	.10
Interaction	8	.6	.73	8	1.6	.13
	Significantly different treatments					
Number of passes	25>200,500; 75>500			25>200,500		
Vegetation types[1]	PH>C,V; PA,C>V			none		

[1]Vegetation types: PH = *Phyllodoce*, PA = *Pachistima*, C = *Carex*, V = *Valeriana*.

Calculations of relative vegetation height permit ready comparisons. The immediate response of vegetation height differed significantly both with the amount of trampling and the vegetation type (table 5). The interaction between these two effects was not statistically significant. After the year of recovery, there were no significant differences between vegetation types. The only difference between trampling intensities was between the 25-pass lane and the 200- and 500-pass lanes.

In the forb-dominated *Valeriana* type, relative height was reduced to 29 percent on the 25-pass lane and just 2 percent on the 500-pass lane (fig. 3). In the two shrub-dominated types, *Pachistima* and *Phyllodoce*, only very heavy trampling reduced height substantially; even on the 500-pass lanes, relative height exceeded 50 percent. The height of the *Carex* turf was reduced at low trampling levels, but its relative height also exceeded 50 percent on the 500-pass lanes. During the year of recovery, however, vegetation on the

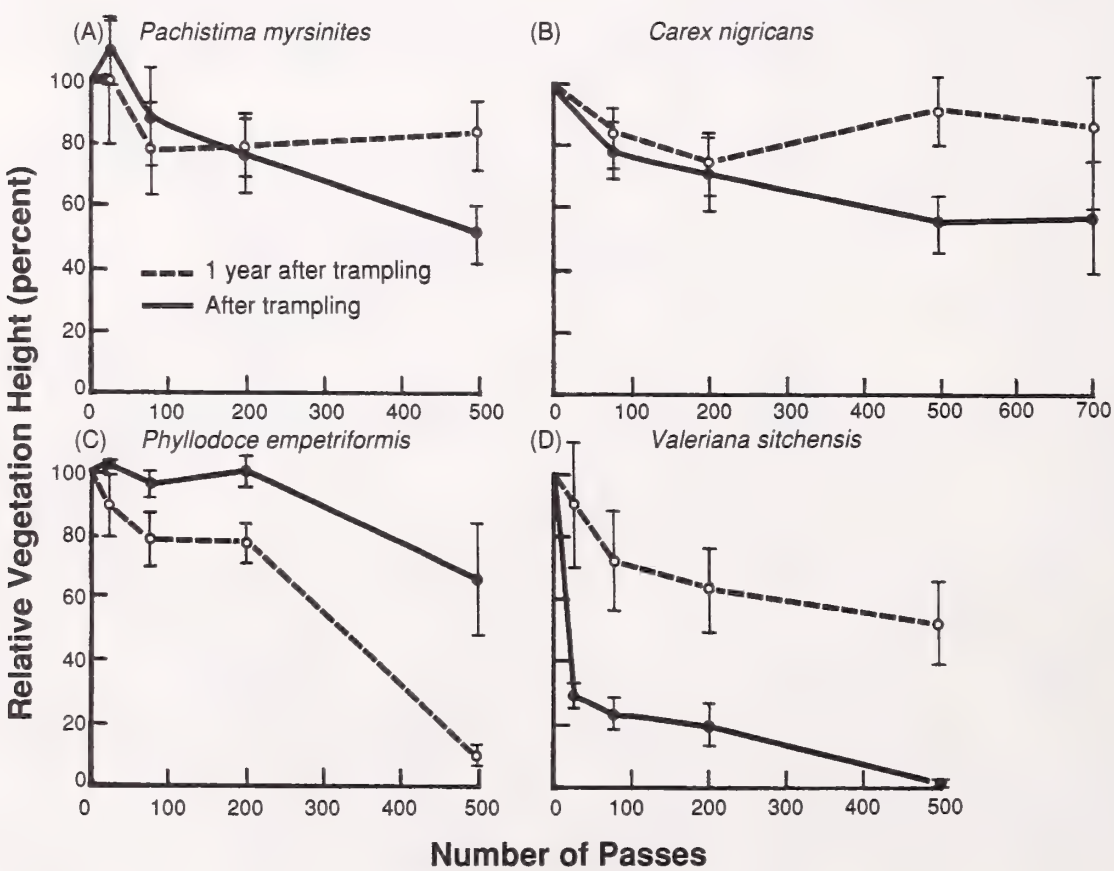

Figure 3—Relative vegetation height after trampling and after 1 year of recovery in four vegetation types in Washington's Cascade Mountains. Vertical bars represent 1 standard error above and below the mean.

Valeriana type regained much of its original height. One year after trampling, relative height was 90 percent on the 25-pass lane and 53 percent on the 500-pass lane. In the *Phyllodoce* type, relative height was lower 1 year after trampling than it had been immediately afterward. This may reflect some dieback of shrub stems and branches.

When comparing the rate of height reduction to the rate of cover loss with increased trampling intensity, only the *Phyllodoce* type showed a substantial difference. *Phyllodoce* was much more resistant to height reduction than to cover loss. In the *Carex* type, height was reduced somewhat at low levels of trampling (75 to 200 passes) that had little effect on relative cover.

Species Richness and Composition

Species richness declined on all four vegetation types as trampling intensity increased. The decline was most rapid on the *Valeriana* type, where the mean number of species on the 25-pass lane declined from 18 before trampling to 14 after trampling; on the 500-pass lane, the mean number of species declined from 20 before trampling to five after trampling (fig. 4). In the *Pachistima* and *Phyllodoce* types species richness did not decline significantly before 200 passes; species richness did not decline significantly before 500 passes in the *Carex* type. Five hundred passes reduced species richness about 40 percent in the *Carex* type, 50 percent in the *Pachistima* type, and 75 percent in the *Phyllodoce* and *Valeriana* types. However, after 1 year species richness approached or exceeded the original levels for all trampling intensities and all vegetation types. This suggests that short-term trampling does not cause a long-term loss of species in these vegetation types.

Species composition shifts with trampling if certain species are more likely to survive and recover from trampling than others. Floristic similarity values provide an indication of shifts in species composition by depicting the similarity between the original composition and the composition immediately after trampling and after 1 year of recovery. A floristic similarity value of 100 percent would mean that the relative abundance of species was identical before and after trampling. Even on controls, species abundance is expected to

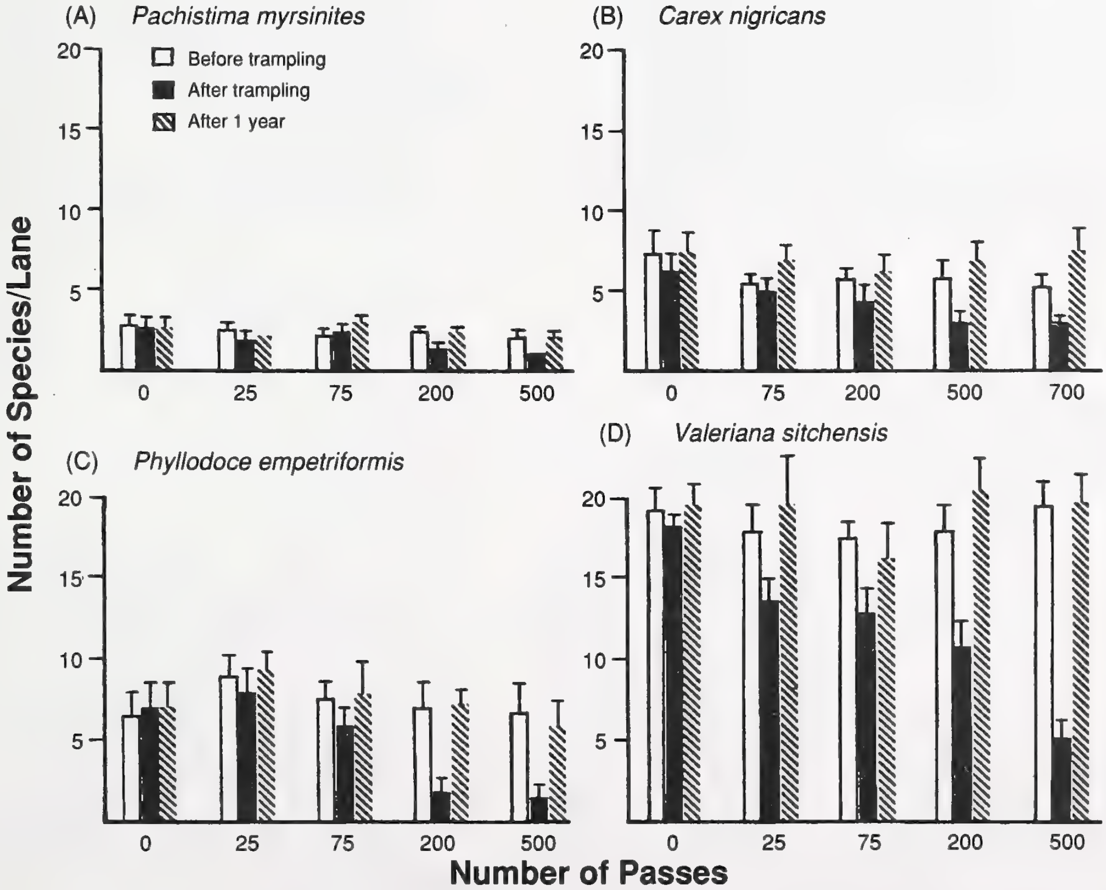

Figure 4—Species richness before and after trampling and after 1 year of recovery in four vegetation types in Washington's Cascade Mountains. Vertical bars represent 1 standard error above the mean.

shift somewhat. Consequently, similarity values for treated lanes must be compared with controls.

In the *Pachistima* and *Carex* types, floristic composition did not change, even on the most heavily trampled lanes; that is, similarity values on treated lanes were not significantly different from controls (fig. 5). In contrast, 75 passes significantly changed composition in the *Valeriana* type and 200 passes significantly changed the *Phyllodoce* type. On the *Valeriana* type, the mean similarity value after 500 passes was only 36 percent; the comparable mean similarity value on controls was 88 percent. After the year of recovery, however, mean similarity values on trampled lanes of all intensities were not significantly different from controls. Shifts in species composition increased during "recovery" in the *Phyllodoce* type, where values on the 200-pass and 500-pass lanes were significantly lower than on controls after the year. One year after 500 passes, the mean similarity value comparing composition to that before trampling was only 56 percent, compared to 90 percent on controls.

The vegetation types where species composition shifted the most were the most diverse, physiognomically in the case of *Phyllodoce* and floristically in

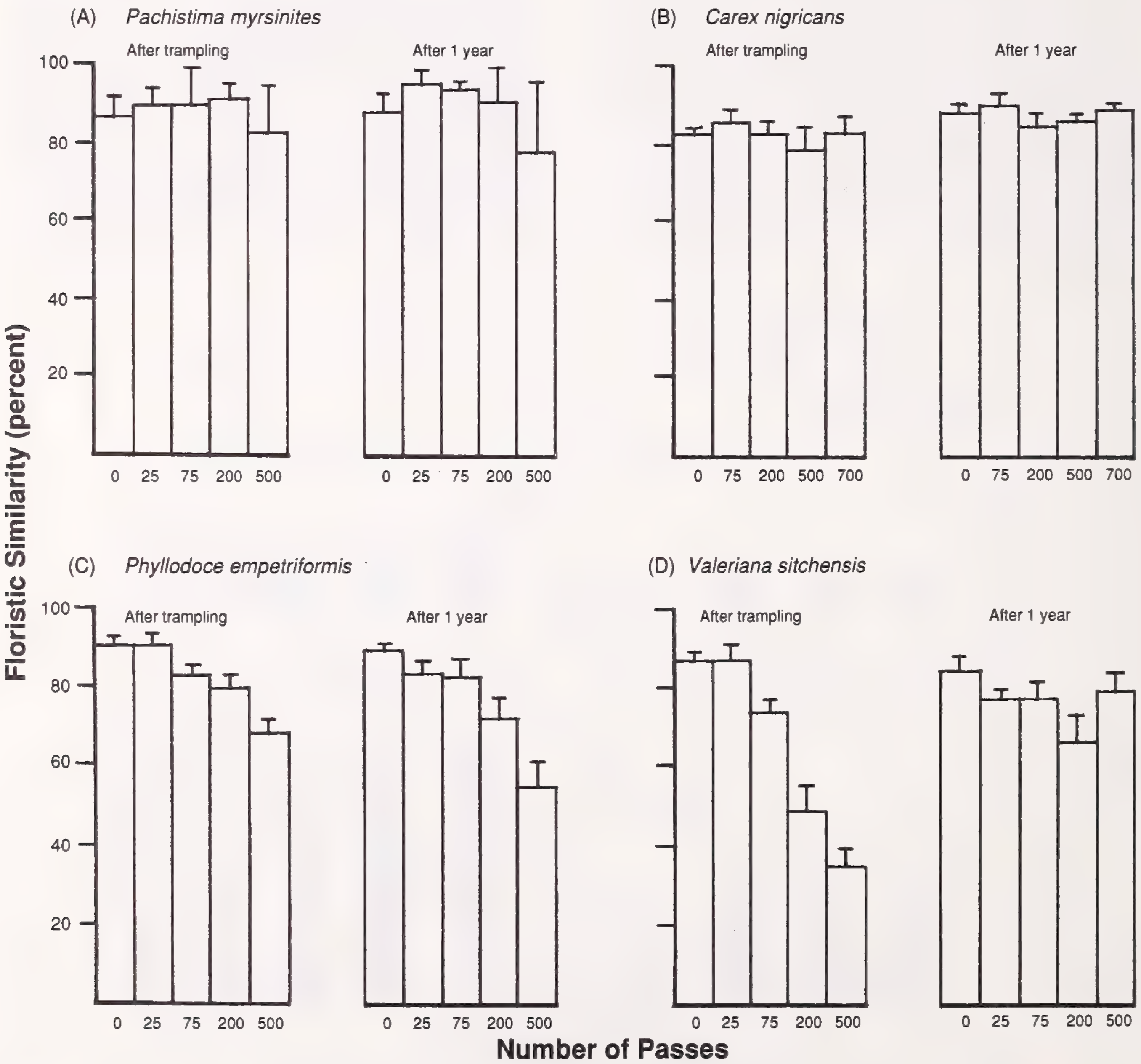

Figure 5—Floristic similarity, comparing composition before and after disturbance, in four vegetation types in Washington's Cascade Mountains. Vertical bars represent 1 standard error above the mean.

the case of *Valeriana*. The greater the diversity, the more likely it is that species will differ in durability. The physiognomic diversity of the *Phyllodoce* type, primarily shrubs and forbs, resulted in a longer-term shift in species composition than for the *Valeriana* type, which had a diversity of forbs, but almost no shrubs.

General Appearance

A final indication of response is the visual evidence of change after trampling. This was evaluated by describing the appearance of the lanes after each level of trampling. Particular attention was given to the amount of trampling that produced an easily discernible path, as evidence of previous use often encourages additional use of the path. Concentration of use can lead to accelerated impact.

Obvious changes occurred most rapidly in the *Valeriana* type, which was dominated by forbs. After 75 passes, most upright stems had been knocked down and an obvious path was created; most vegetation had been eliminated and all vegetation was flattened after 200 passes; virtually all vegetation was gone after 500 passes. An obvious path developed after 75 passes in the *Phyllodoce* type, which was dominated by dwarf shrubs. However, substantial vegetation survived 200 passes. After 500 passes, many upright stems remained, but they were clearly damaged. A path became evident only after 200 passes in the shrubby *Pachistima* type. On the 500-pass lanes, the vegetation appeared ragged because stems and leaves had been damaged, but many of the shrubs survived. In the *Carex* type, a path was not obvious before 500 passes. Even on the 700-pass lanes, a continuous turf remained, although about half of the sedges appeared to have been killed.

One year after trampling, paths were evident only in the *Pachistima* and *Phyllodoce* types, both dominated by shrubs. In the *Pachistima* type, dead shrubs and shrubs with few leaves were evident on the 200-pass lanes, but a path was evident only on the 500-pass lanes. In the *Phyllodoce* type, dead shrubs and leafless stems were evident even on the 75-pass lanes, and a brown path was evident on the 200-pass lanes. In the other two types, a careful observer could see that vegetation was shorter and that cover had been reduced, but only on the most heavily trampled lanes. A casual observer probably would not have detected any evidence of disturbance.

Summary Indicators

Five indicators of vegetation response, both immediately after trampling and after 1 year of recovery, are listed in table 6. The *Carex* turf, dominated by graminoids, was most resistant to all types of change other than reduction in height. Even on the most heavily trampled lanes, changes in this type were minor; recovery was virtually complete after 1 year. The *Valeriana* type, dominated by lush forbs, was the least resistant to all types of change. Even relatively low levels of trampling substantially reduced cover, reduced vegetation height, eliminated many species, shifted species composition, and created an obvious trail. The *Valeriana* type was highly resilient, however. After 1 year of recovery, the only evidence of trampling was a moderate reduction in height and cover on the most heavily trampled lanes.

Table 6—Summary indicators of resistance and tolerance for four vegetation types in Washington's Cascade Mountains

	Vegetation type			
	Pachistima	*Carex*	*Phyllodoce*	*Valeriana*
Resistance indicators[1]				
Relative cover (percent)	71	85	39	16
Relative height (percent)	75	71	89	18
Species richness (number of passes)	200	500	200	25
Species composition (number of passes)	>500	>700	200	75
Evident path (number of passes)	200	500	75	75
Tolerance Indicators[2]				
Relative cover (percent)	58	97	41	80
Relative height (percent)	83	85	59	65
Species richness (number of passes)	>500	>700	>500	>500
Species composition (number of passes)	>500	>700	200	>500
Evident path (number of passes)	500	>700	200	>500

[1]Resistance indicators refer to immediate responses to trampling. They include mean relative cover and relative height, after trampling, for 0 to 500 passes, as well as the minimum number of passes that causes a significant reduction in species richness or floristic similarity, or that results in an evident path. The relative cover and relative height values are the durability indices described in the data analysis section.

[2]Tolerance indicators refer to conditions 1 year after trampling.

The *Pachistima* and *Phyllodoce* types, which were dominated by shrubs, generally experienced intermediate levels of impact. Of these two, the *Pachistima* type, which had taller and stouter shrubs, was substantially more resistant. These shrub types, and *Phyllodoce* in particular, were initially the most resistant to height reduction. They were not very resilient, however. One year after trampling, the *Phyllodoce* type clearly was the most heavily impacted of all four vegetation types. Aside from an increase in species richness, little recovery occurred over the year. The *Pachistima* type continued to show substantial cover loss and an evident trail on the 500-pass lanes, but vegetation height, species richness, and species composition were close to the original conditions.

Individual Species Responses

Relative cover could be calculated for nine species of vascular plants and for mosses as a group (fig. 6).

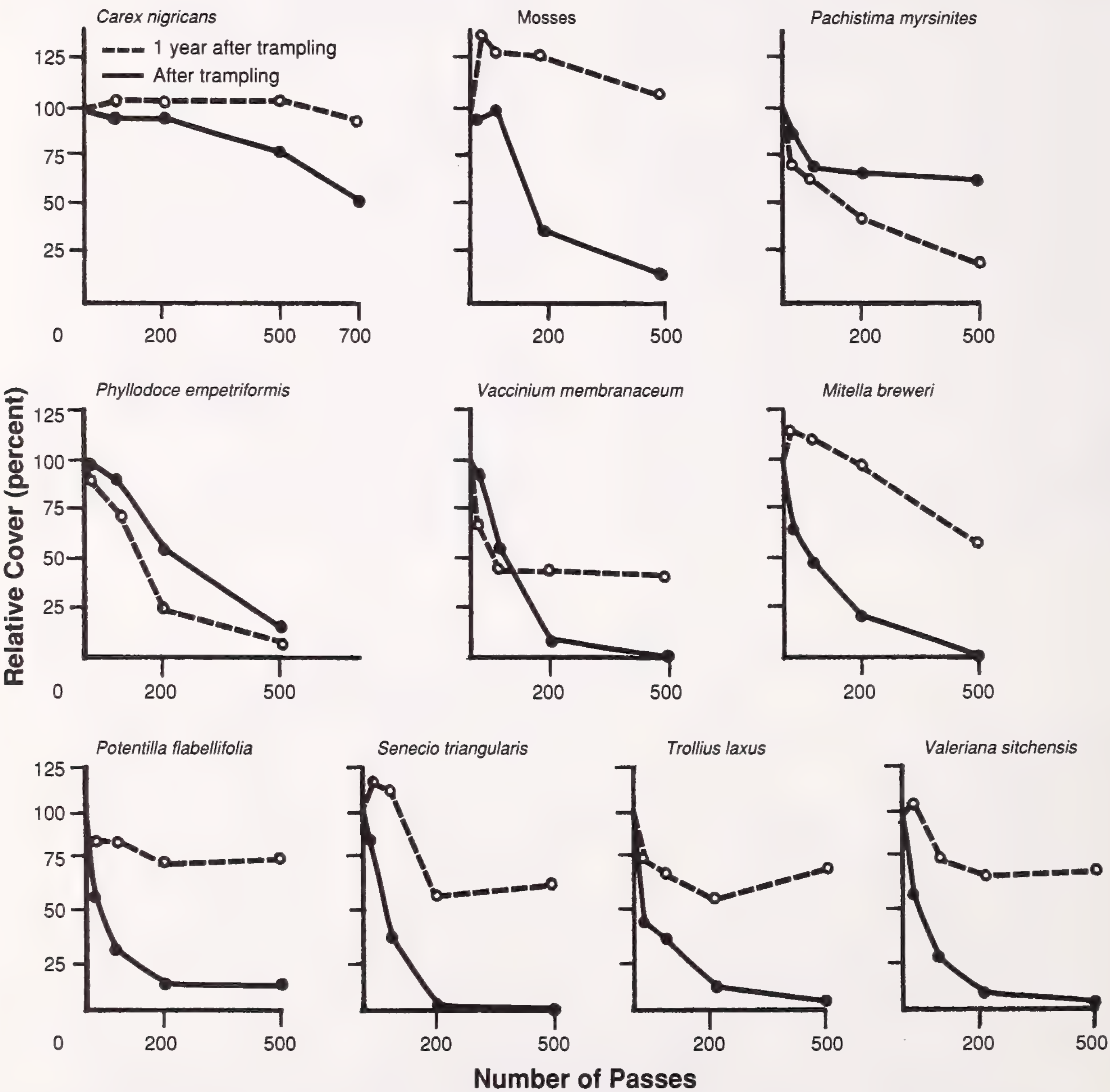

Figure 6—Relative cover after trampling and after 1 year of recovery for abundant species in four vegetation types in Washington's Cascade Mountains.

All other species were too sparse or irregularly distributed for reliable estimates. The responses of individual species were more diverse than the responses of vegetation types. For example, the relative cover of *Carex nigricans* exceeded 50 percent after trampling, even on the 700-pass lanes, while the relative cover of *Senecio triangularis* (arrowleaf groundsel) was only 1 percent on the 200-pass lanes. Recovery also varied greatly. *Pachistima* and *Phyllodoce* both lost cover over the year following trampling, while mosses recovered so dramatically that relative cover exceeded 100 percent, even on the 500-pass lanes.

A plot of the initial response to light trampling (25 passes) on one axis and the response to heavy trampling (500 passes) on the other suggests three levels of resistance (fig. 7). *Carex nigricans* and *Pachistima myrsinites* were generally resistant to trampling, even when intensities were as high as 500 passes. *Senecio triangularis*, *Vaccinium membranaceum* (big huckleberry), *Phyllodoce empetriformis*, and mosses resisted light trampling, but were susceptible to heavy trampling. The other species—*Trollius laxus* (globeflower), *Valeriana sitchensis*, *Potentilla flabellifolia* (fan-leaf cinquefoil), and *Mitella breweri* (Brewer's mitrewort)—were susceptible even to light trampling.

In a similar plot of relative cover after the year of recovery, species groupings are less obvious, and responses to light and heavy trampling are more similar (fig. 8). Species tended to be tolerant of trampling, regardless of its intensity, or intolerant. At one extreme were the highly tolerant mosses and *Carex nigricans*. Relative cover exceeded 100 percent, regardless of how heavily they were trampled. At the other extreme were the three shrub species, which had relative cover values less than 100 percent at all levels of trampling and less than 40 percent on the 500-pass lanes. The response of the forbs was intermediate.

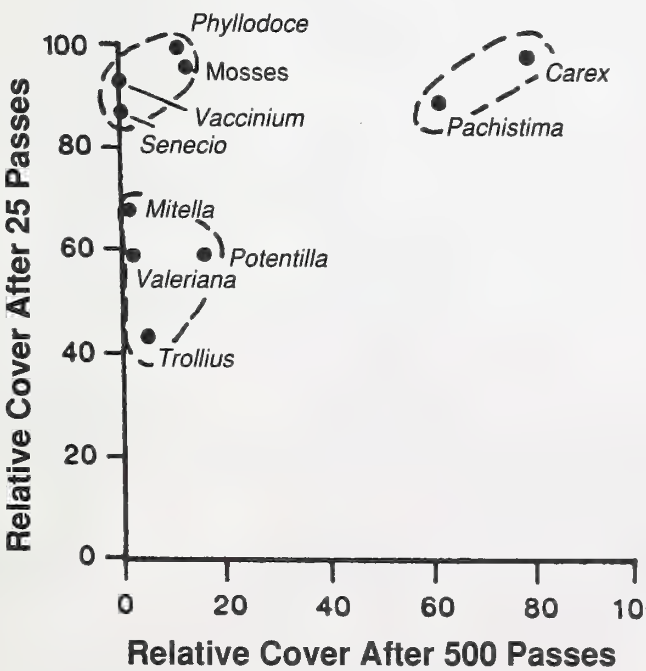

Figure 7—Relative cover after light and heavy trampling for abundant species in four vegetation types in Washington's Cascade Mountains.

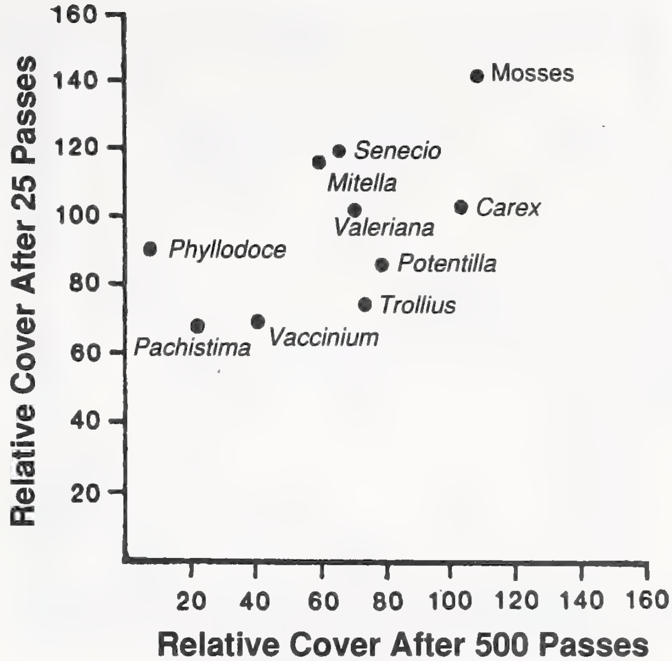

Figure 8—Relative cover 1 year after light and heavy trampling for abundant species in four vegetation types in Washington's Cascade Mountains.

It is possible to plot both the resistance index (mean relative cover immediately after 0 to 500 passes) and the tolerance index (mean relative cover 1 year after 0 to 500 passes) for these species. This depicts the relative resistance and tolerance of each species (fig. 9). Resilience is the perpendicular distance from the line of equal resistance and tolerance. At one extreme was the turf-forming graminoid, *Carex nigricans*, which was highly resistant, resilient, and tolerant. The forbs, *Mitella breweri*, *Potentilla flabellifolia*, *Senecio triangularis*, *Valeriana sitchensis*, and *Trollius laxus*, exhibited low resistance and relatively high resilience. Consequently, they were moderately to highly tolerant. The woody shrubs, *Pachistima myrsinites* and *Phyllodoce empetriformis*, were moderately resistant, but had low resilience. Therefore, they had low tolerance. *Vaccinium membranaceum* was substantially less resistant and more resilient than the two other shrub species, making its response intermediate between the forbs and other shrubs. Its deciduous leaves may contribute to this response, since deciduous leaves are not likely to be as tough as evergreen leaves, but are

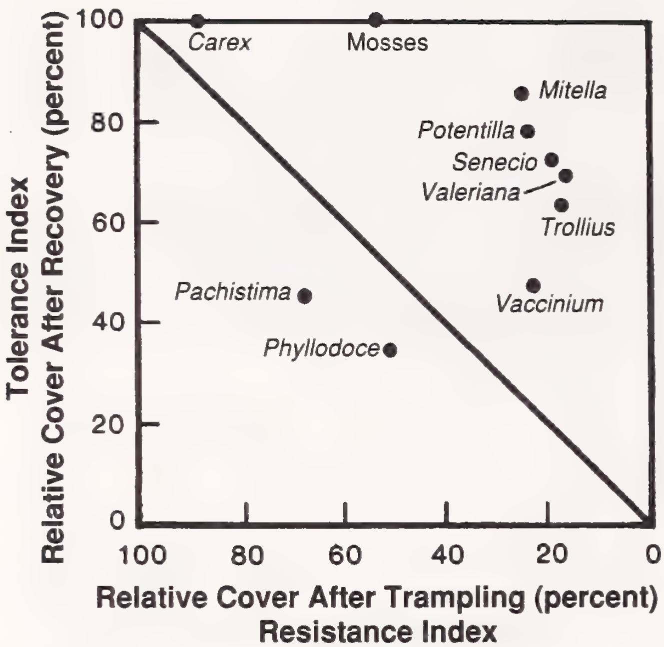

Figure 9—Resistance, tolerance, and resilience of abundant species in four vegetation types in Washington's Cascade Mountains. Resilience is indicated by the perpendicular distance from the diagonal line of equal resistance and tolerance.

likely to grow faster. Mosses were intermediate in response between the graminoid, *Carex nigricans*, and the forbs. They were moderately resistant but highly resilient and, therefore, highly tolerant.

For other species, I prepared tables of mean cover before and after trampling and 1 year after trampling for each level of intensity. These tables allowed me to evaluate the relative resistance of many of the less common species. The minimum number of passes that reduced cover by 50 percent was used to classify each species' resistance as: high (500 passes or more); moderate (200 passes); or low (75 passes or less). For example, *Vaccinium scoparium* cover declined 20 percent on 75-pass lanes (from 2.0 percent to 1.6 percent) and 75 percent on 200-pass lanes (from 1.6 percent to 0.4 percent). Consequently, it was classified as a moderately resistant species. Tolerance was classified, in an analogous fashion, using the maximum number of passes that could be tolerated and still have at least 75 percent of original cover 1 year after trampling. Tolerance classes were high (500 passes or more), moderate (200 passes), and low (75 passes or less). Resilience was evaluated by examining the amount of recovery on lanes where trampling had reduced cover to nearly zero. Resilience classes were high (if cover 1 year after trampling was more than two-thirds of cover before trampling), moderate (if cover after 1 year was between one-third and two-thirds of original cover), and low (if cover was less than one-third of original cover).

This classification (table 7) suggests some general tendencies. The shrubs—as noted before—had moderate to high resistance, but because of their low resilience they were unable to tolerate much trampling. The graminoids also had moderate to high resistance. But their resilience was moderate to high. Consequently, graminoids were the group of plants most capable of tolerating the level and type of trampling administered in this study. The forbs had low to moderate resistance. With a few exceptions, their resilience was moderate to high. Tolerance was generally moderate, although some forbs had low tolerance and others had high tolerance. *Abies lasiocarpa* seedlings had low resistance, resilience, and tolerance. Mosses had moderate or high resistance, resilience, and tolerance, depending on the vegetation type.

Beyond these broad generalizations about shrubs, graminoids, and forbs, other plant characteristics affected response. For example, the differences in resistance between the two forbs, *Veratrum viride* (green false hellebore) and *Leptarrhena pyrolifolia* (false saxifrage), probably reflect differences in the architecture of their leaves and stems and the toughness of their tissues. *Veratrum* is tall, with stems that are leafy and swollen with fluid, or brittle if dry. Stems readily snap at the base, eliminating all of the biomass aboveground. *Leptarrhena* is short, with leathery leaves confined primarily to a basal rosette (a dense cluster of leaves arranged like the spokes of a wheel at the base of the stem). Trampling may crush the erect flower stalk, but the leaves will survive moderate trampling.

The vegetation matrix within which a species occurs also affects its resistance. The ability to survive trampling often increases if the adjacent plants are resistant. These resistant plants can protect fragile plants from trampling (Cole 1988). For example, *Potentilla flabellifolia* had moderate resistance in the *Phyllodoce* and *Carex* types, but low resistance in the *Valeriana* type. Potential explanations for variation in resilience are less apparent, but the variation likely reflects differences in environmental conditions, as well as plant characteristics such as growth rates, means of regeneration, and the protection and toughness of perennating tissues.

EFFECTS OF TRAMPLING IN THE ROCKY MOUNTAINS

Another set of study sites were located in the Arapaho and Roosevelt National Forests, on the east slope of the Rockies in Colorado. One site was located along Bennett Creek, a tributary of the Cache la Poudre

Table 7—Relative resistance, resilience, and tolerance of species in Washington's Cascade Mountains

Species	Resistance[1]	Resilience[2]	Tolerance[3]
Shrubs			
Pachistima myrsinites (1)[4]	h	l	l
Phyllodoce empetriformis (3)	h	l	l
Vaccinium membranaceum (3)	m	l	l
Vaccinium scoparium (3,4)	m	l	l
Graminoids			
Carex nigricans (2)	h	m	h
Carex spectabilis (2,4)	m-h	m-h	m-h
Juncus drummondii (2)	m	m	m
Luzula hitchcockii (2,4)	m-h	m	m-h
Forbs			
Antennaria lanata (2)	m	m	m
Arnica mollis (3,4)	l	l-m	l-m
Aster alpigenus (3,4)	l-m	m	l-m
Caltha bicolor (4)	l	l	l
Equisetum palustre (4)	l	m	m
Erigeron peregrinus (3,4)	m	m	l-m
Heracleum lanatum (4)	l	h	h
Hieracium gracile (2)	m	m	m
Leptarrhena pyrolifolia (3,4)	m-h	h	h
Ligusticum grayi (3,4)	l	m-h	m-h
Lupinus polyphyllus (4)	l	m	m
Mitella breweri (4)	m	m	m
Osmorhiza purpurea (4)	l	m	l
Parnassia fimbriata (4)	l	l	l
Pedicularis bracteosa (4)	l	l	l
Potentilla flabellifolia (2,3,4)	l-m	m-h	m
Saxifraga arguta (4)	l	m	m
Senecio triangularis (4)	l	m	m
Thalictrum occidentale (4)	l	m	m
Trollius laxus (4)	l	m	l
Valeriana sitchensis (4)	l	m	m
Veratrum viride (4)	l	h	h
Veronica cusickii (2)	m	m	h
Viola glabella (4)	l	m	l
Viola orbiculata (4)	m	m	m
Other			
Abies lasiocarpa seedling (3)	l	l	l
Mosses (2,3,4)	m-h	m-h	m-h

[1]Resistance classes are based on the minimum number of passes that reduced cover by 50 percent; h ≥ 500 passes; m = 200 passes; l ≤ 75 passes.
[2]Resilience classes are based on recovery after cover was reduced nearly to zero: h = cover 1 year after trampling was more than two-thirds of the original cover; m = cover 1 year after trampling was between one-third and two-thirds of original cover; l = cover 1 year after trampling was less than one-third of original cover.
[3]Tolerance classes are based on the maximum number of passes that could be tolerated and still have at least 75 percent of original cover 1 year after trampling: h ≥ 500 passes; m = 200 passes; l ≤ 75 passes.
[4]Vegetation types: 1 = *Pachistima myrsinites*; 2 = *Carex nigricans*; 3 = *Phyllodoce empetriformis*; 4 = *Valeriana sitchensis*.

River, at 2,650 m elevation. The site was a moderately dense *Populus tremuloides* (aspen) forest (70 percent cover), with scattered *Abies lasiocarpa* and *Picea pungens* (blue spruce). The ground cover was a dense, diverse mix of herbs, of which *Geranium richardsonii* (white geranium) and *Fragaria ovalis* (strawberry) were most abundant (fig. 10A). This vegetation type and similar stands of aspen with a lush herb understory are common throughout the Central Rockies. It has been termed the *Populus tremuloides/Thalictrum fendleri* habitat type by Hess and Alexander (1986).

The three other sites were close to the headwaters of the West Fork of Sheep Creek, another tributary of the Cache la Poudre River, in the Comanche Peak Wilderness. One vegetation type was in moderately dense (50 percent cover) *Abies lasiocarpa-Picea engelmannii* forest, at 3,350 m elevation. The ground cover was short and only moderately dense (fig. 10B). Diversity was low, given the dominance of the matted shrub, *Vaccinium scoparium* (grouse whortleberry). This vegetation type and related variants is abundant throughout the Northern and Central Rockies. It has been termed the *Abies lasiocarpa/Vaccinium scoparium* habitat type by Hess and Alexander (1986).

The second high-elevation site was in open meadows adjacent to these spruce-fir forests. Ground cover was short and only moderately dense; disturbance by both elk and pocket gophers was common. Species diversity was high; *Danthonia intermedia* (oatgrass), *Trifolium parryi* (clover), *Sibbaldia procumbens* (sibbaldia), and *Potentilla diversifolia* (cinquefoil) were all abundant (fig. 10C). This type has been termed the *Danthonia intermedia-Sibbaldia procumbens* alpine grassland by Baker (1984), although *Trifolium parryi* was the most abundant species on the study sites. Moister areas grade into *Deschampsia caespitosa* (hairgrass) meadows.

The final type was located at a slightly higher elevation (3,450 m), above tree line. Ground cover was a dense, uneven turf, dominated by *Kobresia myosuroides* (kobresia) (fig. 10D). *Geum rossii* (alpine avens) and *Trifolium dasyphyllum* (alpine clover) were common associates. This vegetation type and related variants is a common alpine turf throughout the Colorado Rockies. It has been termed the *Kobresia myosuroides-Geum rossii* alpine turf by Baker (1984).

In sum, the Rocky Mountain vegetation types include one type dominated by graminoids (*Kobresia*),

Figure 10—Vegetation types in Colorado's Rocky Mountains are (A) *Geranium*, (B) *Vaccinium*, (C) *Trifolium*, and (D) *Kobresia*.

one type dominated by shrubs (*Vaccinium*), one type dominated by short forbs (*Trifolium*), and one type dominated by erect forbs (*Geranium*). One type is above timberline; one type is an open subalpine meadow; one type is a subalpine spruce-fir forest; and one type is a montane aspen forest. A list of the most abundant species can be found in the appendix. Nomenclature follows Weber (1976), with the few exceptions of *Geum* (which Weber calls *Acomastylis*), *Polygonum* (which Weber calls *Bistorta*), and *Poa pratensis* (which Weber calls *P. agassizensis*).

Bare Ground and Vegetation Cover

Before trampling, the *Kobresia* (turf) and the *Geranium* (montane forest) vegetation types were very densely vegetated; bare ground was only 2 to 3 percent. The *Trifolium* (subalpine meadow) type had more bare ground (mean of 11 percent), and the *Vaccinium* (subalpine forest) type had the most (mean of 18 percent). Trampling exposed substantial amounts of bare ground on all vegetation types (table 8). In the *Geranium* type, for example, mean bare ground was 11 percent after 25 passes, 26 percent after 75 passes, and 86 percent after 200 passes. After 500 passes, the *Geranium* lanes were 90 percent bare ground. The 500-pass lanes were nearly as barren in the *Vaccinium* and *Trifolium* types (83 and 79 percent bare ground, respectively), but substantially less barren in the *Kobresia* type (61 percent bare ground).

After 1 year, vegetation cover was again approaching the original levels in the *Geranium* type but had not recovered in the other types. In *Trifolium*, gopher activity on control lanes caused bare ground to increase from 8 to 29 percent during the year following trampling. It is impossible to estimate what might have happened if the gophers had not been present. In the *Vaccinium* type, and to a lesser degree in the *Kobresia* type, bare ground exceeded the original levels 1 year after trampling, even on the most lightly trampled lanes.

Relative vegetation cover after trampling differed significantly both with the amount of trampling and the vegetation type (table 9). The interaction between these two effects was not significant. After the year of recovery, differences in relative vegetation cover for the trampling levels and vegetation types were still highly significant. In this case, the interaction between trampling levels and vegetation types was significant and substantial. The effect of trampling on the *Vaccinium* type was much more pronounced, 1 year after trampling, than for any of the other vegetation types.

Of the four vegetation types, the forb-dominated aspen forest (*Geranium*) lost the most vegetation

Table 8—Percent bare ground before and after trampling and after 1 year of recovery for four vegetation types in Colorado's Rocky Mountains[1]

	Number of passes					
	0	25	75	200	500	700
Trifolium parryi (subalpine meadow)						
Before trampling	8 (3)[2]	7 (3)	10 (5)	14 (3)	16 (5)	—
After trampling	21 (3)	22 (5)	29 (8)	59 (4)	79 (5)	—
After 1 year	29 (12)	28 (3)	28 (8)	33 (5)	39 (5)	—
Kobresia myosuroides (alpine turf)						
Before trampling	2 (1)	—	1 (+)	2 (1)	3 (1)	2 (1)
After trampling	4 (1)	—	14 (6)	41 (9)	61 (10)	84 (4)
After 1 year	6 (2)	—	10 (3)	16 (6)	35 (5)	54 (3)
Vaccinium scoparium (subalpine forest)						
Before trampling	19 (5)	17 (3)	23 (4)	13 (6)	16 (6)	—
After trampling	20 (6)	26 (3)	43 (3)	56 (1)	83 (4)	—
After 1 year	23 (5)	28 (6)	56 (1)	73 (3)	90 (4)	—
Geranium richardsonii (montane forest)						
Before trampling	5 (1)	2 (1)	3 (1)	3 (1)	4 (1)	—
After trampling	6 (2)	11 (2)	26 (4)	86 (2)	90 (+)	—
After 1 year	2 (2)	2 (1)	3 (2)	5 (2)	5 (2)	—

[1]Percent bare ground is the mean proportion of each quadrat that is not vegetated.
[2]Standard errors are in parentheses. A + indicates standard error less than 0.5 percent.

Table 9—Analysis of variance and multiple comparisons for relative cover after trampling and after 1 year of recovery in Colorado's Rocky Mountains

Source	After trampling			After 1 year		
	df	F	*p*	df	F	*p*
Number of passes	3	201.6	0.0001	3	20.4	0.0001
Vegetation type	3	48.6	.0001	3	95.4	.0001
Interaction	8	1.5	.18	8	11.2	.0001
	Significantly different treatments					
Number of passes	25>75>200>500			25>75>200>500		
Vegetation types[1]	K,D>V>G			D,K,G>V		

[1]Vegetation types: K = *Kobresia*, D = *Danthonia*, V = *Vaccinium*, G = *Geranium*.

cover when trampled (fig. 11). Relative cover decreased to 62 percent after 25 passes and to only 10 percent after 200 passes. The *Vaccinium* type dominated by dwarf shrubs was significantly more resistant. Relative cover decreased to 51 percent after 200 passes and 17 percent after 500 passes. More resistant still were the matted forbs and graminoids of the *Trifolium* meadow and *Kobresia* turf vegetation types. In the *Trifolium* type, relative cover decreased to 54 percent after 200 passes and 26 percent after 500 passes. In the *Kobresia* type, relative cover decreased to 61 percent after 200 passes and 39 percent after 500 passes. In these latter two types, relative cover on lanes trampled 75 times or less was not significantly different from the control.

One year after trampling, disturbance could not be detected on any of the *Trifolium* or *Geranium* lanes. Both had substantially recovered. Considering that *Geranium* was the type most disturbed after trampling,

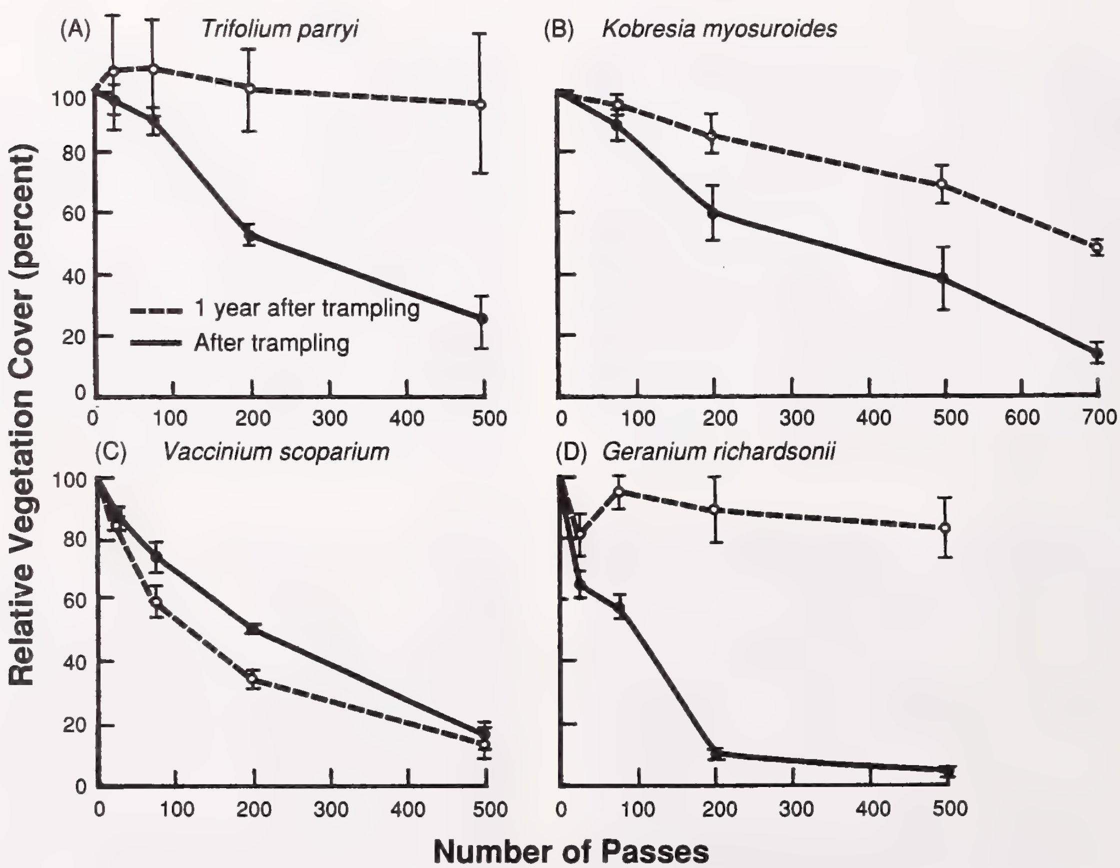

Figure 11—Relative vegetation cover after trampling and after 1 year of recovery in four vegetation types in Colorado's Rocky Mountains. Vertical bars represent 1 standard error above and below the mean.

Table 10—Mean vegetation height (cm) before and after trampling and after 1 year of recovery for four vegetation types in Colorado's Rocky Mountains

	Number of passes					
	0	25	75	200	500	700
Trifolium parryi (subalpine meadow)						
Before trampling	3 (+)[1]	2 (+)	3 (+)	3 (+)	3 (+)	—
After trampling	3 (+)	2 (+)	2 (+)	1 (+)	1 (+)	—
After 1 year	3 (+)	3 (+)	2 (+)	2 (+)	2 (+)	—
Kobresia myosuroides (alpine turf)						
Before trampling	6 (+)	—	6 (1)	7 (1)	7 (1)	7 (+)
After trampling	6 (+)	—	4 (+)	3 (+)	2 (+)	1 (+)
After 1 year	5 (1)	—	4 (+)	4 (+)	3 (+)	3 (+)
Vaccinium scoparium (subalpine forest)						
Before trampling	7 (1)	8 (1)	7 (1)	7 (1)	7 (1)	—
After trampling	7 (1)	6 (1)	5 (1)	4 (1)	2 (1)	—
After 1 year	7 (1)	7 (2)	6 (1)	2 (1)	1 (+)	—
Geranium richardsonii (montane forest)						
Before trampling	18 (3)	20 (4)	20 (3)	17 (3)	18 (4)	—
After trampling	18 (3)	4 (+)	3 (+)	1 (+)	1 (+)	—
After 1 year	19 (2)	13 (2)	15 (2)	14 (2)	12 (2)	—

[1]Values in parentheses are one standard error. A + indicates standard error less than 0.5 cm.

the recovery is remarkable. The *Kobresia* lanes recovered some, but remained disturbed 1 year after trampling. Relative cover on the 500-pass lanes was 39 percent after trampling and 70 percent 1 year later. Largely because *Kobresia* was the type that was least disturbed initially, its relative cover 1 year after trampling was not significantly different from the *Trifolium* and *Geranium* types. The *Vaccinium* type responded uniquely. Relative cover declined over the year following trampling. On the 200-pass lanes, for example, relative cover was 51 percent immediately after trampling but only 35 percent a year later. Shrubs appeared to have been damaged by trampling, but did not die that summer. The dieback the following summer appeared to be aggravated by pronounced drought.

Vegetation Height

Before trampling, ground cover was tallest in the *Geranium* type (mean of 19 cm) and shortest in the *Trifolium* type (mean of 3 cm). Mean height was 7 cm in both the *Kobresia* and *Vaccinium* types (table 10). Trampling reduced vegetation height in all types; however, the rate of decline varied among types. Relative height differed significantly both with the amount of trampling and with the vegetation type. The interaction between these effects was not significant (table 11). One year after trampling, the effects of the amount of trampling and the vegetation type were still statistically significant, as was the interaction between the two.

Table 11—Analysis of variance and multiple comparisons for relative height after trampling and after 1 year of recovery in Colorado's Rocky Mountains

	After trampling			After 1 year		
Source	df	F	*p*	df	F	*p*
Number of passes	3	27.3	0.0001	3	13.3	0.0001
Vegetation type	3	59.6	.0001	3	39.8	.0001
Interaction	8	1.6	.16	8	6.7	.0001
Significantly different treatments						
Number of passes	25,75>200,500			25>75>200,500		
Vegetation types[1]	V,D>K>G			D>G,K,V; G>V		

[1]Vegetation types: V = *Vaccinium*, D = *Danthonia*, K = *Kobresia*, G = *Geranium*.

Initially, the *Geranium* type reacted most strongly to trampling. It was dominated by erect herbs—mostly forbs. The relative height decreased to 24 percent after 25 passes and to 8 percent after 200 passes (fig. 12). The most resistant types were *Trifolium* and *Vaccinium*, where relative height exceeded 80 percent after 25 passes and was still about 50 percent after 200 passes. The response of the *Kobresia* type was intermediate, with a relative height of 39 percent after 200 passes.

Three types of response are apparent during the year after trampling. In the *Vaccinium* type dominated by dwarf shrubs, height continued to decline. In the *Kobresia* type dominated by graminoids, height increased somewhat, with the amount largely independent of trampling intensity and relative height immediately after trampling. In these two types, relative height 1 year after trampling varied with trampling intensity. The relative height increased much more during the year in the *Geranium* and *Trifolium* types, often increasing more on the more heavily trampled lanes. Consequently, relative height 1 year after trampling was largely independent of trampling intensity on these types. The significant interaction between trampling intensity and vegetation type, apparent in the analysis of variance, reflects these responses. One year after trampling, relative height approached 100 percent on all lanes in the *Trifolium* type. In the *Geranium* type relative height was 70 to 80 percent on all lanes.

The rate of height reduction and the rate of cover loss were substantially different only in the *Kobresia* and *Geranium* types. In both of these types, height reduction occurred more rapidly than cover loss and recovery after 1 year was less complete. For example, in *Kobresia*,75 passes eliminated about 10 percent of the cover, but it reduced height by about 35 percent.

Species Richness and Composition

Species richness declined as trampling increased on all four vegetation types. The response was most rapid on the *Kobresia* and *Geranium* types, where 75 passes caused a significant reduction (fig. 13). In *Geranium*, the mean number of species on the 500-pass lanes was 12 before trampling and three after trampling. In the *Vaccinium* type, the number of species was significantly reduced only on the 500-pass lanes. In

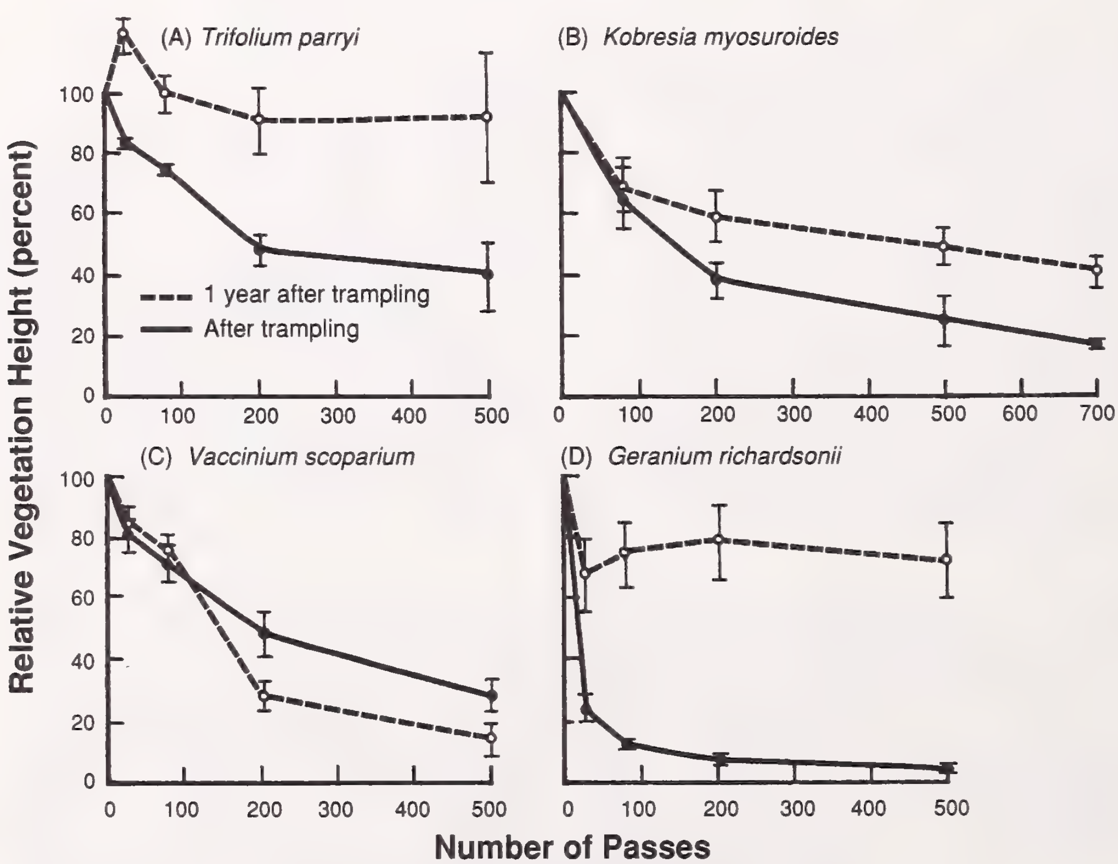

Figure 12—Relative vegetation height after trampling and after 1 year of recovery in four vegetation types in Colorado's Rocky Mountains. Vertical bars represent 1 standard error above and below the mean.

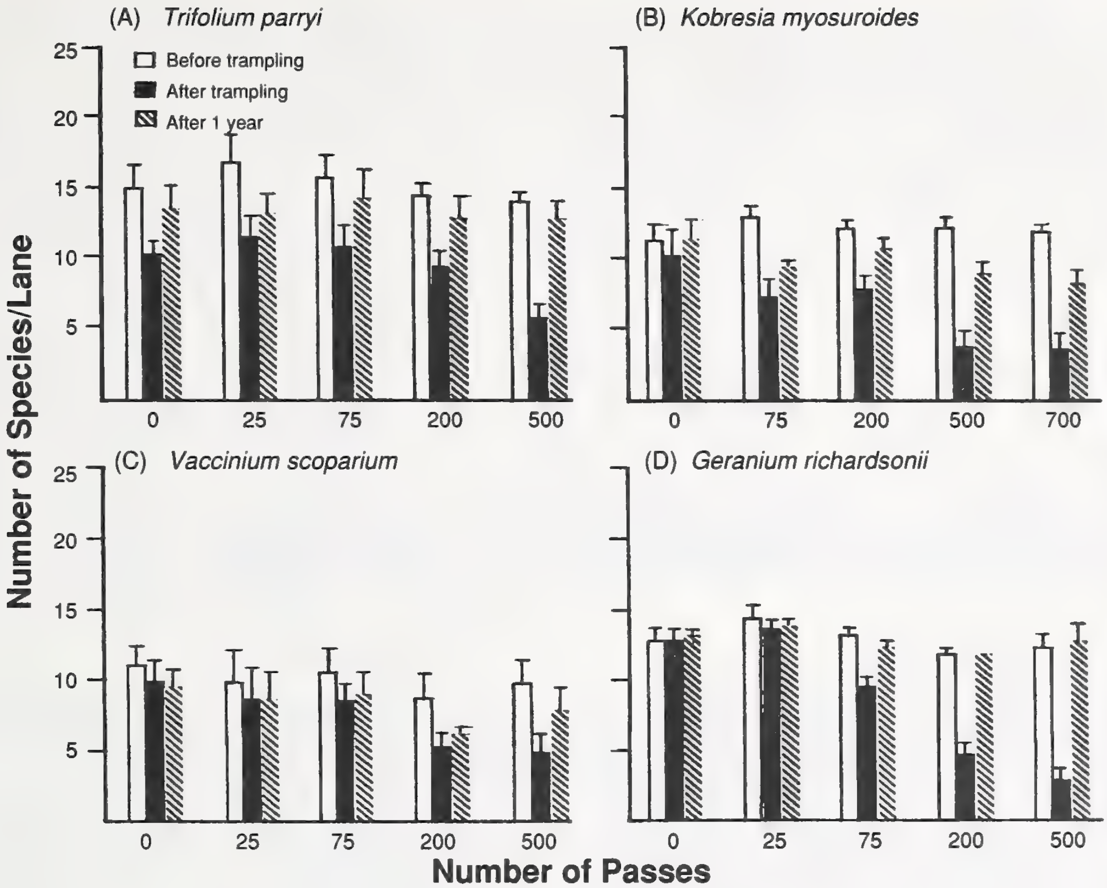

Figure 13—Species richness before and after trampling and after 1 year of recovery in four vegetation types in Colorado's Rocky Mountains. Vertical bars represent 1 standard error above the mean.

Trifolium, the number of species declined significantly on all lanes, including the control lanes that weren't trampled at all. This reflected both seasonal dieback of plants and gopher activity. Accounting for changes on the control, trampling's only significant effect was on the 500-pass lanes. One year after trampling, species richness approached or exceeded the original levels on nearly all lanes and types. The chief exceptions were the 500- and 700-pass lanes in *Kobresia*, where species richness remained depressed.

Species composition did not change as a result of trampling on any of the *Trifolium* lanes (fig. 14). Similarity values for 500-pass lanes were 80 percent compared with 89 percent for controls. In contrast, just 25 passes significantly changed species composition in the *Geranium* type. Significant changes occurred after 200 passes in *Vaccinium* and after 500 passes in *Kobresia*. Similarity values for 500-pass lanes were 78 percent in *Kobresia*, 58 percent in *Vaccinium*, and 52 percent in *Geranium*. After the year of recovery, mean similarity values for treated lanes were similar to those for controls in three of the four types. Shifts in species composition actually increased over the year in the *Vaccinium* type. One year after trampling, the mean similarity value for the 500-pass lanes was 33 percent (compared to 94 percent for controls). This reflects the continued decline of the dominant species, *Vaccinium scoparium*, over the year following trampling.

General Appearance

Visually obvious changes occurred most rapidly in the *Geranium* type, dominated by erect forbs. After 75 passes many of the plants were flattened and a path of broken vegetation was apparent. After 200 passes, most of the vegetation had been eliminated. In the *Vaccinium* type, a path was evident only on lanes trampled at least 200 times. In the *Trifolium* and *Kobresia* types, some obvious flattening occurred after 200 passes, but a path was not obvious until lanes had been trampled at least 500 times. One year after trampling, paths were evident only in the *Vaccinium* type, and only on lanes trampled at least 200 times. In the three other types, the visual evidence of trampling was minimal.

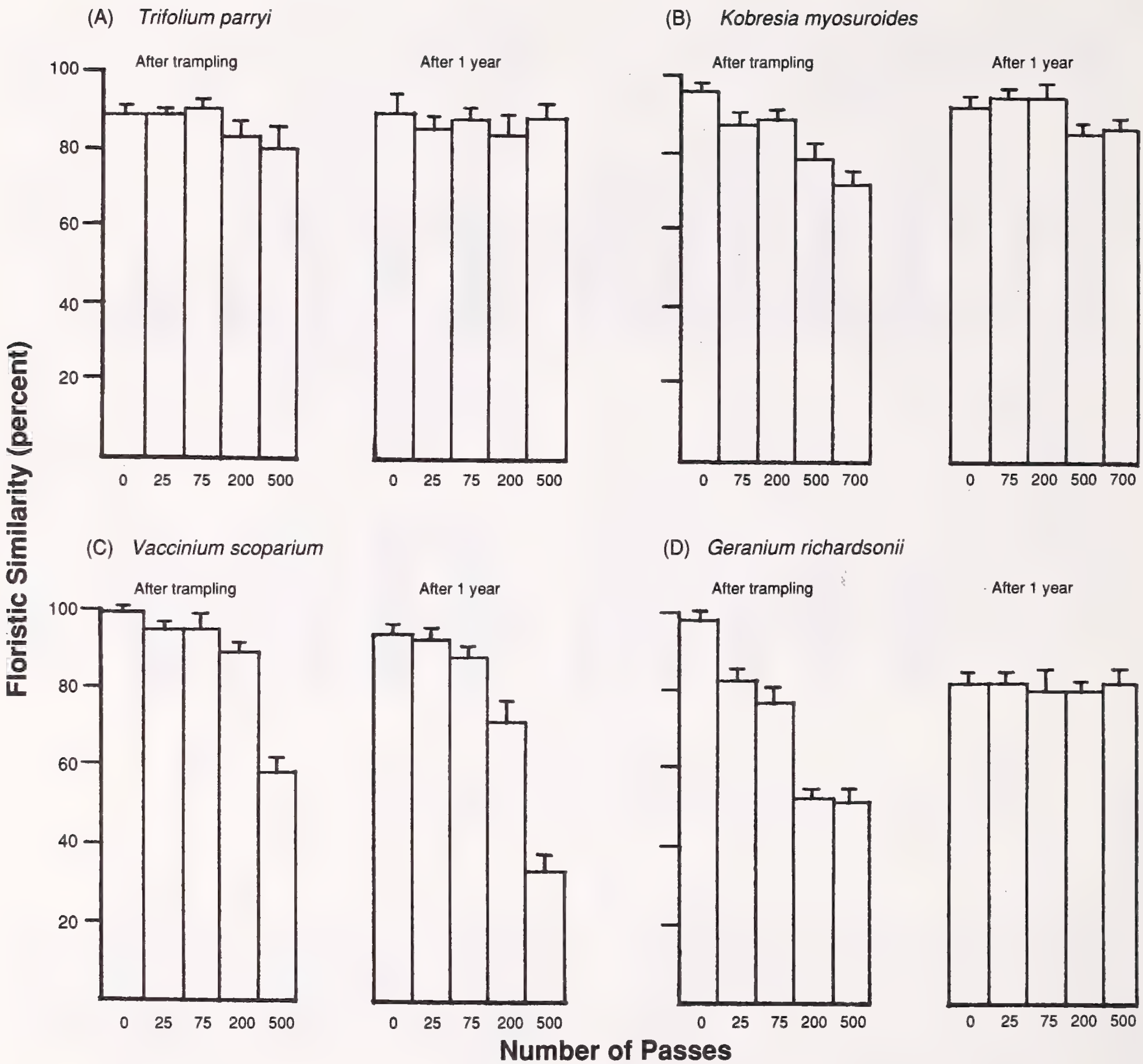

Figure 14—Floristic similarity, comparing composition before and after disturbance, in four vegetation types in Colorado's Rocky Mountains. Vertical bars represent 1 standard error above the mean.

Summary Indicators

The *Trifolium* type, dominated by matted and creeping forbs, along with short, tufted graminoids, was most able to tolerate trampling. It resisted all five of the changes examined (table 12). Even the 500-pass lanes returned to the original conditions within 1 year. The *Kobresia* type was even more resistant to cover loss, but it lost more species and was flattened more than *Trifolium*. More important, it was less resilient than *Trifolium*. On the more heavily trampled lanes, cover, height, and richness remained depressed 1 year after trampling.

The other extreme, in terms of initial response, was the *Geranium* type, dominated by erect forbs. Even relatively low levels of trampling reduced cover substantially, reduced vegetation height, eliminated many species, shifted species composition, and created an obvious trail. One year after trampling, recovery in this type was second only to *Trifolium*.

The response of the *Vaccinium* type, dominated by dwarf shrubs, was unique. It experienced moderate

Table 12—Summary indicators of resistance and tolerance for four vegetation types in Colorado's Rocky Mountains

	Vegetation type			
	Trifolium	*Kobresia*	*Vaccinium*	*Geranium*
Resistance indicators[1]				
Relative cover (percent)	57	63	49	23
Relative height (percent)	55	45	51	11
Species richness (number of passes)	500	75	500	75
Species composition (number of passes)	>500	500	200	25
Evident path (number of passes)	500	500	200	75
Tolerance indicators[2]				
Relative cover (percent)	100	85	38	88
Relative height (percent)	95	62	39	76
Species richness (number of passes)	>500	500	>500	>500
Species composition (number of passes)	>500	>700	200	>500
Evident path (number of passes)	>500	700	200	>500

[1]Resistance indicators refer to immediate responses to trampling. They include mean relative cover and relative height, after trampling, for 0 to 500 passes, as well as the minimum number of passes that causes a significant reduction in species richness or floristic similarity, or that results in an evident path. The relative cover and relative height values are the durability indices described in the data analysis section.

[2]Tolerance indicators refer to conditions 1 year after trampling.

levels of change after trampling. Height reduction was unusually low. However, over the year after trampling, cover and height continued to decline. Changes in species composition and the visual evidence of impact increased. The only sign of recovery was the regrowth or colonization of species that had been eliminated by trampling. Species richness returned to the original levels on all lanes.

Individual Species Responses

Relative cover could be calculated for 16 species (fig. 15). The responses ranged widely. Relative cover of *Carex rossii* (Ross' sedge) was 76 percent after 500 passes, while *Thermopsis divaricarpa* (pine goldenpea) and *Viola canadensis* (Canada violet) were eliminated after 200 passes. Most species recovered over the year after trampling, but *Vaccinium scoparium* decreased in cover over the year. Some species, such as *Thermopsis divaricarpa*, recovered greatly, while others, such as *Kobresia myosuroides,* made more modest recoveries.

A plot of response to light and heavy trampling illustrates how resistance to trampling varied between species (fig. 16). On the left side of the graph are species that did not resist heavy trampling. They range from *Thermopsis divaricarpa*, which could not resist even light trampling, to *Erigeron melanocephalus* (blackheaded fleabane), which could. Across the top of the graph are species that resisted light trampling. They range from *Erigeron melanocephalus*, which did not resist heavy trampling, to *Carex rossii*, which did.

A similar plot of relative cover after the year of recovery provides a more linear distribution of points, ranging from *Trifolium parryi*, tolerant of both light and heavy trampling, to *Viola canadensis*, only moderately tolerant of light or heavy trampling (fig. 17). The primary exception is *Vaccinium scoparium*, which tolerated light trampling, but was not at all tolerant of heavy trampling. The response of *Thermopsis divaricarpa* is difficult to explain. It recovered after heavy trampling, but not after light trampling.

A plot of resistance and tolerance indices depicts a broad range of responses (fig. 18). At one extreme was the caespitose graminoid, *Carex rossii*, both highly resistant and tolerant. The erect, caulescent (leafy-stemmed) forbs, *Aster laevis* (smooth aster), *Achillea lanulosa* (western yarrow), *Thermopsis divaricarpa*, *Geranium richardsonii*, and *Viola canadensis* all exhibited low resistance and relatively high resilience. Consequently, their tolerance was moderate to high. Intermediate between the erect forbs and *Carex rossii* were a variety of other caespitose graminoids and reptant (creeping) or rosette (leaves like the spokes of a wheel at the plant's base) forbs. The dwarf shrub, *Vaccinium scoparium*, was characterized by very low resilience. Its resistance was moderate, but its tolerance was very low, due to its inability to recover during the year following trampling.

Table 13 classifies the responses of less common species as low, moderate, or high. The table reinforces the pattern of responses established by the more detailed analysis of common species. The graminoids were generally more resistant than the forbs. Among the forbs, the most resistant species were short, creeping plants with tough leaves, or without leafy stems. Mosses were resistant, but lichens were not. The one shrub species had low resilience. Resilience was moderate to high in graminoids, low to high in forbs, low to moderate in lichens, and moderate to high in mosses.

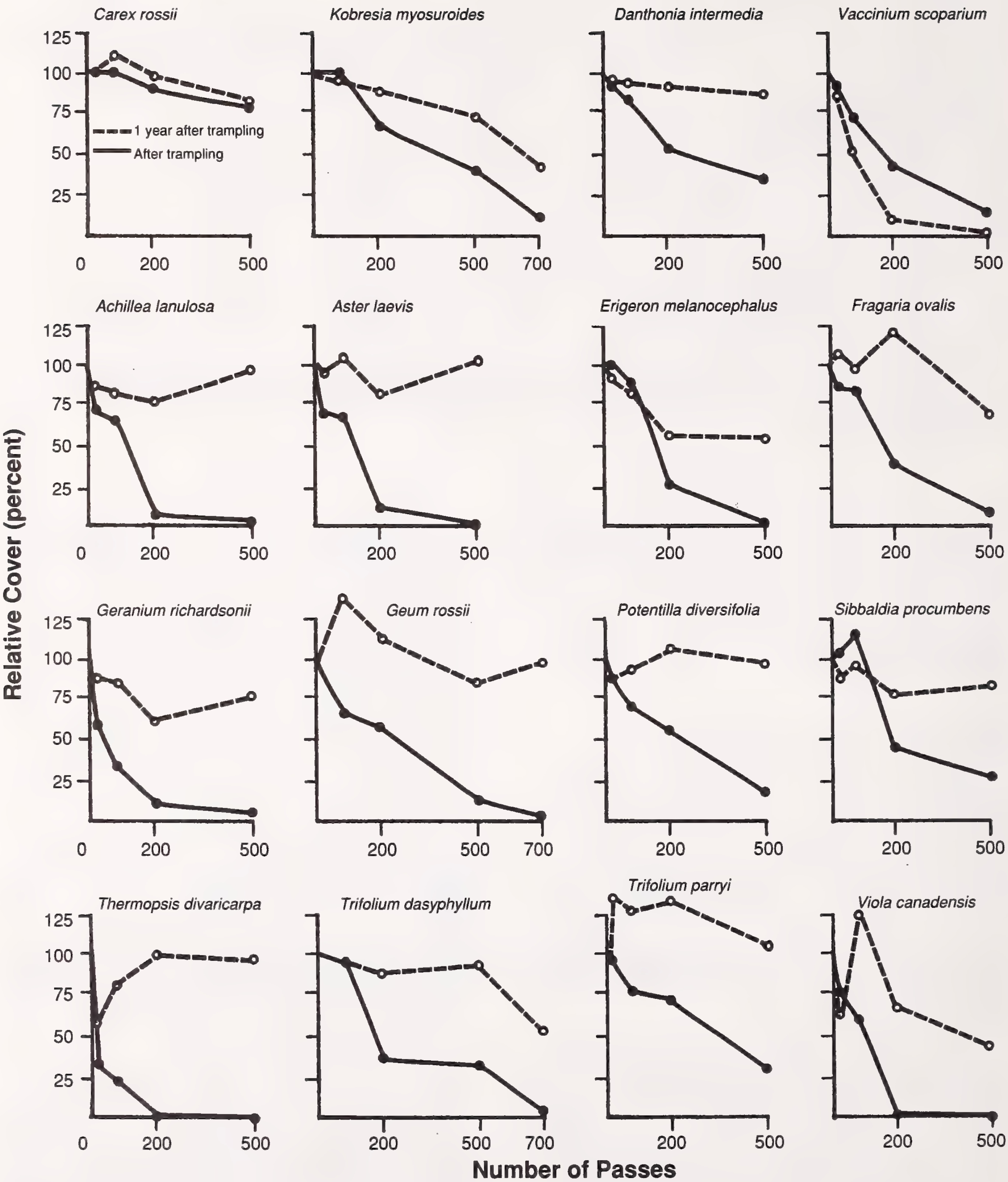

Figure 15—Relative cover after trampling and after 1 year of recovery for abundant species in four vegetation types in Colorado's Rocky Mountains.

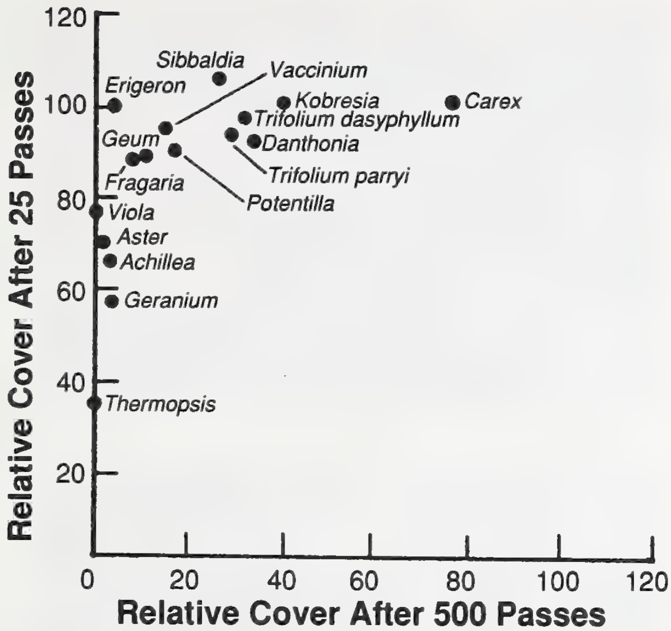

Figure 16—Relative cover after light and heavy trampling for abundant species in four vegetation types in Colorado's Rocky Mountains.

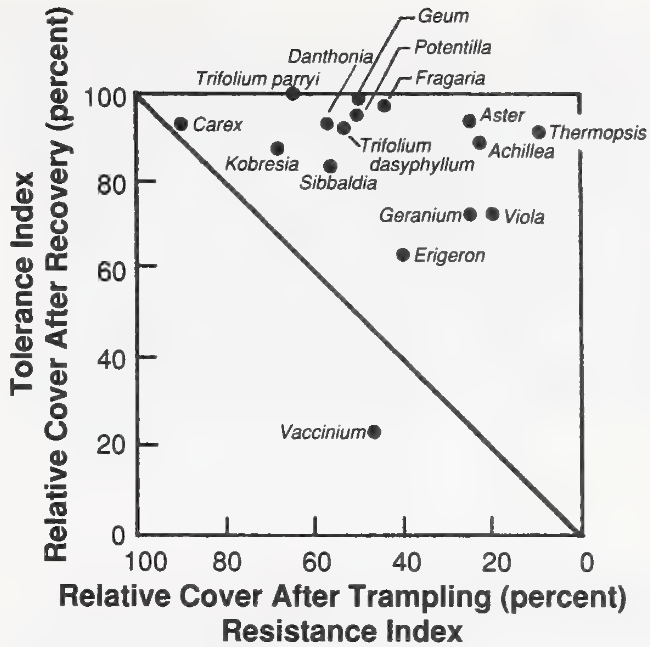

Figure 18—Resistance, tolerance, and resilience of abundant species in four vegetation types in Colorado's Rocky Mountains. Resilience is indicated by the perpendicular distance from the diagonal line of equal resistance and tolerance.

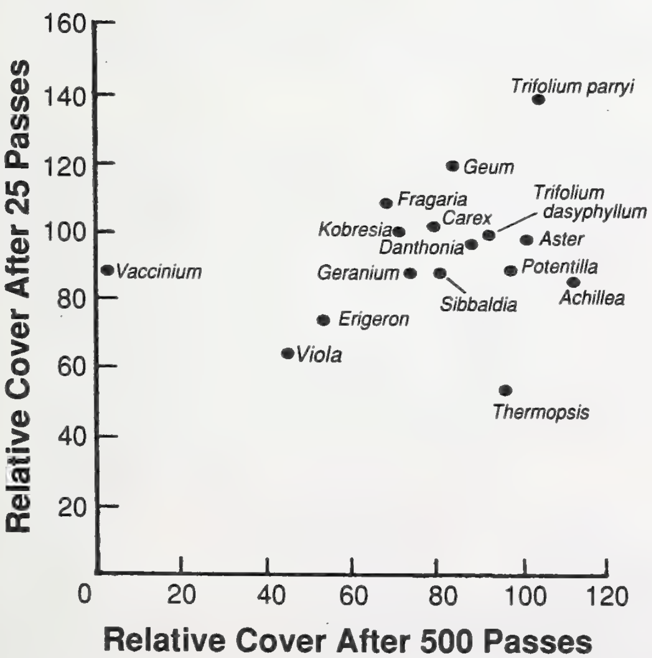

Figure 17—Relative cover 1 year after light and heavy trampling for abundant species in four vegetation types in Colorado's Rocky Mountains.

EFFECTS OF TRAMPLING IN THE WHITE MOUNTAINS

The study sites in the Northeast were all located in the White Mountain National Forest in northern New Hampshire. The sites were along the eastern flank and summit of the Presidential Range, near the Great Gulf Wilderness. Two sites were in northern hardwood forests at low elevations (450 m) close to the West Branch of the Peabody River. On one site, soils appeared to be saturated with water throughout the year. Overstory trees were moderately dense (70 percent cover) and diverse, with *Betula lutea* (yellow birch) and *Acer rubrum* (red maple) most abundant. The ground cover was tall, dense, and diverse (fig. 19A). The most abundant species were *Leersia oryzoides* (cutgrass), *Viola pallens* (northern white violet), and *Onoclea sensibilis* (sensitive fern). This vegetation type was not widely distributed, but appeared to be representative of poorly drained sites in hardwood forests.

The other low-elevation site was well drained most of the year, although it was flooded seasonally by the Peabody River. Both low-elevation sites had been logged 75 to 100 years ago. The tree canopy was dense (85 percent cover) and diverse. Conifers (red spruce—*Picea rubens*, balsam fir—*Abies balsamea*,

Table 13—Relative resistance, resilience, and tolerance of species in Colorado's Rocky Mountains

Species	Resistance[1]	Resilience[2]	Tolerance[3]
Shrubs			
Vaccinium scoparium (3)[4]	m	l	l
Graminoids			
Bromopsis porteri (4)	m	m	m
Carex norvegica (4)	m	h	h
Carex microptera (2)	h	m	m
Carex phaeocephala (1)	m	m	m
Carex rossii (3)	h	—	h
Danthonia intermedia (1)	h	h	h
Deschampsia caespitosa (1)	h	h	h
Kobresia myosuroides (2)	h	m	h
Poa pratensis (4)	m	h	h
Forbs			
Achillea lanulosa (4)	m	h	h
Antennaria alpina (1)	m	m	m
Aquilegia caerulea (4)	l	h	h
Arnica cordifolia (4)	l	m	l
Artemisia scopulorum (1)	m	m	m
Aster laevis (4)	m	h	h
Erigeron melanocephalus (1)	m	l	l
Erigeron peregrinus (3)	m	l	l
Erigeron simplex (2)	l	m	m
Fragaria ovalis (4)	m	h	h
Galium boreale (4)	l	h	h
Geranium richardsonii (4)	l	m	l
Geum rossii (2)	h	h	h
Hieracium gracile (3)	m	l	l
Pedicularis bracteata (3)	l	l	l
Pedicularis racemosa (3)	m	l	l
Polygonum bistortoides (1)	—	h	h
Polygonum vivipara (2)	m	m	m
Potentilla diversifolia (1)	m	h	h
Sibbaldia procumbens (1,3)	m	m-h	m-h
Taraxacum officinale (4)	m	h	h
Thermopsis divaricarpa (4)	l	h	h
Thalictrum fendleri (4)	l	l	l
Trifolium dasyphyllum (2)	m	h	h
Trifolium parryi (1)	h	h	h
Viola canadensis (4)	m	h	h
Other			
Lichens (1,2,3)	l-m	l-m	l-m
Mosses (1,2)	h	m-h	m-h

[1]Resistance classes are based on the minimum number of passes that reduced cover by 50 percent: h ≥ 500 passes; m = 200 passes; l ≤ 75 passes.

[2]Resilience classes are based on recovery after cover was reduced nearly to zero: h = cover 1 year after trampling was more than two-thirds of the original cover; m = cover 1 year after trampling was between one-third and two-thirds of original cover; l = cover 1 year after trampling was less than one-third of original cover.

[3]Tolerance classes are based on the maximum number of passes that could be tolerated and still have at least 75 percent of original cover 1 year after trampling: h ≥ 500 passes; m = 200 passes; l ≤ 75 passes.

[4]Vegetation types: 1 = *Trifolium parryi*; 2 = *Kobresia myosuroides*; 3 = *Vaccinium scoparium*; 4 = *Geranium richardsonii*.

Figure 19—Vegetation types in New Hampshire's White Mountains are (A) *Leersia*, (B) *Maianthemum*, (C) *Lycopodium*, and (D) *Carex*.

and eastern hemlock—*Tsuga canadensis*) were more common than on the poorly drained site, but a diverse mix of hardwoods was still present. The ground cover was shorter, less dense, and less diverse than on the poorly drained site (fig. 19B). The most abundant ground cover species were *Maianthemum canadensis* (Canada mayflower), *Dryopteris spinulosa* var. *americana* (wood fern), and *Oxalis montana* (wood sorrel). This association of understory species is typical of much of the low-elevation hardwood forest in the White Mountains (Siccama and others 1970).

The third site was located at higher elevations (1,050 m) on the eastern slopes of Mount Washington in the spruce-fir zone. The overstory was relatively open for this forest type (70 percent cover), allowing the development of a moderately dense ground cover layer. Both *Abies balsamea* and *Picea rubens* were abundant in the overstory. *Pyrus americana* (mountain ash) and *Betula papyrifera* (paper birch) were the only hardwood species. They were less abundant than the conifers. The ground cover flora were not very diverse; *Lycopodium lucidulum* (shining clubmoss), *Oxalis montana*, and *Dryopteris spinulosa* were the most abundant species (fig. 19C). This assemblage of species is typical and widespread in the spruce-fir zone of the White Mountains (Oosting and Billings 1951; Reiners and Lang 1979).

The final site was located above tree line at an elevation of about 1,600 m. It was on the Monticello Lawn, a sedge meadow with small amounts of dwarf-shrub heath located near the southern base of the Mount Jefferson summit cone. Trees were absent, although krummholz (stunted, deformed trees near timberline) was found in the vicinity. Ground cover was dense and of moderate height (fig. 19D); diversity was low, given the dominance of *Carex bigelowii* (Bigelow sedge). Study sites were in vegetation that was intermediate between the sedge meadow and sedge-dwarf-shrub heath plant communities described in the Presidential Range by Bliss (1963). The meadow affinities were more pronounced than the heath affinities.

In sum, the vegetation types in the White Mountains included one type dominated by graminoids (*Carex*), two types dominated by forbs and ferns (*Leersia* and *Maianthemum*), and one type dominated by clubmosses, forbs, and ferns (*Lycopodium*). One type was above timberline; one type was in subalpine spruce-fir forest; and two types were in lower elevation hardwood forests. A list of the most abundant species can be found in the appendix. Nomenclature follows

Table 14—Percent bare ground before and after trampling and after 1 year of recovery for four vegetation types in New Hampshire's White Mountains[1]

	Number of passes				
	0	25	75	200	500
Carex bigelowii (alpine meadow)					
Before trampling	6 (3)[2]	5 (2)	6 (3)	9 (5)	1 (1)
After trampling	7 (4)	5 (2)	8 (4)	31 (8)	68 (10)
After 1 year	1 (1)	8 (4)	9 (4)	25 (3)	58 (11)
Leersia oryzoides (hardwood forest)					
Before trampling	9 (6)	3 (1)	2 (1)	2 (1)	2 (1)
After trampling	5 (2)	14 (7)	55 (9)	86 (7)	95 (3)
After 1 year	18 (9)	24 (4)	17 (6)	46 (11)	74 (5)
Lycopodium lucidulum (subalpine forest)					
Before trampling	9 (1)	12 (4)	9 (3)	5 (1)	8 (4)
After trampling	10 (3)	35 (5)	48 (8)	71 (11)	93 (5)
After 1 year	11 (3)	35 (3)	46 (10)	44 (8)	71 (7)
Maianthemum canadensis (hardwood forest)					
Before trampling	18 (7)	17 (4)	14 (3)	14 (4)	14 (4)
After trampling	21 (8)	49 (6)	80 (5)	96 (2)	100 (+)
After 1 year	18 (3)	25 (3)	33 (7)	49 (10)	36 (4)

[1]Percent bare ground is the mean proportion of each quadrat that is not vegetated.
[2]Standard errors are in parentheses. A + indicates standard error less than 0.5 percent.

Gleason and Cronquist (1963), with a few exceptions (such as *Dryopteris spinulosa*, which they call *D. austriaca*, and *Oxalis montana*, which they call *O. acetosella*.

Bare Ground and Vegetation Cover

Before trampling, three of the four vegetation types had dense ground cover, with mean bare ground less than 10 percent. The *Maianthemum* type had mean bare ground of 15 percent (table 14). Even light trampling substantially increased bare ground in three of the four vegetation types. Heavy trampling (500 passes) removed virtually all vegetation in these three types and about two-thirds of the vegetation in the *Carex* type. Bare ground generally decreased during the year following trampling, but did not return to the original levels on any of the treated lanes.

Relative vegetation cover after trampling differed significantly both with amount of trampling and with vegetation type (table 15). The interaction between these two effects was not significant. After the year of recovery, differences between trampling levels and vegetation types were still highly significant. In this case, the interaction was significant and substantial. The effect of trampling on *Maianthemum* was substantially less pronounced 1 year after trampling than it was on the other types.

Table 15—Analysis of variance and multiple comparisons for relative cover after trampling and after 1 year of recovery in New Hampshire's White Mountains

	After trampling			After 1 year		
Source	df	F	*p*	df	F	*p*
Number of passes	3	47.5	0.0001	3	27.0	0.0001
Vegetation type	3	20.1	.0001	3	7.2	.0003
Interaction	9	.9	.49	9	2.9	.006
	Significantly different treatments					
Number of passes	25>75>200>500			25,75>200>500		
Vegetation types[1]	C>Ly,Le,M			M,C,Le>Ly		

[1]Vegetation types: C = *Carex*, Ly = *Lycopodium*, Le = *Leersia*, M = *Maianthemum*.

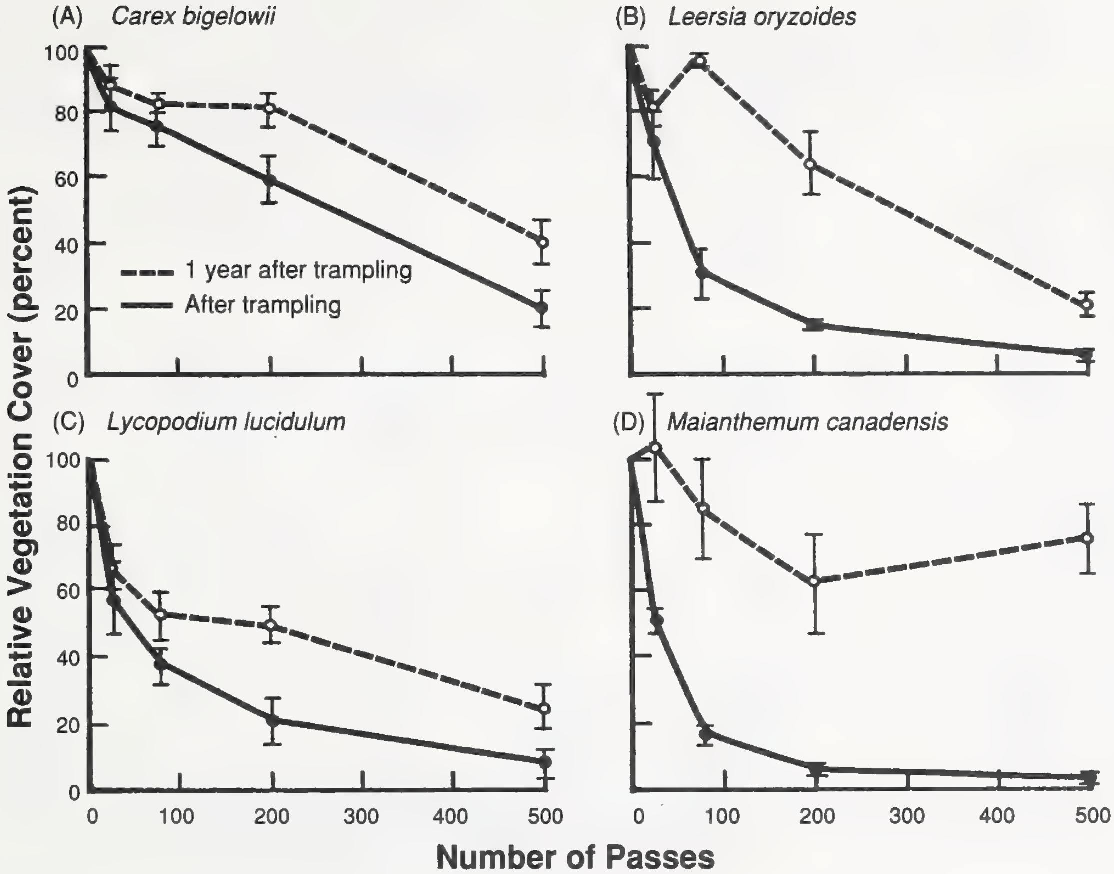

Figure 20—Relative vegetation cover after trampling and after 1 year of recovery in four vegetation types in New Hampshire's White Mountains. Vertical bars represent 1 standard error above and below the mean.

Of the four vegetation types, the three types with abundant ferns and forbs—*Leersia*, *Lycopodium*, and *Maianthemum*—lost cover rapidly (fig. 20); their differences in relative cover after trampling were not statistically significant. In all three types, relative cover was less than 40 percent after 75 passes and less than 10 percent after 500 passes. In contrast, the graminoid-dominated *Carex* turf had a relative cover of 76 percent after 75 passes and 20 percent after 500 passes.

During the year after trampling, relative cover increased on all trampling treatments in all types. The increase was greatest in *Maianthemum*, the type that lost the most cover initially. In the *Leersia* type, cover also increased substantially; it increased more modestly in the *Lycopodium* and *Carex* types. One year after trampling, differences in relative cover among *Carex*, *Leersia*, and *Maianthemum* were not significant; all three had significantly more cover than *Lycopodium*. The relatively high tolerance of *Carex* came from its initial resistance to disturbance; the tolerance of *Leersia* and *Maianthemum* reflected their ability to recover following substantial disturbance. *Lycopodium* was neither resistant nor resilient.

Vegetation Height

Before trampling, the ground cover was tallest in the *Leersia* type (mean height of 31 cm, table 16). Heights were moderate in the other three types (means of 10 to 15 cm). Even low levels of trampling caused immediate, substantial reductions in vegetation height. The most dramatic was in the tall vegetation of the *Leersia* type, 35 cm before 25 passes, reduced to just 3 cm afterward. Relative height differed significantly both with the amount of trampling and with the vegetation type. The interaction between these effects was not significant (table 17). Differences were generally more pronounced after trampling than after the year of recovery. After recovery, only the 500-pass lane was different from the others. The only significant difference between vegetation types was that relative height was less in *Lycopodium* than in *Leersia* and *Maianthemum*.

Initially, height reduction was most pronounced in *Leersia* and least pronounced in *Carex* and *Lycopodium* (fig. 21). In *Leersia*, the relative height was 9 percent after 25 passes and 1 percent after 500 passes. In *Carex* and *Lycopodium*, the relative height was about

Table 16—Mean vegetation height (cm) before and after trampling and after 1 year of recovery for four vegetation types in New Hampshire's White Mountains

	Number of passes				
	0	25	75	200	500
Carex bigelowii (alpine meadow)					
Before trampling	16 (1)[1]	13 (2)	15 (2)	14 (1)	15 (2)
After trampling	16 (1)	6 (+)	5 (+)	3 (+)	2 (+)
After 1 year	18 (2)	12 (2)	12 (+)	9 (1)	8 (1)
Leersia oryzoides (hardwood forest)					
Before trampling	33 (3)	35 (1)	28 (4)	29 (3)	29 (3)
After trampling	33 (3)	3 (1)	2 (1)	1 (+)	+ (+)
After 1 year	19 (8)	16 (1)	16 (3)	14 (5)	5 (1)
Lycopodium lucidulum (subalpine forest)					
Before trampling	11 (2)	9 (1)	11 (2)	18 (6)	14 (3)
After trampling	11 (2)	4 (1)	4 (1)	5 (3)	1 (1)
After 1 year	12 (3)	6 (1)	6 (1)	10 (4)	5 (1)
Maianthemum canadensis (hardwood forest)					
Before trampling	11 (3)	10 (3)	8 (3)	10 (3)	13 (4)
After trampling	11 (3)	5 (3)	2 (+)	1 (+)	3 (2)
After 1 year	8 (1)	7 (1)	5 (1)	5 (1)	6 (1)

[1]Values in parentheses are one standard error. A + indicates mean height or standard error less than 0.5 cm.

50 percent after 25 passes and about 15 percent after 500 passes. During the year after trampling, height increased in all vegetation types. As was the case with cover, recovery was greatest in *Leersia* and *Maianthemum* and least in *Lycopodium*.

When comparing the rate of height reduction to the rate of cover loss, only *Carex* and *Leersia* showed substantial differences. In both of these types, height was reduced more rapidly than cover was lost. *Leersia* recovered more of its height after 1 year than *Carex*.

Species Richness and Composition

Species richness declined only on the most heavily trampled lanes and only on three of the four vegetation types (fig. 22). Even 500 passes did not significantly reduce species richness in the *Carex* type. Species richness declined significantly after 500 passes in the *Leersia* and *Lycopodium* types and after 200 passes in the *Maianthemum* type. One year after trampling, species richness was not significantly different from

Table 17—Analysis of variance and multiple comparisons for relative height after trampling and after 1 year of recovery in New Hampshire's White Mountains

Source	After trampling df	After trampling F	After trampling p	After 1 year df	After 1 year F	After 1 year p
Number of passes	3	17.2	0.0001	3	11.5	0.0001
Vegetation type	3	18.5	.0001	3	4.2	.009
Interaction	9	.5	.90	9	1.0	.48
	Significantly different treatments					
Number of passes	25>200,500; 75,200>500			25,75,200>500		
Vegetation types[1]	C,Ly>M>Le			Le,M>Ly		

[1]Vegetation types: C = *Carex*, Ly = *Lycopodium*, M = *Maianthemum*, Le = *Leersia*.

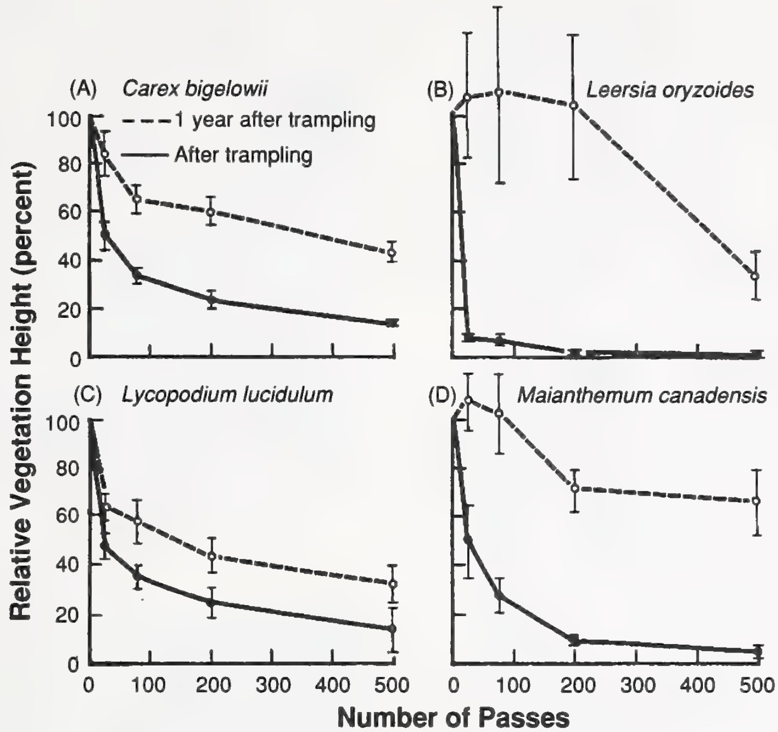

Figure 21—Relative vegetation height after trampling and after 1 year of recovery in four vegetation types in New Hampshire's White Mountains. Vertical bars represent 1 standard error above and below the mean.

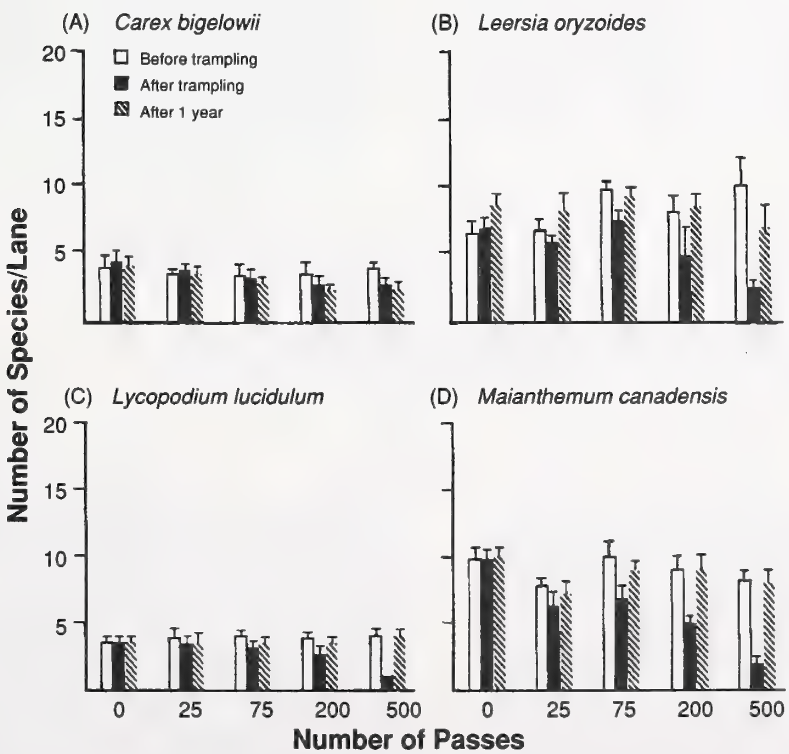

Figure 22—Species richness before and after trampling and after 1 year of recovery in four vegetation types in New Hampshire's White Mountains. Vertical bars represent 1 standard error above the mean.

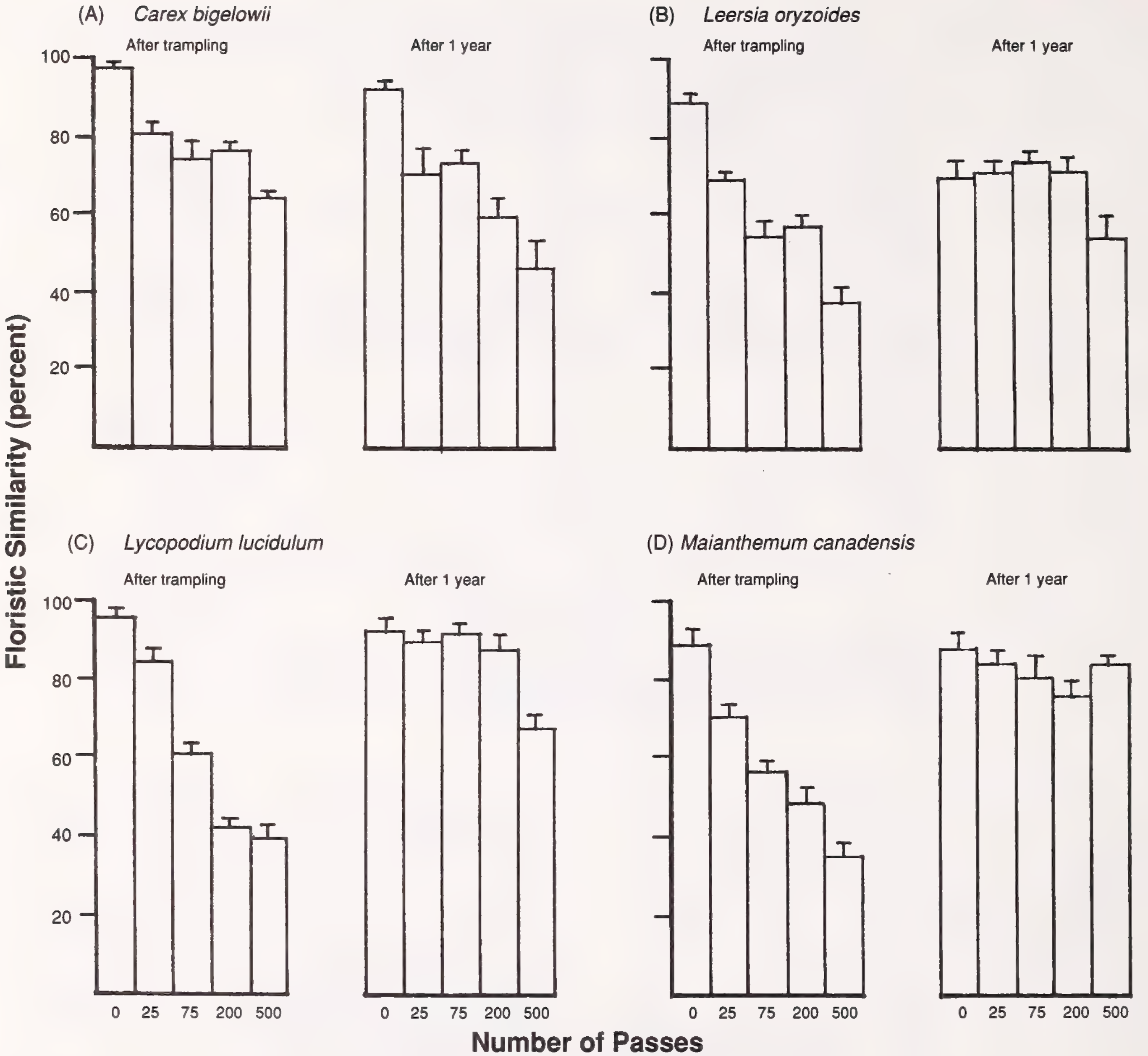

Figure 23—Floristic similarity, comparing composition before and after disturbance, in four vegetation types in New Hampshire's White Mountains. Vertical bars represent 1 standard error above the mean.

the original levels on any of the lanes in any of the types. The means were somewhat lower on heavily trampled lanes in *Carex* and *Leersia*, but standard errors were large.

Species composition changed rapidly in all four of these vegetation types (fig. 23). Significant changes occurred after 25 passes in *Carex*, *Leersia*, and *Maianthemum* and after 75 passes in *Lycopodium*. Floristic similarity values, immediately after trampling, were below 40 percent for the 500-pass lanes in all types but *Carex*. In *Leersia* and *Maianthemum*, composition 1 year after trampling was similar to that before trampling on all lanes. In *Lycopodium*, only the 500-pass lanes were significantly different 1 year after trampling. However, in *Carex*, all of the trampled lanes remained significantly different from their original composition. In fact, composition became more dissimilar over the year of recovery. This was the result of pronounced recovery of *Carex bigelowii*, while few of the subordinate species recovered as quickly.

General Appearance

Obvious changes occurred rapidly in the three forested vegetation types with substantial quantities of forbs and ferns—*Leersia*, *Lycopodium*, and *Maianthemum*. In each of these types, much of the vegetation was flattened after 25 passes and a path was apparent after 75 passes. After 200 passes, most of the vegetation was gone. In *Carex*, a path was evident only after at least 200 passes. After the year of recovery, only the 500-pass lanes in *Lycopodium* had paths that would have been obvious to the casual observer. However, more subtle evidence of disturbance—flattening, discoloration, or churned soil—remained on the 500-pass lanes in *Carex* and *Maianthemum*, the 200- and 500-pass lanes in *Leersia*, and the 75-, 200-, and 500-pass lanes in *Lycopodium*.

Summary Indicators

Compared with the Washington and Colorado study areas, differences between these four vegetation types were relatively small. The type most able to resist trampling disturbance was the graminoid-dominated *Carex* alpine turf. It resisted the measured changes better than all other types, with the exception of *Lycopodium*, which was better able to resist changes in species composition (table 18). Even though species composition changed significantly after just 25 passes, similarity values on 500-pass lanes exceeded 60 percent. The three other types—all forested with various combinations of forbs, ferns, and graminoids—did not differ much in their resistance. *Lycopodium* was the most resistant, particularly with respect to height reduction and change in species composition. *Leersia* was particularly vulnerable to height reduction, while *Maianthemum* was particularly vulnerable to cover loss and decline in species richness.

During the year that followed trampling, recovery was pronounced in *Leersia* and *Maianthemum* and modest in *Carex* and *Lycopodium*. One year after trampling, relative cover was greatest in *Maianthemum* and relative height was generally greatest in *Leersia*. The type with the most pronounced impact 1 year after trampling was *Lycopodium*.

Individual Species Responses

Relative cover could be calculated for nine vascular species and for mosses and lichens (fig. 24). The most resistant vascular species were *Carex bigelowii* and *Lycopodium lucidulum*. For these species relative cover exceeded 50 percent on lanes trampled 200 times or less. The mosses appeared to be even more resistant initially. Relative cover exceeded 50 percent even on the 500-pass lanes; however, relative cover was so much lower 1 year later that cover surviving trampling may have been overestimated. The least resistant species was *Aster acuminatus* (wood aster), which had a relative cover of 31 percent after 25 passes and was virtually eliminated after 200 passes.

Most species recovered over the year following trampling, although the amount of recovery varied. For example, *Rubus pubescens* (dwarf blackberry) cover approximated original levels even though heavy trampling had reduced cover to zero. In contrast, *Oxalis montana* cover was only 18 percent 1 year after 500 passes. Cover of mosses, lichens, and *Lycopodium lucidulum* decreased over the year following trampling.

Table 18—Summary indicators of resistance and tolerance for four vegetation types in New Hampshire's White Mountains

	Vegetation type			
	Carex	*Leersia*	*Lycopodium*	*Maianthemum*
Resistance indicators[1]				
Relative cover (percent)	53	21	24	12
Relative height (percent)	27	6	26	17
Species richness (number of passes)	>500	500	500	200
Species composition (number of passes)	25	25	75	25
Evident path (number of passes)	200	75	75	75
Tolerance indicators[2]				
Relative cover (percent)	70	59	45	74
Relative height (percent)	60	82	46	79
Species richness (number of passes)	>500	>500	>500	>500
Species composition (number of passes)	25	>500	500	>500
Evident path (number of passes)	>500	>500	500	>500

[1]Resistance indicators refer to immediate responses to trampling. They include mean relative cover and relative height, after trampling, for 0 to 500 passes, as well as the minimum number of passes that causes a significant reduction in species richness or floristic similarity, or that results in an evident path. The relative cover and relative height values are the durability indices described in the data analysis section.

[2]Tolerance indicators refer to conditions 1 year after trampling.

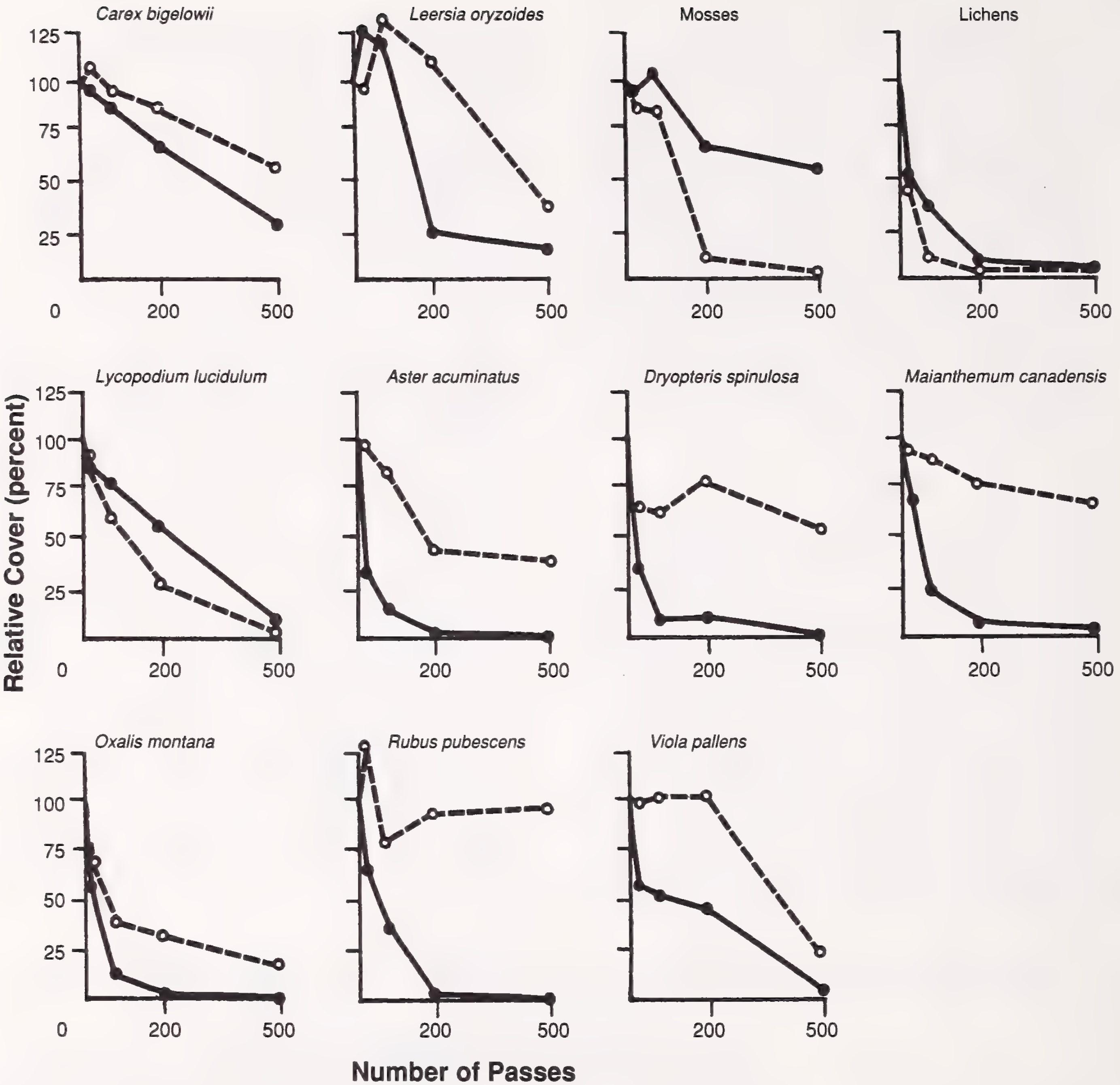

Figure 24—Relative cover after trampling and after 1 year of recovery for abundant species in four vegetation types in New Hampshire's White Mountains.

A plot of response to light and heavy trampling (fig. 25) shows a distribution similar to that of other study areas. The broad-leaved herbaceous species, ferns, and lichens varied only in their ability to resist light trampling; heavy trampling eliminated them. *Lycopodium lucidulum*, the graminoids, and the mosses all withstood light trampling, but varied in their ability to withstand heavy trampling.

The plot of relative cover after the year of recovery (fig. 26) also shows a pattern similar to other areas. In the White Mountains, however, fewer species recovered from heavy trampling within 1 year. Those least capable of tolerating trampling were the lichens, mosses (those found in the *Carex* type), *Lycopodium lucidulum*, and *Oxalis montana*. The most tolerant species was *Rubus pubescens*.

The plot of resistance and tolerance index values illustrates the wide range of responses to trampling disturbance (fig. 27). At one extreme was the stoloniferous (spreading by horizontal stems) graminoid,

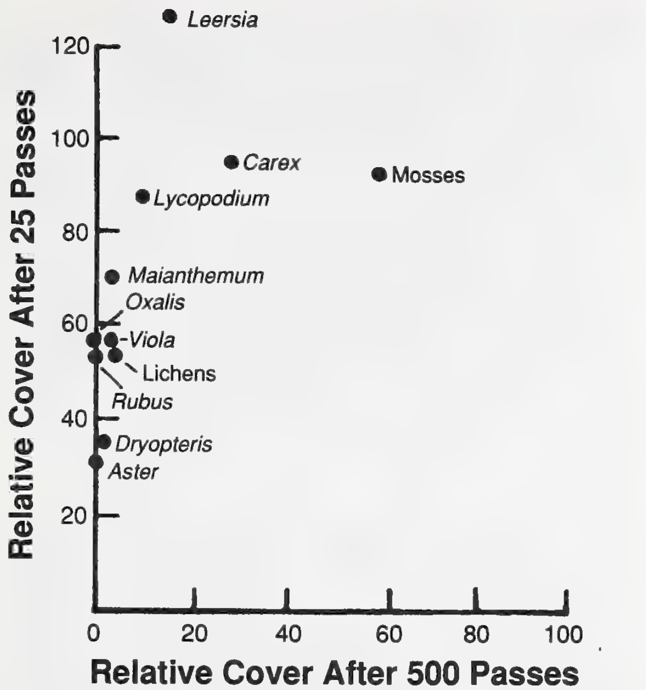

Figure 25—Relative cover after light and heavy trampling for abundant species in four vegetation types in New Hampshire's White Mountains.

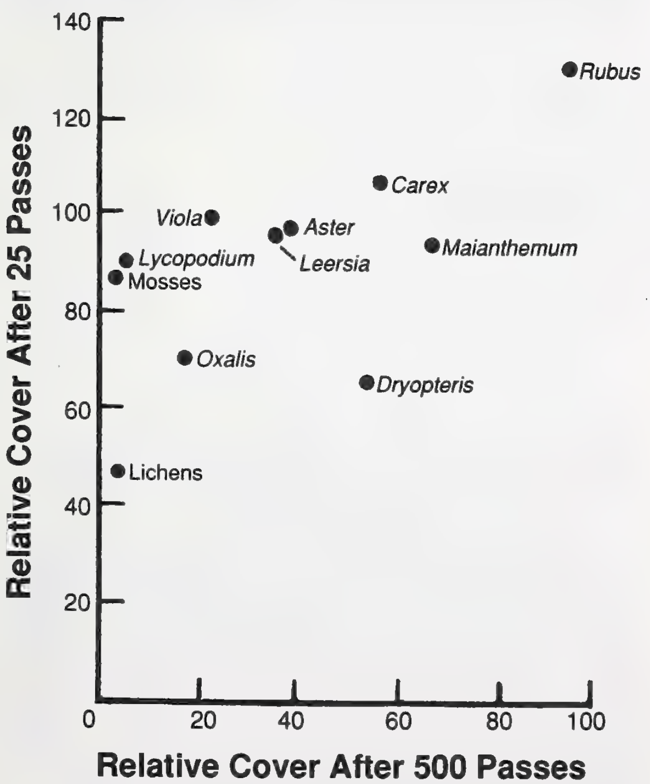

Figure 26—Relative cover 1 year after light and heavy trampling for abundant species in four vegetation types in New Hampshire's White Mountains.

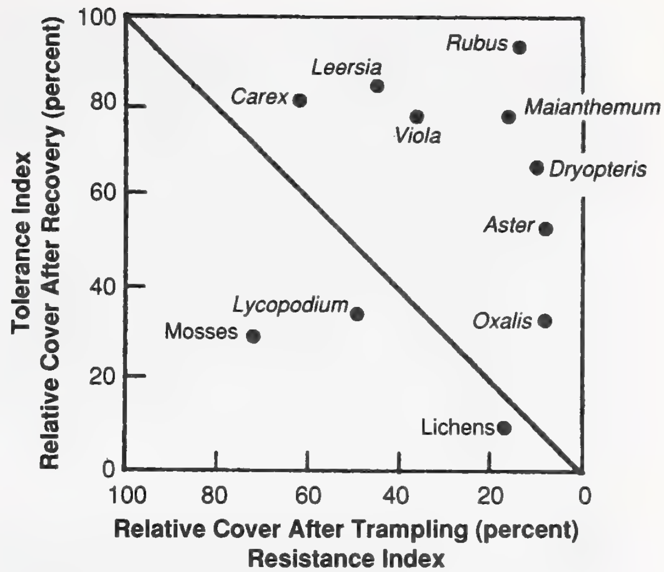

Figure 27—Resistance, tolerance, and resilience of abundant species in four vegetation types in New Hampshire's White Mountains. Resilience is indicated by the perpendicular distance from the diagonal line of equal resistance and tolerance.

Carex bigelowii. It was quite resistant to trampling and moderately resilient; therefore, its tolerance was moderately high. It responded similarly during trampling experiments in Scotland (Bayfield 1979). A variety of erect, herbaceous plants had low resistance and moderate to high resilience and tolerance. These included a fern (*Dryopteris spinulosa*) and three forbs (*Rubus pubescens*, *Maianthemum canadensis*, and *Aster acuminatus*). The mosses and lichens, found in the *Carex* type, and *Lycopodium lucidulum* all had low resilience and tolerance, although the mosses and *Lycopodium* were quite resistant initially. The responses of *Leersia oryzoides* and *Viola pallens* were intermediate between the *Carex* and the erect forbs. *Oxalis montana* was intermediate between the erect forbs and the plants with low resilence.

Table 19 classifies the responses of less common species as low, moderate, or high. As elsewhere, the shrub (*Vaccinium uliginosum* or bog bilberry) had moderate resistance, but low resilience and tolerance. The clubmoss (*Lycopodium*) also had relatively high resistance, but low resilience and tolerance. Like shrubs, clubmosses are chamaephytes with perennating tissues located above ground. This characteristic generally appears to be associated with low resilience and tolerance. Graminoids had moderate to high resistance and moderate resilience and tolerance. Ferns had low resistance and moderate resilience and tolerance. The forbs generally had low resistance. However, resilience and tolerance varied from low to

Table 19—Relative resistance, resilience, and tolerance of species in New Hampshire's White Mountains

Species	Resistance[1]	Resilience[2]	Tolerance[3]
Shrubs			
Vaccinium uliginosum (1)[4]	m	l	l
Graminoids			
Carex bigelowii (1)	h	m	m
Carex crinita (2)	m	m	m
Leersia oryzoides (2)	m	m	m
Ferns			
Dryopteris spinulosa (3,4)	l	m	m
Gymnocarpium dryopteris (4)	l	m	m
Onoclea sensibilis (2)	l	m	m
Forbs			
Aralia nudicaulis (4)	l	l	l
Arenaria groenlandica (1)	l	l	l
Aster acuminatus (2,3,4)	l	l-m	l-m
Impatiens pallida (2)	l	m	m
Maianthemum canadensis (2,4)	l	m	m
Oxalis montana (2,3,4)	l	l	l
Rubus pubescens (2)	l	h	h
Trientalis borealis (4)	l	m	l
Viola pallens (2)	m	m	m
Other			
Abies balsamea seedling (3,4)	m	l	l
Acer rubrum seedling (4)	l	l	l
Acer saccharum seedling (2)	l	l	l
Lycopodium lucidulum (3,4)	h	l	l
Mosses (1,2,4)	h	l-h	l-h
Lichens (1)	l	l	l

[1]Resistance classes are based on the minimum number of passes that reduced cover by 50 percent: h ≥ 500 passes; m = 200 passes; l ≤ 75 passes.

[2]Resilience classes are based on recovery after cover was reduced nearly to zero: h = cover 1 year after trampling was more than two-thirds of the original cover; m = cover 1 year after trampling was between one-third and two-thirds of original cover; l = cover 1 year after trampling was less than one-third of original cover.

[3]Tolerance classes are based on the maximum number of passes that could be tolerated and still have at least 75 percent of original cover 1 year after trampling: h ≥ 500 passes; m = 200 passes; l ≤ 75 passes.

[4]Vegetation types: 1 = *Carex bigelowii*; 2 = *Leersia oryzoides*; 3 = *Lycopodium lucidulum*; 4 = *Maianthemum canadensis*.

high. The maple seedlings had low resistance, while the fir seedlings had moderate resistance; all had low resilience and tolerance. Lichens had low resistance, resilience, and tolerance. Mosses were highly resistant in all three vegetation types, but resilience and tolerance were low in the *Carex* type and high in the others. The resilience of mosses has generally been found to be moderate to extremely high—both in other areas in this study and elsewhere (Leonard and others 1984; Studlar 1983). The low resilience of the mosses (primarily *Polytrichum juniperum*) in the alpine *Carex* type was unusual. Bayfield (1979) also found variable rates of recovery among mosses, sometimes even for the same species, following trampling of alpine plant communities in Scotland.

EFFECTS OF TRAMPLING IN THE GREAT SMOKY MOUNTAINS

The study sites in the Southeast were all located along the crest and southeastern flank of the Great Smoky Mountains, within the portion of Great Smoky Mountains National Park in North Carolina. Two sites were at relatively low elevations (about 700 m) near Smokemont Campground. One site was along the Oconoluftee River in an undisturbed cove hardwood forest. The overstory was dense (90 percent cover) and diverse. *Liriodendron tulipifera* (yellow-poplar) was the most abundant species in the overstory. The ground cover layer was moderate in height, density, and diversity (fig. 28A). The most abundant species

Figure 28—Vegetation types in North Carolina's Great Smoky Mountains are (A) *Amphicarpa*, (B) *Potentilla*, (C) *Carex*, and (D) *Dryopteris*.

were forbs—*Amphicarpa bracteata* (hog-peanut), *Phlox stolonifera* (creeping phlox), and *Thaspium trifoliata* (meadow parsnip).

The other low-elevation site was along the Bradley Fork of the Oconoluftee River in an area that was recovering from farming. Tree species were slowly filling in the old field. Canopy coverage was typically about 25 percent. *Liriodendron tulipifera* was the most abundant of the six tree species. The ground cover was relatively tall, dense, and diverse; introduced species were common (fig. 28B). The most abundant species were *Potentilla simplex* (old-field cinquefoil), *Panicum boscii* (panicum grass), and *Holcus lanatus* (velvet grass).

The third site was at Bearpen Gap, elevation 1,375 m. Overstory cover was dense (95 percent) with high diversity of tree species. Deciduous species were dominant, particularly *Acer saccharum* (sugar maple), *Quercus rubra* (northern red oak), and *Fagus grandifolia* (beech), although there were a few scattered *Tsuga canadensis* as well. This overstory has affinities with both cove hardwood and gray beech forest (Whittaker 1956), which intergrade at elevations between 1,350 and 1,400 m. The ground cover was of moderate height, but sparse and low in diversity (fig. 28C). A sedge, *Carex pensylvanica*, was the only abundant species. This ground cover appears representative of the gray beech forest-*Carex* site type described by Whittaker (1956) and Crandall (1958).

The final site was along the crest of the mountains, near Clingman's Dome, at an elevation of 1,800 m. The overstory was a spruce-fir (*Abies fraseri-Picea rubens*) forest, but about 80 percent of the trees were dead. Most of the surviving trees were *Betula lutea* (yellow birch), providing about 30 percent coverage. The ground cover was tall and dense, but diversity was only moderate (fig. 28D). The most abundant species were *Dryopteris campyloptera* (mountain wood fern), *Athyrium asplenioides* (lady fern), and *Clintonia borealis* (bluebead lily). This composition fits the description of a moist phase of the spruce-fir/*Viburnum-Vaccinium-Dryopteris* site type described by Crandall (1958).

In sum, the vegetation types in the Smokies included one type dominated by graminoids (*Carex*), one type dominated by forbs (*Amphicarpa*), one type

Table 20—Percent bare ground before and after trampling and after 1 year of recovery for four vegetation types in North Carolina's Great Smoky Mountains[1]

	Number of passes				
	0	25	75	200	500
Carex pensylvanica (beech forest)					
Before trampling	50 (7)[2]	55 (6)	49 (5)	46 (6)	44 (2)
After trampling	48 (9)	59 (9)	66 (4)	76 (1)	88 (2)
After 1 year	43 (8)	54 (4)	51 (7)	60 (6)	66 (9)
Potentilla simplex (old-field)					
Before trampling	9 (4)	14 (4)	11 (3)	9 (3)	15 (3)
After trampling	8 (3)	26 (10)	39 (7)	66 (7)	88 (1)
After 1 year	11 (2)	10 (4)	8 (3)	6 (3)	28 (7)
Amphicarpa bracteata (cove hardwood forest)					
Before trampling	14 (3)	14 (3)	19 (4)	14 (1)	26 (7)
After trampling	14 (1)	41 (9)	74 (6)	88 (3)	94 (4)
After 1 year	18 (4)	26 (7)	44 (7)	45 (5)	69 (5)
Dryopteris campyloptera (subalpine forest)					
Before trampling	5 (2)	5 (3)	4 (2)	3 (2)	3 (1)
After trampling	2 (1)	64 (9)	88 (5)	93 (1)	99 (1)
After 1 year	2 (1)	2 (1)	16 (6)	20 (9)	27 (9)

[1]Percent bare ground is the mean proportion of each quadrat that is not vegetated.
[2]Standard errors are in parentheses.

dominated by ferns (*Dryopteris*), and one type codominated by forbs and graminoids (*Potentilla*). In contrast to the other regions, no types occurred above tree line. One type was in subalpine forest, two types were in low-elevation forest, and one type was a low-elevation, partially forested type. A list of the most abundant species can be found in the appendix. Nomenclature follows Radford and others (1968).

Bare Ground and Vegetation Cover

Before trampling, the *Dryopteris* type (subalpine forest) was densely vegetated (mean bare ground of 4 percent). The *Carex* type (beech forest) was sparsely vegetated (mean bare ground of 49 percent), while the *Potentilla* type (old-field) and *Amphicarpa* type (cove hardwood forest) were intermediate in cover (mean bare ground of 12 and 17 percent, respectively). Trampling exposed substantial amounts of bare ground on all vegetation types (table 20). In the densely vegetated *Dryopteris* type, for example, bare ground was 64 percent after 25 passes, 88 percent after 75 passes, and 99 percent after 500 passes. The 500-pass lanes were nearly barren in all four vegetation types.

During the year following trampling, vegetation cover increased on all of the trampled lanes. However, few of the trampled lanes approached original conditions in three of the four types. In *Amphicarpa* and *Dryopteris*, only the 25-pass lanes were similar to original conditions. In *Carex*, the 25-pass and 75-pass lanes approached original conditions. In *Potentilla*, all lanes except the 500-pass lanes approached original conditions.

Relative cover after trampling differed significantly with the amount of trampling and with the vegetation type. The interaction between these effects was not significant (table 21). After the year of recovery, differences between trampling levels and vegetation types were still significant. However, the difference was not as great and fewer differences were significant. The interaction was still not significant. Relative cover after the year of recovery was higher in *Dryopteris* than in *Amphicarpa*. This was the only significant difference among vegetation types.

Of the four vegetation types, the fern- and forb-dominated *Dryopteris* type lost the most vegetation cover (fig. 29). Relative cover decreased to 33 percent after just 25 passes and to 4 percent after 200 passes. The graminoid-dominated *Carex* type was the most resistant. The relative cover after 25 passes was not significantly different from the cover on control lanes, decreasing to 45 percent after 200 passes. The forb-dominated *Potentilla* and *Amphicarpa* types had similar responses that were intermediate. Relative cover after 25 passes was 63 and 45 percent, respectively; after 200 passes it was 15 and 12 percent. Differences

Table 21—Analysis of variance and multiple comparisons for relative cover after trampling and after 1 year of recovery in North Carolina's Great Smoky Mountains

Source	After trampling			After 1 year		
	df	F	p	df	F	p
Number of passes	3	90.0	0.0001	3	10.5	0.0001
Vegetation type	3	43.4	.0001	3	4.7	.005
Interaction	9	1.4	.19	9	0.8	.60
	Significantly different treatments					
Number of passes	25>75>200>500			25>200,500; 75>500		
Vegetation types[1]	C>A,P>D			D>A		

[1]Vegetation types: C = *Carex*, A = *Amphicarpa*, P = *Panicum*, D = *Dryopteris*.

between vegetation types were similar to those in New Hampshire and less pronounced than in Washington and Colorado.

One year after trampling, vegetation loss remained most pronounced in the *Amphicarpa* type. Relative cover was 50 percent on the 500-pass lanes and 71 percent on the 25-pass lanes. The only other lanes on which relative cover remained substantially reduced were the 200- and 500-pass lanes in *Carex*. All other lanes had relative cover of 70 percent or more. Although relative cover was greatest in the *Dryopteris* type, this measure of recovery is misleading. Much of the increase in cover came from the fronds of ferns rooted outside of the trampling lanes leaning over the lanes. A visual assessment after the year of recovery would suggest that damage was least in the *Potentilla* type.

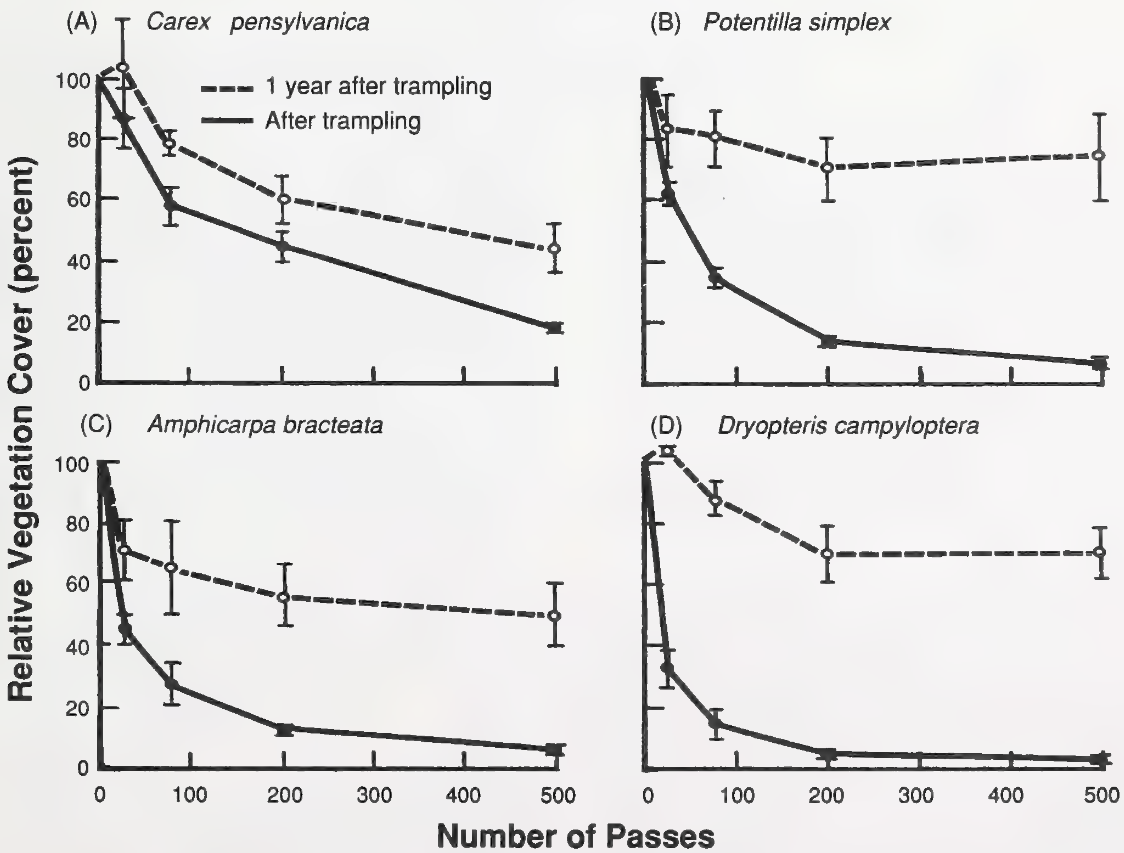

Figure 29—Relative vegetation cover after trampling and after 1 year of recovery in four vegetation types in North Carolina's Great Smoky Mountains. Vertical bars represent 1 standard error above and below the mean.

Table 22—Mean vegetation height (cm) before and after trampling and after 1 year of recovery for four vegetation types in North Carolina's Great Smoky Mountains

	Number of passes				
	0	25	75	200	500
Carex pensylvanica (beech forest)					
Before trampling	15 (1)[1]	14 (1)	16 (1)	15 (1)	16 (1)
After trampling	14 (1)	4 (1)	2 (+)	1 (+)	1 (+)
After 1 year	14 (1)	12 (1)	12 (1)	11 (+)	12 (+)
Potentilla simplex (old-field)					
Before trampling	22 (3)	22 (5)	29 (3)	26 (6)	23 (2)
After trampling	21 (1)	5 (+)	3 (1)	1 (1)	+ (+)
After 1 year	20 (2)	17 (3)	24 (4)	18 (3)	14 (3)
Amphicarpa bracteata (cove hardwood forest)					
Before trampling	15 (2)	14 (2)	16 (3)	14 (2)	14 (1)
After trampling	15 (2)	3 (1)	1 (+)	1 (+)	+ (+)
After 1 year	14 (1)	13 (2)	10 (1)	8 (1)	8 (1)
Dryopteris campyloptera (subalpine forest)					
Before trampling	48 (6)	49 (4)	44 (7)	42 (8)	50 (6)
After trampling	49 (7)	3 (1)	2 (+)	1 (+)	+ (+)
After 1 year	46 (9)	36 (5)	36 (6)	29 (7)	28 (3)

[1]Values in parentheses are one standard error. A + indicates mean height or standard error less than 0.5 cm.

Vegetation Height

In comparison to other study areas, ground cover vegetation was relatively tall prior to trampling, particularly in the *Dryopteris* type (mean height of 47 cm). Vegetation in the *Potentilla* type was also tall (mean height of 24 cm), while height was moderate in the *Carex* and *Amphicarpa* types (mean of 15 cm). Trampling reduced vegetation height quickly and dramatically in all four types (table 22). Mean height was 5 cm or less after 25 passes and 1 cm or less after 200 passes in each of these types.

Relative height differed significantly with the amount of trampling and with the vegetation type. The interaction between these effects was not significant (table 23). These effects were still significant 1 year after trampling, but the differences decreased markedly. The only significant difference between trampling intensities was between the 25-pass lanes and all others. The only significant difference between vegetation types was that relative height was greater in *Potentilla* than *Amphicarpa*.

Even light trampling dramatically reduced the height of all four types (fig. 30). The height of *Dryopteris* was reduced more than the other types, which were not significantly different. For example, relative height after 25 passes was 30 percent in *Carex* and *Potentilla*, 22 percent in *Amphicarpa*, and 7 percent

Table 23—Analysis of variance and multiple comparisons for relative height after trampling and after 1 year of recovery in North Carolina's Great Smoky Mountains

Source	After trampling df	F	p	After 1 year df	F	p
Number of passes	3	67.1	0.0001	3	6.4	0.0007
Vegetation type	3	17.0	.0001	3	3.0	.04
Interaction	9	1.2	.30	9	1.2	.31
	Significantly different treatments					
Number of passes	25>75>200>500			25>75,200,500		
Vegetation types[1]	C,P,A>D			P>A		

[1]Vegetation types: C = *Carex*, P = *Panicum*, A = *Amphicarpa*, D = *Dryopteris*.

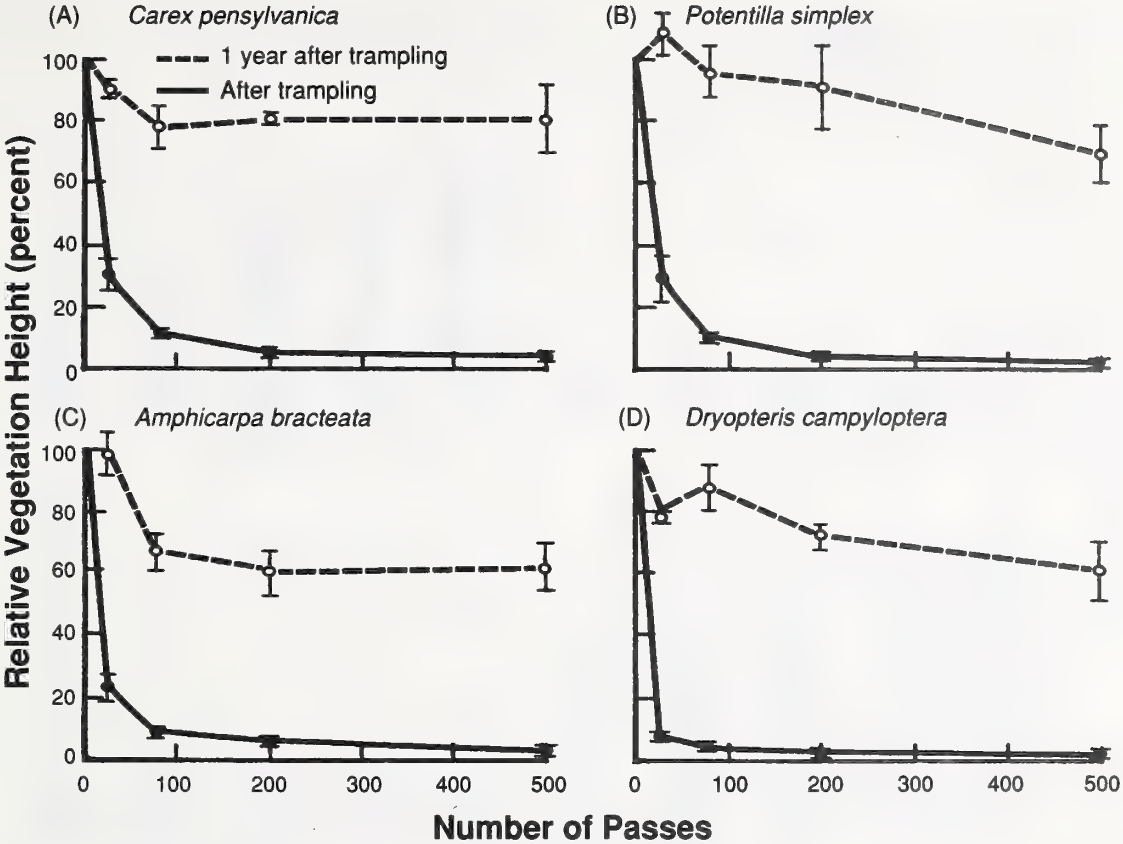

Figure 30—Relative vegetation height after trampling and after 1 year of recovery in four vegetation types in North Carolina's Great Smoky Mountains. Vertical bars represent 1 standard error above and below the mean.

in *Dryopteris*. After 200 passes, relative height was 1 percent in *Dryopteris* and 5 percent in the three other types. During the year after trampling, height recovered greatly in all four types. Compared with the other study areas, these vegetation types had very similar responses. They all experienced dramatic reductions in height and substantial recovery.

In all four vegetation types height was lost more quickly than cover. This difference was most pronounced in *Carex*. One year after trampling, however, height tended to be closer to original conditions than cover. Again, this difference was most pronounced in *Carex*. For example, after recovery on the 500-pass lanes, relative cover in *Carex* was 45 percent and relative height was 81 percent.

Species Richness and Composition

Species richness declined on all four vegetation types as trampling intensity increased (fig. 31). The response was most rapid on the *Carex* and *Amphicarpa* types, which had significant reductions on the 75-pass lanes. The other types first had significant reductions on the 200-pass lanes. In all four types, species richness was only 25 to 35 percent of original levels on the 500-pass lanes. One year after trampling, species richness approached or exceeded original levels on virtually all lanes and types. The only exception was the 500-pass lane in *Amphicarpa*, where richness 1 year after trampling was 80 percent of the original.

Shifts in species composition occurred in all four vegetation types following trampling; however, the rate and magnitude of change varied (fig. 32). The *Carex* type was least affected. Only the 200- and 500-pass lanes were significantly different from the controls. Even on these lanes, the similarity of floristic composition values were about 70 percent. Both *Amphicarpa* and *Drypoteris* experienced significant changes in composition after just 25 passes. Change was greatest in *Dryopteris* where similarity values on the 200- and 500-pass lanes were just 5 to 10 percent. In *Potentilla*, changes were signficant only on lanes trampled at least 75 times. However, after 500 passes, similarity values were only about 30 percent—a more substantial change than on 500-pass lanes in *Amphicarpa*. In all four vegetation types, changes declined over the year of recovery. One year after trampling, the only lanes where species composition was significantly different from controls were the 500-pass lanes in *Amphicarpa* and *Dryopteris*.

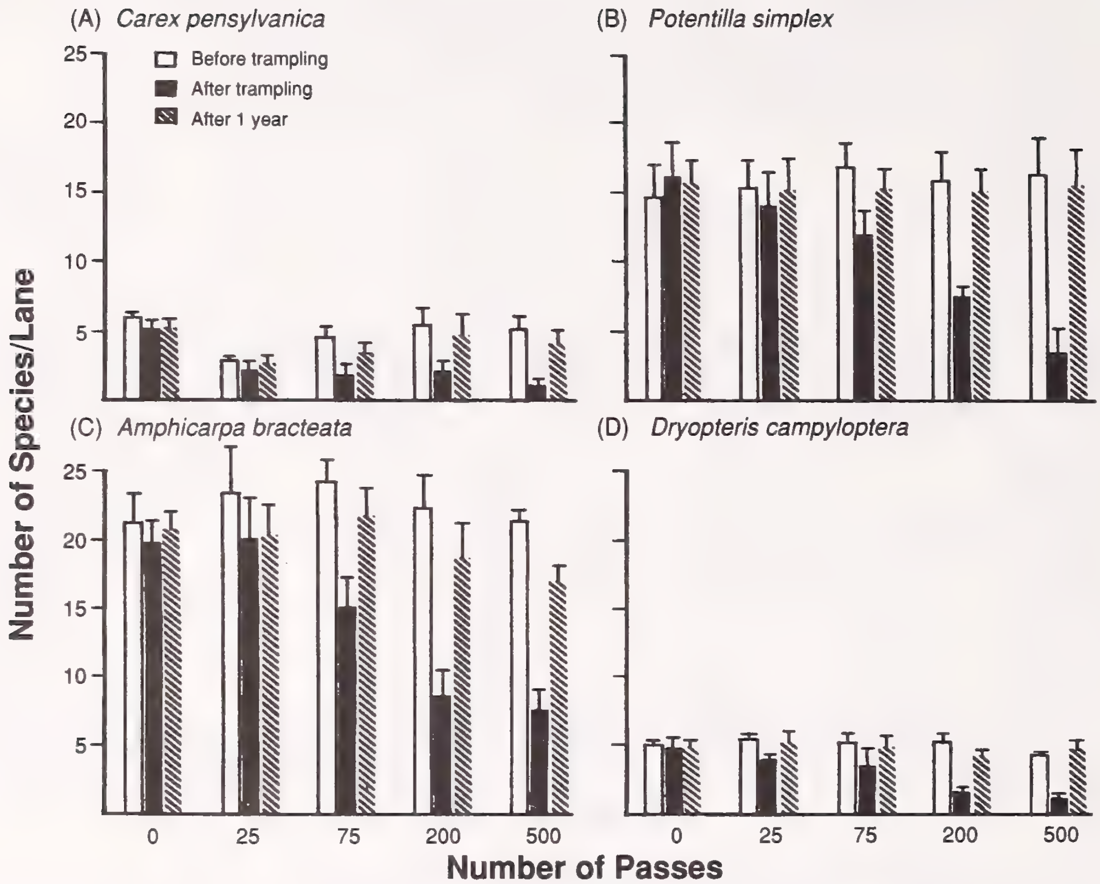

Figure 31—Species richness before and after trampling and after 1 year of recovery in four vegetation types in North Carolina's Great Smoky Mountains. Vertical bars represent 1 standard error above the mean.

General Appearance

Obvious changes occurred most rapidly in the *Dryopteris* type, dominated by ferns and forbs. Ferns were flattened and shredded after just a few passes. A path was evident after just 25 passes. Virtually all vegetation had been obliterated after 200 passes. In both the *Amphicarpa* and *Potentilla* types, paths were evident after 75 passes; however, damage was more apparent in *Amphicarpa*. In *Carex*, a path was obvious only on the 200- and 500-pass lanes. Evidence of trampling disturbance declined over the year of recovery in all four vegetation types. Recovery was most pronounced in *Potentilla*, where impact was barely evident, even on the most heavily trampled lanes. In the three other types, paths were still evident on the 500-pass lanes.

Summary Indicators

The most resistant type was clearly *Carex*, which had a relatively sparse cover dominated by the tall stoloniferous sedge, *Carex pensylvanica* (table 24). Because the sedge was resistant, cover was not lost, species composition was not changed, and paths were not developed as rapidly as in other types. Several associated species were relatively fragile; consequently, species richness declined more rapidly than in some of the other types. In comparison to the other study areas, differences in the relative resistance of each type to cover loss and height reduction are less pronounced. *Dryopteris* was the least resistant type to all changes other than reduction in species richness. In terms of resistance, *Potentilla* and *Amphicarpa* were intermediate in response, although *Potentilla* was clearly more resistant than *Amphicarpa*.

All four vegetation types were quite resilient. Recovery was probably most pronounced in *Potentilla*, with little evidence of disturbance 1 year after trampling. *Dryopteris* recovered substantially as well. However, recovery of vegetation rooted in the trampling lanes was not as pronounced as measurements suggest. Relative cover and height would be much lower if only vegetation rooted in the trampling lanes was considered. The least resilient type was probably *Carex*, the type that was most resistant. *Carex* cover increased little during the year following trampling. The type that showed the impact of trampling the most a year later was *Amphicarpa*.

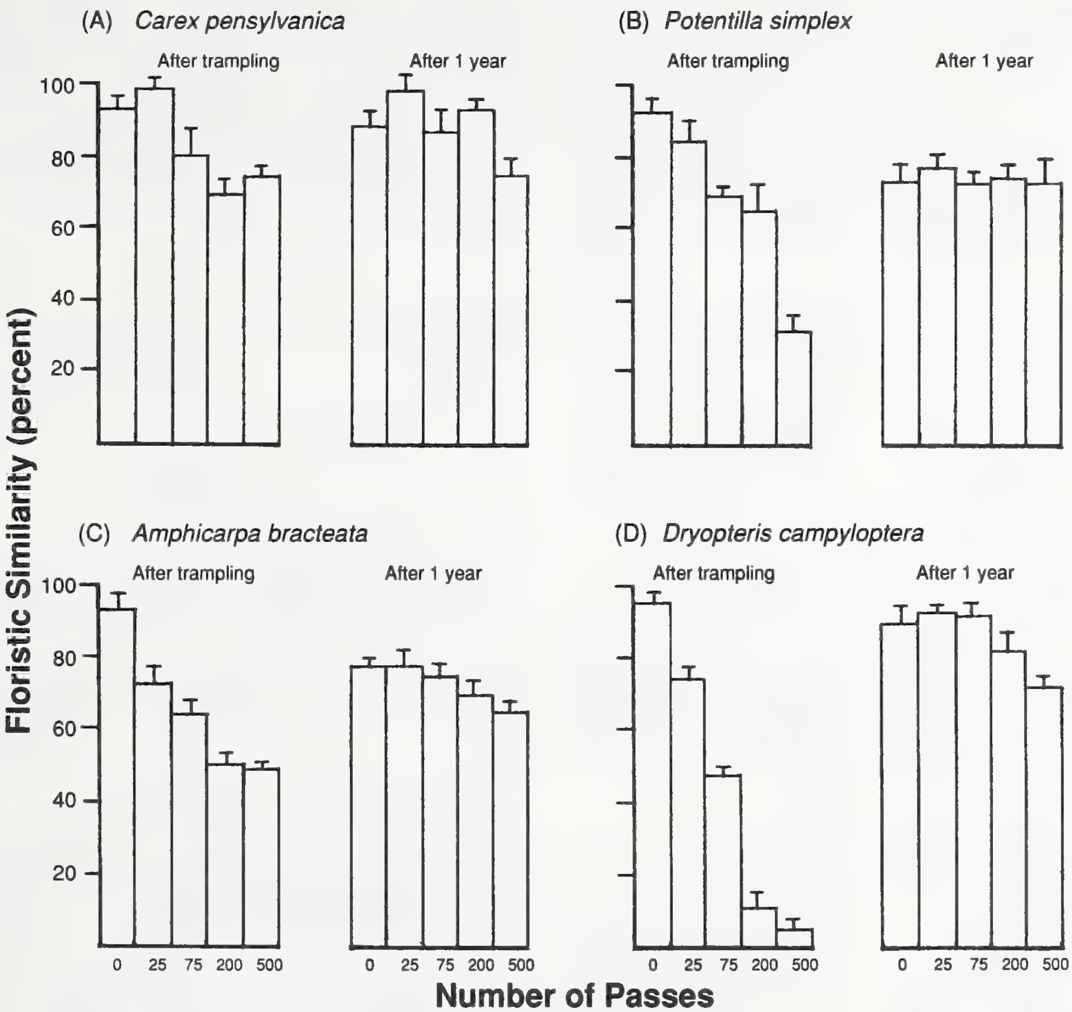

Figure 32—Floristic similarity, comparing composition before and after disturbance, in four vegetation types in North Carolina's Great Smoky Mountains. Vertical bars represent 1 standard error above the mean.

Table 24—Summary indicators of resistance and tolerance for four vegetation types in North Carolina's Great Smoky Mountains

	Vegetation type			
	Carex	***Potentilla***	***Amphicarpa***	***Dryopteris***
Resistance indicators[1]				
Relative cover (percent)	44	22	18	10
Relative height (percent)	10	9	8	4
Species richness (number of passes)	75	200	75	200
Species composition (number of passes)	200	75	25	25
Evident path (number of passes)	200	75	75	25
Tolerance indicators[2]				
Relative cover (percent)	63	77	58	77
Relative height (percent)	81	87	65	72
Species richness (number of passes)	>500	>500	500	>500
Species composition (number of passes)	>500	>500	500	500
Evident path (number of passes)	500	>500	500	500

[1]Resistance indicators refer to immediate responses to trampling. They include mean relative cover and relative height, after trampling, for 0 to 500 passes, as well as the minimum number of passes that causes a significant reduction in species richness or floristic similarity, or that results in an evident path. The relative cover and relative height values are the durability indices described in the data analysis section.

[2] Tolerance indicators refer to conditions 1 year after trampling.

Individual Species Responses

Relative cover could be calculated for 12 species and for mosses (fig. 33). The range of responses was high, although not as high as in some of the other study areas. The response of mosses was unique. Even 500 passes reduced relative cover no lower than 63 percent. One year after trampling, relative cover exceeded 100 percent on all lanes. No vascular plants were as resistant. Of the vascular plants, the two sedges, *Carex pensylvanica* and *Carex swanii* (downy green sedge), were most resistant, with relative cover of 21 percent and 33 percent after 500 passes. These two species were also among the least resilient. *Geranium*

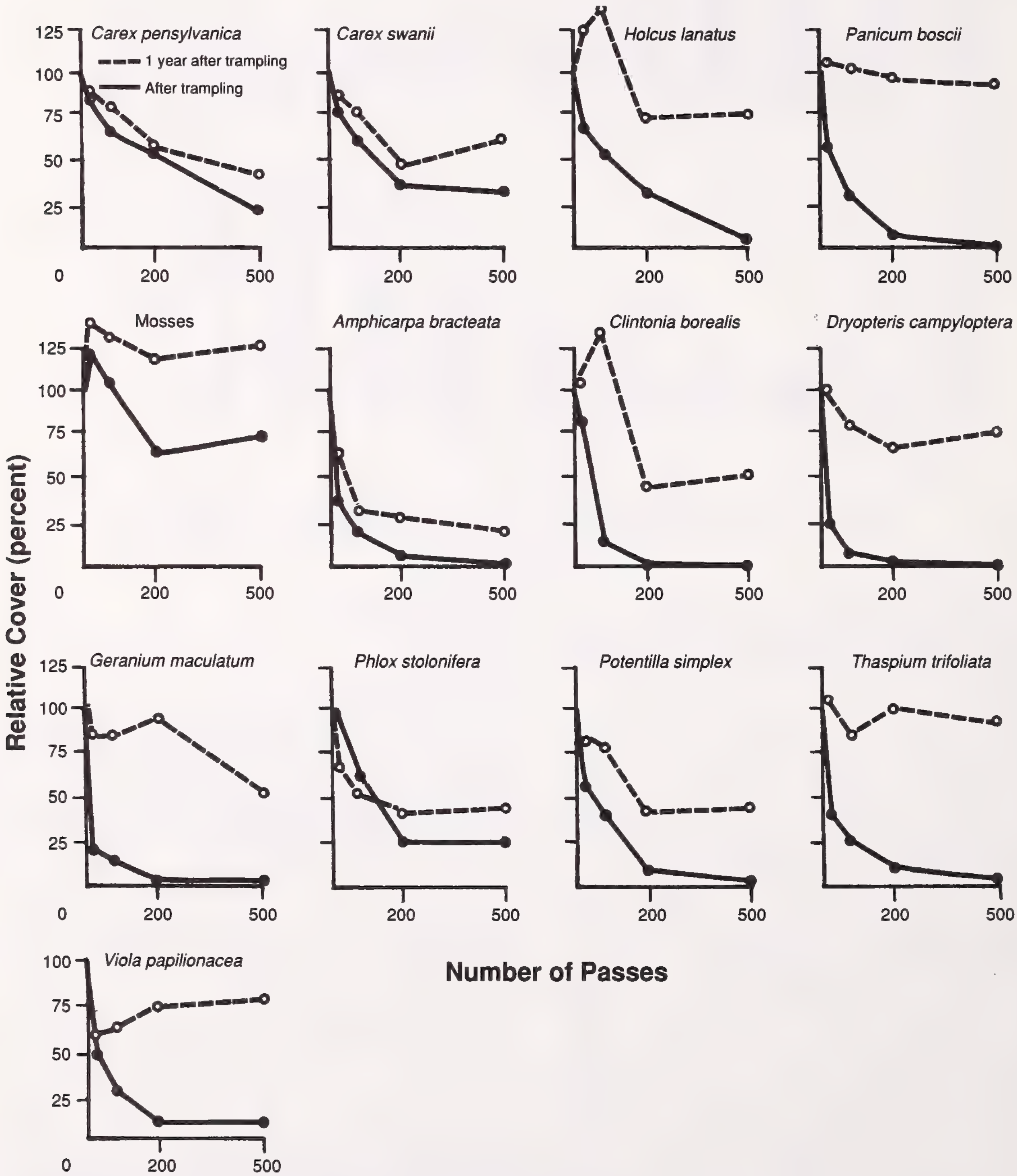

Figure 33—Relative cover after trampling and after 1 year of recovery for abundant species in four vegetation types in North Carolina's Great Smoky Mountains.

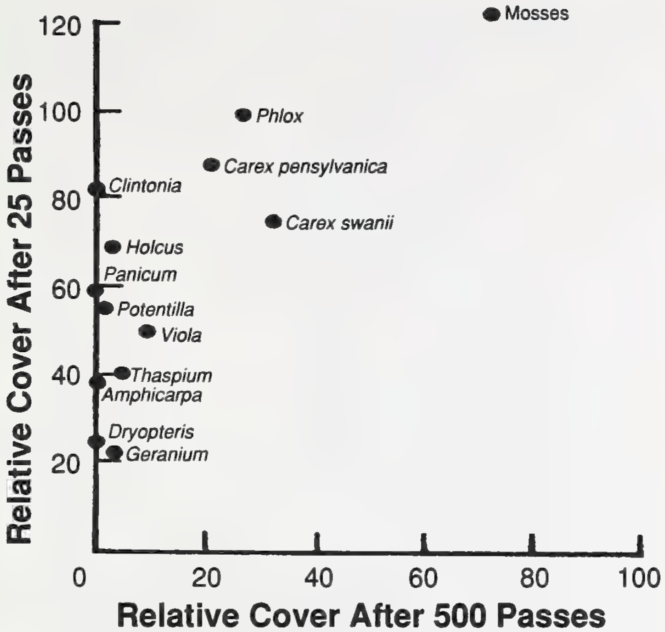

Figure 34—Relative cover after light and heavy trampling for abundant species in four vegetation types in North Carolina's Great Smoky Mountains.

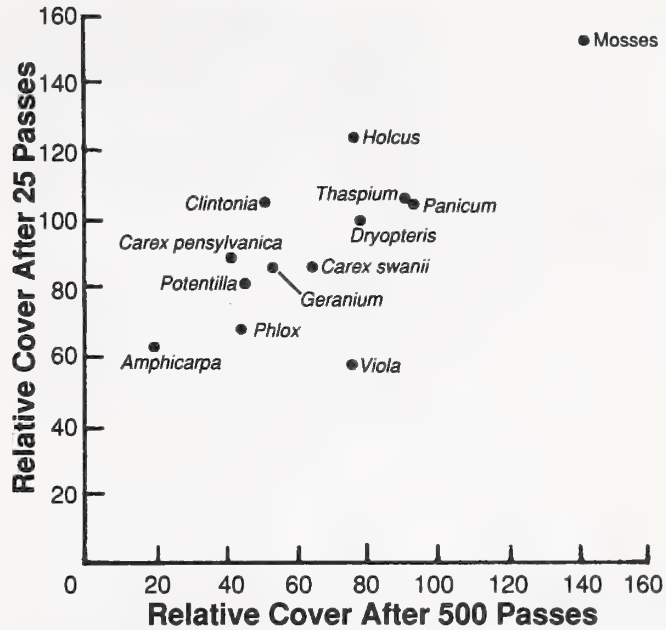

Figure 35—Relative cover 1 year after light and heavy trampling for abundant species in four vegetation types in North Carolina's Great Smoky Mountains.

maculatum (wild geranium) and *Dryopteris campyloptera* were the least resistant species, with relative covers of 21 and 24 percent after just 25 passes. They were among the most resilient species.

A plot of response to light or heavy trampling reveals a variety of initial responses (fig. 34). Most species were arrayed along the left side of the graph. These species did not resist heavy trampling; however, the resistance to light trampling varied greatly. *Carex pensylvanica*, *Carex swanii*, and *Phlox stolonifera*, little affected by light trampling, also survived heavy trampling—to some extent. Mosses were the only plants able to resist heavy trampling.

A plot of relative cover after the year of recovery is more linear, ranging from the mosses, which tolerated light and heavy trampling, to *Amphicarpa bracteata*, which was only moderately tolerant of even light trampling (fig. 35). Despite being relatively resistant, the *Carex* species and *Phlox stolonifera* were relatively intolerant because they did not recover much.

Relationships between resistance, resilience, and tolerance are more apparent in a plot of resistance and tolerance indexes (fig. 36). The unique response was that of the mosses, which were highly resistant, resilient, and tolerant. At the other extreme was the twining herb, *Amphicarpa bracteata*, which had relatively low resistance and resilience and, therefore, very low tolerance. In contrast to the other study areas, the graminoids were highly variable in their responses.

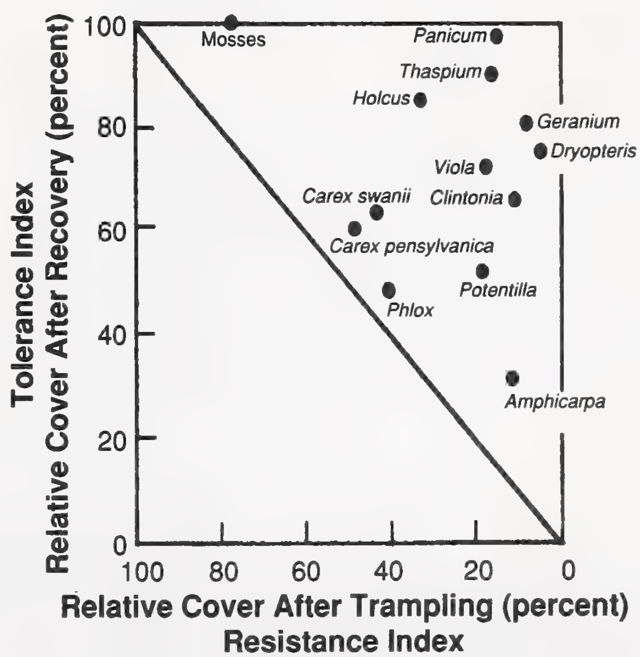

Figure 36—Resistance, tolerance, and resilience of abundant species in four vegetation types in North Carolina's Great Smoky Mountains. Resilience is indicated by the perpendicular distance of the point from the diagonal line of equal resistance and tolerance.

The *Carex* species were quite resistant, but not very resilient. The grasses, *Holcus lanatus* and *Panicum boscii*, were not very resistant, but they were highly resilient. Their resilience made the grasses substantially more tolerant than the sedges. The forbs and ferns were generally not very resistant; however, their resilience and tolerance varied greatly. The most resistant of the forbs was *Phlox stolonifera*, which is a prostrate chamaephyte with evergreen leaves. *Phlox* was the least resilient of the forbs, probably reflecting its slow growth dependent on perennating buds located aboveground where they are susceptible to damage. One of the most resilient forbs was *Geranium maculatum*, the forb that was least resistant.

Table 25 classifies the responses of less common species as low, moderate, or high. This table reinforces the lack of resistance of most species, as well as the great variability in resilience and tolerance. In contrast to other areas, even the responses of graminoids varied greatly. This was the only place with graminoids of low resistance or low tolerance. The low tolerance of the *Carex* species may result from (1) being tall rather than having the resistant caespitose or matted growth forms and (2) growing under forest canopies where low light levels reduce growth rates.

DISCUSSION AND MANAGEMENT IMPLICATIONS

Among experimental trampling studies, this one was unique in (1) the number of vegetation response variables examined, (2) the wide variety of vegetation types examined, and (3) the four different regions of the country examined. This makes it possible to describe the rate and magnitude of various vegetation responses to trampling. It provides an opportunity to assess the variability of responses among vegetation types and to explain the variability. Finally, it is possible to evaluate whether or not response varies by region.

Vegetation Responses to Trampling

The first question we can address is which of these types of vegetation change is the most sensitive indicator of trampling disturbance? Which response to trampling occurs most rapidly and which is most pronounced? The physiognomic changes in vegetation—reduction in height and cover—always occur more rapidly and are more pronounced than the floristic changes—reduction in species richness and change in species composition. Height reduction generally occurred more rapidly than cover loss in types dominated by tall forbs (*Geranium*, *Leersia*, *Potentilla*, *Amphicarpa*, and *Dryopteris*) or by resistant graminoids (*Carex nigricans*, *C. bigelowii*, *C. pensylvanica*, and *Kobresia*). Cover loss occurred more rapidly than height reduction only in the shrub-dominated *Phyllodoce* type. There was little difference in the six other vegetation types. In general, the types of change that occurred most rapidly also were most pronounced.

In most vegetation types, species were lost more rapidly than the composition changed. This would be expected where a few relatively uncommon species are particularly fragile. They may be quickly eliminated by trampling, but their loss has little effect on overall composition. In *Kobresia*, for example, 75 passes reduced species richness 40 percent without significantly changing composition. Sparsely distributed forbs, growing within the matrix of resistant graminoids, were eliminated by light trampling; however, their loss had little effect on similarity values based on plant cover. Where the dominant species is particularly fragile, composition would be expected to change more rapidly than richness. This was the case in *Dryopteris*, where significant changes in composition occurred after 25 passes, while a significant decrease in richness did not occur until after 200 passes.

One year after trampling, richness and composition were almost always closer to original levels than cover and height. In most vegetation types, both richness and similarity made similar recoveries. However, in some types the dominant species were much more or much less tolerant than other species (*Phyllodoce*, *Vaccinium*, *Carex bigelowii*, and *Lycopodium*). In such types, richness recovered more quickly than composition. The magnitude of height reduction and cover loss, after 1 year of recovery, were also similar in most types.

With only a few exceptions, a vegetation type's durability could be assessed using any of these response variables. However, height reduction and cover loss are the most sensitive measures. They change most rapidly. Cover is easier to measure. It is also easiest to interpret and probably best describes observable changes. This validates the reliance of most trampling studies on this single response variable.

Variation Among Vegetation Types

Another important issue we can address is the magnitude of variation in the responses of different vegetation types. If variation is pronounced, impacts potentially could be reduced by confining trampling to more tolerant vegetation types.

In all four regions cover loss differed significantly among three of the four vegetation types. Many different statistics could be used to portray the magnitude of variation. The most resistant type, *Carex nigricans*, lost no cover after 75 passes, while the least resistant type, *Dryopteris*, had just 14 percent relative cover after 75 passes. Alternatively, we can compare the number of passes that caused a 50 percent cover loss—20 passes in *Dryopteris* and 600 passes in *Carex*. The *Carex* type can absorb 30 times as much trampling.

Table 25—Relative resistance, resilience, and tolerance of species in North Carolina's Great Smoky Mountains

Species	Resistance[1]	Resilience[2]	Tolerance[3]
Graminoids			
Carex pensylvanica (1)[4]	h	l	l
Carex swanii (2)	m	l	l
Holcus lanatus (2)	m	h	h
Luzula echinata (2)	m	m	m
Panicum boscii (2)	l	h	h
Ferns			
Asplenium platyneuron (2)	l	h	h
Dryopteris campyloptera (4)	l	h	h
Forbs			
Agrimonia parviflora (2)	m	m	m
Amphicarpa bracteata (3)	l	l	l
Aster divaricatus (3)	l	h	h
Chrysanthemum leucanthemum (2)	l	l	l
Clintonia borealis (4)	l	m	l
Dioscorea villosa (1)	l	l	l
Fragaria virginiana (2)	l	m	m
Geranium maculatum (3)	l	m	m
Geum virginianum (3)	l	l	l
Impatiens capensis (3)	l	m	m
Laportea canadensis (3)	l	h	h
Medeola virginiana (1)	l	l	l
Osmorhiza claytonii (3)	l	l	l
Oxalis acetosella (4)	l	l	l
Parthenocissus quinquefolia (2,3)	l	m	m
Phlox stolonifera (3)	m	l	l
Potentilla simplex (2)	l	l	l
Prunella vulgaris (2)	m	h	h
Rubus canadensis (1,2)	l-m	m-h	m
Rudbeckia hirta (2)	l	m	m
Sanicula trifoliata (3)	l	l	l
Senecio rugelii (4)	l	m	l
Solidago gigantea (2)	l	h	h
Thaspium trifoliatum (3)	l	h	h
Verbesina alternifolia (3)	l	m	m
Viola papilionacea (3)	l	m	m
Other			
Mosses (3,4)	m-h	h	h

[1]Resistance classes are based on the minimum number of passes that reduced cover by 50 percent: h ≥ 500 passes; m = 200 passes; l ≤ 75 passes.

[2]Resilience classes are based on recovery after cover was reduced nearly to zero: h = cover 1 year after trampling was more than two-thirds of the original cover; m = cover 1 year after trampling was between one-third and two-thirds of original cover; l = cover 1 year after trampling was less than one-third of original cover.

[3]Tolerance classes are based on the maximum number of passes that could be tolerated and still have at least 75 percent of original cover 1 year after trampling: h ≥ 500 passes; m = 200 passes; l ≤ 75 passes.

[4]Vegetation types: 1 = *Carex pensylvanica*; 2 = *Potentilla simplex*; 3 = *Amphicarpa bracteata*; 4 = *Dryopteris campyloptera*.

As mentioned earlier, the amount of trampling that leaves an evident path is a significant threshold of impact. Once a path forms it tends to attract further use, initiating a positive feedback mechanism that leads to more concentrated and pronounced impact. This leads to the development of multiple trails, social trails, and trails and campsites in remote areas without trails. In *Dryopteris*, a path was evident after just 25 passes; in *Carex nigricans*, *Trifolium*, and *Kobresia*, paths were evident only on lanes trampled at least

500 times. This suggests those vegetation types were 25 times as resistant to trampling damage.

After the year of recovery, cover loss still varied among vegetation types, but the number of types differing from each other declined. In one region, only one type differed from one other type. In two regions, one type was different from the other three; in the other region, two types were different from the other two. Although the response of most vegetation types became more similar over the year of recovery, this was not the case for all types. The magnitude of difference between the most and least durable types, 1 year after trampling, was about the same as it was immediately after trampling. The most tolerant type, *Trifolium*, had relative cover of 96 percent 1 year after 500 passes, while the least tolerant type, *Vaccinium*, had just 14 percent relative cover. One year after trampling, paths could not be seen on the most heavily trampled lanes in nine vegetation types, while in *Phyllodoce* and *Vaccinium* paths were evident on 200-pass lanes.

These results suggest that if most trampling can be confined to more resistant vegetation types, impacts can be reduced dramatically. Some of the more resistant types can handle 25 to 30 times as much use as less resistant types. Most vegetation types lost most of their cover after 100 to 200 passes; however, a few types retained most of their cover even after 500 passes. Six of the vegetation types had largely recovered, 1 year after trampling, even on the lanes that received 500 passes. However, in several types, lanes trampled only 200 times remained largely devegetated 1 year later. Most vegetation types recovered from several hundred passes, but not from 500 passes. These figures should provide some estimates of the use levels likely to lead to trail formation in areas without trails.

Effects of Various Levels of Trampling

In most of these vegetation types, fewer than 100 people following the same route will leave an evident path that is likely to attract others. On the other hand, several types are so durable that a few hundred people following the same route will leave virtually no evidence of their passing.

In attempting to assess acceptable levels of trampling, a number of impact indicators might be used. Two seem particularly useful, given the objective of maintaining an area in a trailless condition: (1) the level of trampling that leaves an evident path (because an evident path encourages additional use) and (2) the level of trampling with impacts that do not disappear within 1 year (levels likely to cause long-term impact). Data suggest that, to keep trails from developing, no more than about 75 people should follow the same route through *Phyllodoce*, *Vaccinium*, and *Lycopodium*. Similar maximum levels would be about 100 to 150 people in *Pachistima*, *Leersia*, *Carex pensylvanica*, *Amphicarpa*, and *Dryopteris*. Maximum use levels would be several hundred people in *Valeriana*, *Geranium*, *Carex bigelowii*, *Maianthemum*, and *Potentilla*. *Carex nigricans*, *Kobresia*, and *Trifolium* probably could tolerate about 400 people following the same route in 1 year.

These data could be interpreted differently. Data presented for each vegetation type should help managers assess the likely impacts associated with various levels of use. Data can be extrapolated, with caution, to other vegetation types with similar growth forms.

Factors That Influence Response

These data improve our ability to predict the durability of different vegetation types. Several hypotheses about the durability of vegetation have been advanced. Some suggest regional differences, such as between the Eastern and Western United States (Hall 1989). Others suggest differences related to environmental gradients (Kuss 1986). Finally, others have tended to explain variation on the basis of vegetation characteristics (Kuss 1986; Liddle 1991).

The importance of these factors was assessed by examining their influence on cover loss and recovery following trampling. Figure 37 depicts the resistance, resilience, and tolerance of the 16 vegetation types in the four regions. There were pronounced differences, among vegetation types, in each of these three attributes. *Carex nigricans* was most resistant. *Dryopteris*

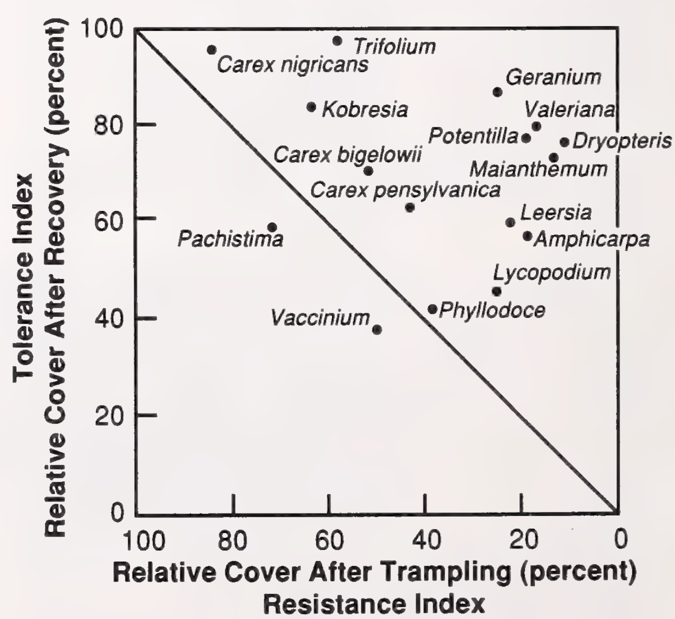

Figure 37—Resistance, tolerance, and resilience of the 16 vegetation types in all four regions. Resilience is indicated by the perpendicular distance from the diagonal line of equal resistance and tolerance.

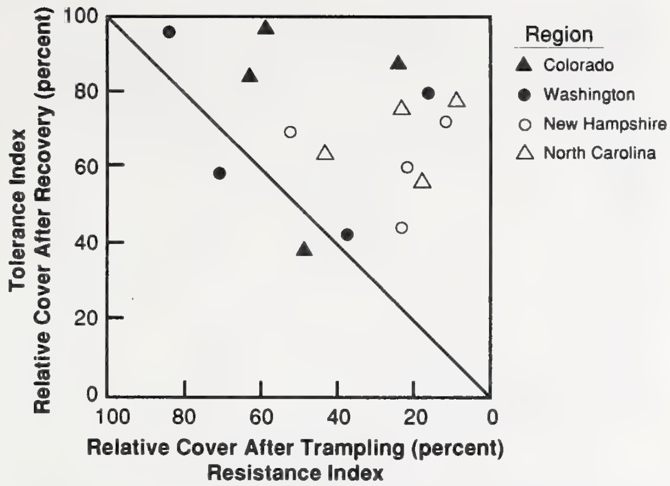

Figure 38—Resistance, tolerance, and resilience of vegetation types in each of the four regions. Resilience is indicated by the perpendicular distance from the diagonal line of equal resistance and tolerance. Refer to figure 37 for names of each vegetation type.

was least resistant. *Trifolium* was most resilient. *Pachistima* was least resilient. *Trifolium* was most tolerant. *Vaccinium* was least tolerant.

Regional Differences—Most research on the impacts of wilderness use has been conducted in the Western United States and northern Minnesota. Managers of areas in the Eastern United States have questioned whether those results apply in eastern areas. Growing conditions are often more favorable there, leading some to suggest that impacts might be less severe. One study of campsite impacts in eastern areas, using techniques directly comparable to those used in western areas, found little difference between East and West (Cole and Marion 1988).

Analysis of variance was used to determine whether or not these attributes differed significantly with region or with environmental or plant characteristics. The analysis found that the Colorado and Washington vegetation types included in this study were significantly more resistant than the New Hampshire and North Carolina types. The four most resistant vegetation types were located in Colorado and Washington (fig. 38). Despite this general tendency, there was more variation within regions than among regions. For example, the *Geranium* and *Valeriana* types in Colorado and Washington were not resistant, and the *Carex bigelowii* and *Carex pensylvanica* types in New Hampshire and North Carolina were quite resistant. Each region had a graminoid-dominated type that was quite resistant and one or more types dominated by erect forbs that were not resistant. There were no significant differences, among regions, in resilience or in tolerance.

The results of this study are influenced by the specific vegetation types selected for study. However, these results do confirm the earlier campsite study in which vegetation types in eastern areas were no more tolerant of trampling than those in western areas. Both western and eastern areas have some vegetation types that are resistant and others that are fragile. If anything, these results suggest that eastern areas have a greater proportion of fragile types. This may reflect the prevalence of environmental conditions that favor erect forbs—a plant growth form that is generally not resistant. Variation among vegetation types was less pronounced in the eastern areas than in the western areas.

Elevation—Another common generalization is that vegetation durability decreases as elevation increases; therefore, alpine vegetation would be particularly fragile. The data from these 16 vegetation types suggest the opposite. Alpine vegetation types were significantly more resistant than subalpine and low-elevation types (fig. 39). In the three regions with an alpine zone, the vegetation type located above timberline was the most resistant to trampling. Resilience did not vary significantly with elevation, despite suggestions that resilience might decrease at higher elevations (Cole 1987). Tolerance was greatest in alpine vegetation types and least in subalpine types.

The resistance of alpine vegetation is not likely to be a direct effect of elevation. It is more likely to reflect the kinds of plants that grow above timberline.

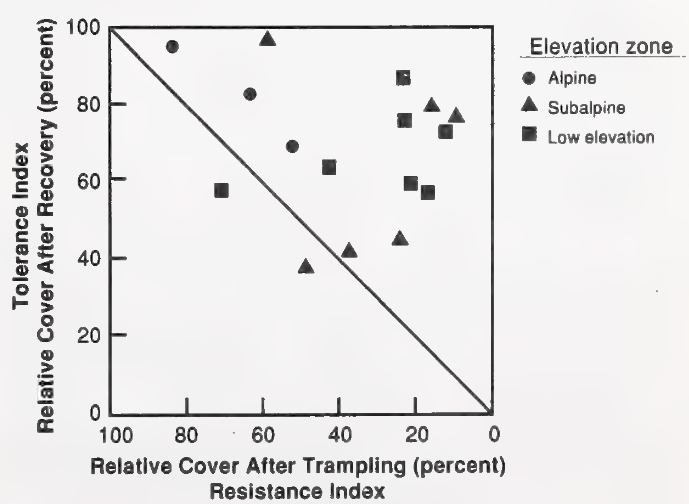

Figure 39—Resistance, tolerance, and resilience of vegetation types in different elevation zones. Resilience is indicated by the perpendicular distance from the diagonal line of equal resistance and tolerance. Refer to figure 37 for names of each vegetation type.

Alpine plants must be capable of tolerating harsh and abrasive conditions, such as high winds and blowing snow and ice. Therefore, most of the plant biomass is below the ground. The aboveground tissues are generally tough and grow low to the ground. These characteristics also make a plant resistant to trampling. All three of the alpine vegetation types were dominated by turf-forming graminoids, the most resistant growth forms (as suggested by their use on football fields and lawns). Other alpine vegetation types are likely to be less resistant (Bell and Bliss 1973).

The resilience of alpine vegetation was unexpected. I suspect that resilience would be low following either high-intensity or long-duration trampling. This study's results apply only to the low-intensity, short-duration use these experiments simulated. Even above timberline, the capacity for recovery from this type of use is high.

The subalpine zone is characterized by tremendous variation in response. The most tolerant type (*Trifolium*), two intermediate types (*Valeriana* and *Dryopteris*), and the three least tolerant types (*Vaccinium*, *Phyllodoce*, and *Lycopodium*) were all in the subalpine zone. In subalpine basins, it is not uncommon for four or five different vegetation types within a few hundred meters of each other to vary in response from highly tolerant to highly intolerant. Attention to the durability of vegetation is particularly important in the subalpine zone. This conclusion is further underscored by the attractiveness of the subalpine zone, usually the primary destination of most wilderness visitors, particularly in the West.

Canopy Density—A number of impact studies have found that vegetation types found in open areas tend to be less severely impacted than those found in closed forests (Cole 1979; Marion and Merriam 1985; Schreiner and Moorhead 1979). Direct sunlight does not confer greater durability; rather, the growth forms of plants adapted to shade tend to make them susceptible to damage from trampling (Cole 1979).

Of the 16 vegetation types in this study, the four types found in open areas were significantly more resistant than those found in partially and completely forested areas (fig. 40). The four types found in open areas were among the five most resistant vegetation types. They also were more tolerant; however, resilience did not vary with canopy density. This confirms the conclusion that vegetation types in open areas are generally more tolerant of trampling impact than ground cover vegetation in forests.

Plant Morphology—Many studies have related observed differences in impact to differences in the morphology of the species involved (Kuss 1986; Liddle 1991). Tolerant plants are generally short rather than tall, with a tufted or prostrate rather than an erect

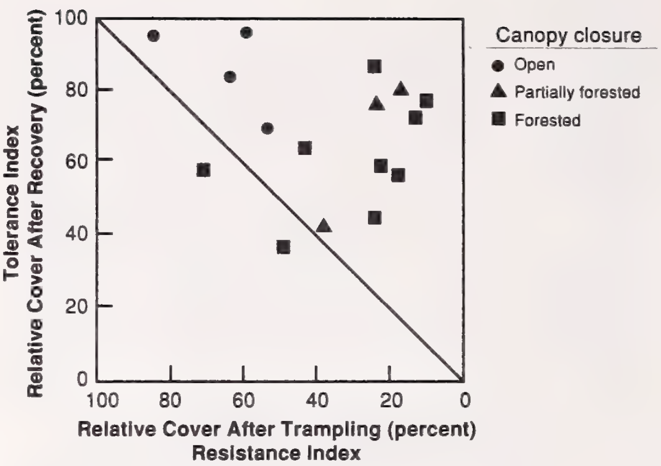

Figure 40—Resistance, tolerance, and resilience of vegetation types with varying degrees of canopy closure. Resilience is indicated by the perpendicular distance from the diagonal line of equal resistance and tolerance. Refer to figure 37 for names of each vegetation type.

growth form. Two alternative classifications of life forms have also been used to assess durability. One classification distinguishes between shrubs and herbaceous vegetation, subdividing herbs into graminoids and forbs. Using this classification, graminoids have frequently been found to be resistant (Holmes and Dobson 1976). Life forms also have been classified on the basis of the location of growing points (perennating tissues such as buds) (Raunkiaer 1934). Chamaephytes (plants with perennating buds above the soil surface) have generally been found to be less durable than hemicryptophytes and cryptophytes (plants with perennating buds at or below the soil surface, respectively). Most of these generalizations were made after comparing the vegetation in trampled and untrampled areas. This makes any conclusions about cause and effect risky. Moreover, any single study is likely to have assessed impacts only in a few vegetation types.

This experimental study of 16 different vegetation types avoids these drawbacks, allowing comparisons between (1) tall, erect growth forms and short growth forms that are not erect, (2) shrubs, graminoids, and forbs, and (3) chamaephytes, hemicryptophytes, and cryptophytes. Vegetation types dominated by erect plants were significantly less resistant than those dominated by caespitose or matted plants (fig. 41). However, erectness had no effect on resilience or tolerance. Regression analysis also showed a significant negative relationship between plant height and resistance ($p = 0.005$, $r^2 = 0.14$). Plant height was not significantly related to resilience or tolerance.

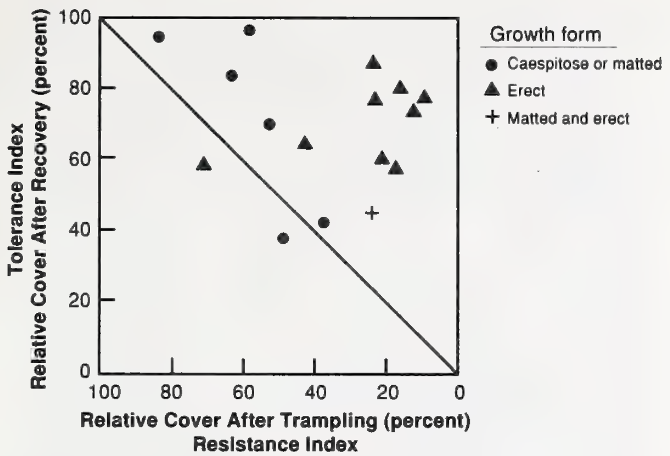

Figure 41—Resistance, tolerance, and resilience of vegetation types in relation to the growth form of dominant species. Resilience is indicated by the perpendicular distance from the diagonal line of equal resistance and tolerance. Refer to figure 37 for names of each vegetation type.

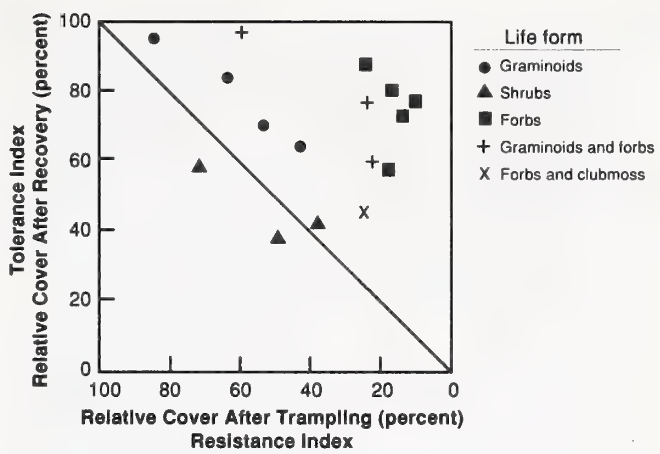

Figure 42—Resistance, tolerance, and resilience of vegetation types dominated by graminoids, shrubs, and forbs. Resilience is indicated by the perpendicular distance from the diagonal line of equal resistance and tolerance. Refer to figure 37 for names of each vegetation type.

The vegetation types dominated by graminoids, shrubs, and forbs fall into discrete positions in figure 42. The graminoids are characterized by high resistance. The shrubs are characterized by low resilience. The forbs generally had low resistance and high resilience. Vegetation types codominated by different growth forms usually had an intermediate response. Analysis of variance indicated that graminoids and shrubs were significantly more resistant than forbs. Forbs and graminoids were both more resilient and more tolerant than shrubs. The responses of the Raunkiaer life forms are less discrete (fig. 43). The chamaephytes are the best distinguished group, characterized by low resilience and tolerance. Analysis of variance shows that the chamaephytes and cryptophytes are significantly more resistant than the hemicryptophytes. However, the hemicryptophytes and cryptophytes are significantly more resilient and more tolerant than the chamaephytes.

Although all three sets of morphological characteristics influence response to trampling, they are not equally important. The shrub/graminoid/forb classification (r^2 = 0.59) and erectness (r^2 = 0.51) explain much more variation in resistance than the location of perennating buds (r^2 = 0.05). Resilience is more strongly related to location of perennating buds (r^2 = 0.64) and shrub/graminoid/forb classification (r^2 = 0.57) than to erectness (r^2 = 0.28). Tolerance is related to all these attributes: the shrub/graminoid/forb classification (r^2 = 0.38), erectness (r^2 = 0.41), and location of perennating buds (r^2 = 0.48).

These differences related to plant morphology may explain the differences between regions and the differences related to elevation and canopy density. The vegetation types in Colorado and Washington tend to be more resistant than those in New Hampshire and North Carolina because less ground cover vegetation consists of erect forbs—the least resistant type of plant. The alpine types and those found in

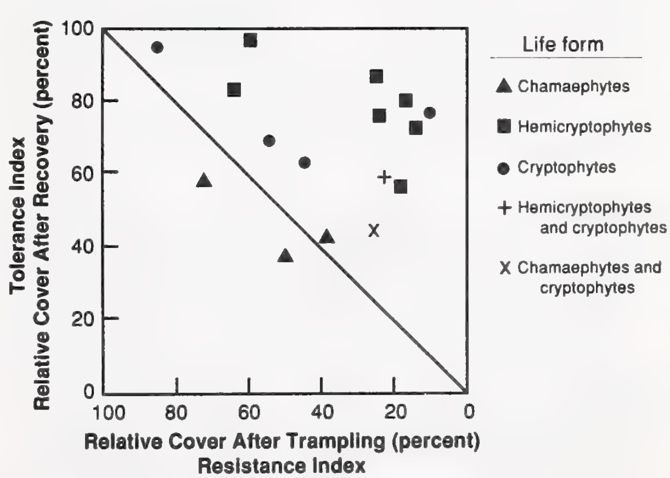

Figure 43—Resistance, tolerance, and resilience of vegetation types dominated by chamaephytes, hemicryptophytes, and cryptophytes. Resilience is indicated by the perpendicular distance from the diagonal line of equal resistance and tolerance. Chamaephytes have perennating buds above the soil surface; hemicryptophytes have perennating buds at the soil surface; cryptophytes have perennating buds below the soil surface. Refer to figure 37 for names of each vegetation type.

open areas tend to be more resistant and tolerant because they are dominated by turf-forming graminoids.

These results suggest that the durability of a vegetation type can be predicted quite accurately by examining characteristics of the dominant ground cover species. If those species are woody or have aboveground perennating buds, they will probably have low tolerance for trampling. If they are tufted or matted graminoids, they will probably have high resistance and enough resilience to be very tolerant of trampling. If they are erect forbs, they will probably have little resistance to trampling; however, they are likely to have high resilience and, therefore, relatively high tolerance. Types that are dominated by low-growing forbs or by erect graminoids have an intermediate response, between that of low-growing graminoids and that of erect forbs.

CONCLUSIONS

The results of this study apply only to the effects of short-duration trampling on relatively undisturbed vegetation. However, they can be applied to the management of most wilderness acreage—the lightly used places away from established trails and campsites. Even low levels of trampling can cause pronounced changes in vegetation, but the rate and magnitude of change varies between vegetation types. Variation is best explained by differences in plant characteristics, although these are sometimes correlated with environmental characteristics. There is no reason to think that the response of vegetation in any part of the country is fundamentally different from that in any other part of the country.

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APPENDIX: SPECIES LISTS FOR THE FOUR REGIONS

Table 26—Initial frequency and mean percent cover of the more abundant species in each of four vegetation types in Washington's Cascade Mountains[1]

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

[1]Only species with mean cover of at least 2 percent are included. Frequency is the percent of the forty 30- by 50-cm subplots in which the species was found. A + indicates cover less than 0.5 percent.

Table 27—Initial frequency and mean percent cover of the more abundant species in each of four vegetation types in Colorado's Rocky Mountains[1]

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

[1]Only species with mean cover of at least 2 percent are included. Frequency is the percent of the forty 30- by 50-cm subplots in which the species was found.

Table 28—Initial frequency and mean percent cover of the more abundant species in each of four vegetation types in New Hampshire's White Mountains[1]

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

[1]Only species with mean cover of at least 2 percent are included. Frequency is the percent of the forty 30- by 50-cm subplots in which the species was found. A + indicates cover less than 0.5 percent.

Table 29—Initial frequency and mean percent cover of the more abundant species in each of four vegetation types in North Carolina's Great Smoky Mountains[1]

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

[1]Only species with mean cover of at least 2 percent are included. Frequency is the percent of the forty 30- by 50-cm subplots in which the species was found. A + indicates cover less than 0.5 percent.

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Cole, David N. 1993. Trampling effects on mountain vegetation in Washington, Colorado, New Hampshire, and North Carolina. Res. Pap. INT-464. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 56 p.

Experimental trampling simulating hiking was conducted in 16 vegetation types around the country. Changes in vegetation cover and height, species richness (the number of species), and species composition were quantified. Some vegetation types were 25 to 30 times more resistant to trampling than others. Physiognomic characteristics of abundant species were the best predictor of vegetation type response. Management implications of findings are explored.

KEYWORDS: resistance, tolerance, ecological impacts, outdoor recreation, recreation management

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