Biological Conservation 1993, 63, 209-215

RECREATIONAL TRAMPLING OF VEGETATION: STANDARD EXPERIMENTAL PROCEDURES

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(Received 19 March 1991; revised version received 10 February 1992; accepted 21 February 1992)

Abstract

In order to promote an increased ability to compare results from different studies, a standard protocol for controlled trampling experiments is suggested. The procedure will provide information on both damage to vegetation in response to short-duration trampling and subsequent recovery over a one-year period. Changes in vegetation cover, vegetation height, bare ground cover, and the cover of individual species can be assessed. It is designed to be efficient both in area and in time requirements? Each vegetation type to be examined will require a total area of about 30 m^2; treatments and measurements will require about three to four person-days of time. The protocol was developed after extensive trials and discussion in the USA and UK. It can be applied in a wide variety of vegetation types.

INTRODUCTION

Recreation ecology seeks to understand the effects of recreationists on natural environments. Considerable attention has been focused on the effects of trampling on vegetation. Two key topics of interest are the relationship between amount of trampling and vegetative response, and the relative vulnerability of different plant species and communities. An effective approach for isolating the effect of amount of trampling from other confounding variables is to apply controlled levels of trampling to previously undisturbed sites, usually on small plots. This experimental approach has been taken many times in different vegetation types, from the early work of Wagar (1964) to the recent work of Sun and Liddle (1991) and Kuss and Hall (1991).

There are both conceptual and procedural problems with experimental trampling studies, however. The conceptual problems are broadly those of any experimental technique; the approach does not precisely simulate the way in which trampling occurs in practice. Trampling in the field can be erratic, extended over long periods, and variable both in season and intensity.

Although trampling experiments have examined prolonged trampling and extended recovery (Bayfield, 1979; Cole, 1987), there are problems with using small experimental plots for such studies. In particular, the recovery of vegetation on small plots surrounded by undisturbed vegetation may be atypical of large recreation sites, and prolonged experiments can require complex and space-demanding designs and input over many years. It may be more effective to study extended recovery on worn sites that have been closed and to assess prolonged wear on sites with a known history of use, such as a monitored trail system. Experimental trampling is, however, an effective approach for assessing the response of vegetation to short-duration trampling.

The procedural problems relate mainly to the lack of standardization in levels of trampling, plot sire, recovery periods, and measurements taken. Lack of standardization makes it difficult to compare the responses of vegetation types from different studies. Some studies, for example, have only examined initial damage without assessing recovery (Bell & Bliss, 1973). Very few have considered structural changes, such as the reduc tion in height that is usually the initial response to trampling.

There has also been great variation in plot size and layout. The width of trampling lanes, which influences effective trampling intensity, has varied from 25 cm (Kay & Liddle, 1989) to 1.2 m (Bayfield, 1979). Measurement plot dimensions have also varied greatly. Even a fairly simple trial can occupy quite a large area if each level of use and replicate has a separate plot of several square metres (Bayfield, 1979). Such trials can be visually intrusive, and it can be difficult to find sufficient homogeneous vegetation. Emanuelsson (1984) devised an ingenious fan-shaped plot that incorporated a range of levels of trampling. While very efficient in some respects, a drawback was that the different levels affected different sizes of subplot, making analysis difficult to interpret.

Biological Conservation 0006-3207/93/$06.00

The present proposal aims at a procedure that can be applied, in a standard manner, in as wide a variety of plant communities as possible. The method has evolved after several years of trial and discussion in the USA and UK. It has standardized and easily repeatable treatments and recordings. It provides information on both damage and recovery of vegetation. Damage refers to the amount of vegetation change that occurs as a result of trampling disturbance; recovery refers to the rate at which the vegetation reverts to pre-disturbance conditions once trampling ceases. Finally, the protocol is efficient in area and time requirements.

Where feasible, use of this protocol will mean that the results generated by different studies and different observers should be readily comparable, improving our ability to draw generalizations about trampling impact and the vulnerability of different communities. There are communities, however, where this protocol will not work well (e.g. communities of large, widely-spaced individuals).

A STANDARD PROCEDURE

Layout of treatment lanes

In each vegetation type to be examined there should be a minimum of four replications, with each replication consisting of five lanes delineated at the comers by stakes. Lanes should be 0·5 m wide and separated by a buffer at least 0·4 m wide (Fig. 1). This width was selected because (1) it occupies an intermediate position in the range of widths that have been utilized; (2) it approximates a common width for a footpath; and (3) it is wide enough to accommodate a 30-cm-wide quadrat while minimizing edge effects. A standard length is less critical. We have been using 1·5m-long lanes. We consider this the shortest length that can be trampled in a reasonably natural way and also hold a representative stand of vegetation. Longer lanes would permit a more

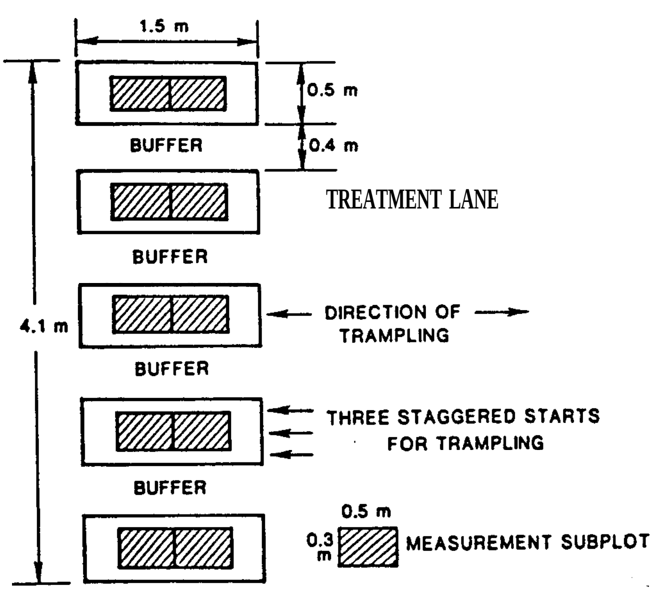


Fig. 1. Layout of treatment lanes, buffers, and measurement of subplots within treatment lanes.

natural gait, but they require larger areas of homogeneous vegetation. The total area required is about 30 m^2 per vegetation type.

The configuration of lanes is not fixed; they can be arranged in a line or placed irregularly, if this suits the site. Lane locations should be chosen for homogeneity and where they are unlikely to get spurious disturbance. They should be located on flat ground or, where this is not possible, oriented so that their long axis is perpendicular to the slope.

Trampling treatments and timing

Each lane should be randomly assigned one of five trampling treatments: Control (no trampling), 25, 75, 200, and 500 passes. A pass is a one-way walk at a natural gait down the lane. The walker should stagger starts from three locations across the width of the 0·5-m-wide lane so that the entire width of the lane is trampled uniformly (Fig. 1). The direction and precise location of turning (between passes) should be varied so that locations along the length of the lane are trampled uniformly. Turning should always occur beyond the lanes. Trampling should occur on the same day for all treatments, and preferably also for all replications. There is no clear evidence to suggest any difference between the effects of trampling all at once and spreading the trampling out over a few months (Bayfield, 1979; Cole, 1985). Trampling all at once eliminates confounding situations such as trampling occurring partly on rainy and partly on dry days. Treatments should be administered during the time of year when vegetative cover is at or near a maximum and at least half the growing season remains. Exceptions would be when the aim is to look specially at seasonal effects of disturbance.

Preliminary experimentation using this procedure suggests that there is no substantial difference in the responses caused by tramplers of differing weight or shoe type. Heavier people frequently have larger shoes, so the pressure per unit area may be constant across a range of weights. Apparently, standardizing weight and shoe type is not critical. For most studies, however, we have used walkers of moderate weight (75 ± 10 kg), wearing boots with lug soles, as our standard treatment.

The range 0-500 passes has been found suitable for most vegetation types. It is usually adequate to assess the disturbance necessary to cause a 50% reduction in cover-a key level of response in this procedure. In extremely resistant vegetation types, where 500 passes have little effect on the vegetation, trampling treatments should be increased to cause at least a 50% cover loss. If it appears that 500 passes will not eliminate 50% of the vegetation cover then the 25-pass lane should be trampled more than 500 times-to the level necessary to cause at least a 50% reduction in cover. No changes are required on other lanes. We have examined some resistant vegetation types that do not lose 50% cover until they have been trampled more than 1000 times (Cole, 1987).

Measurements

Recording aims to assess the effect of trampling on both vegetation cover and structure (the height of the vegetation). Measurements are taken on two 30 X 50-cm subplots located adjacent to each other, with long axis parallel to the long axis of the lanes, 0·25 m from each end of the lane (Fig. 1). Parameters to be measured in each subplot are:

(1) Visual estimates of the canopy coverage of each vascular plant species and of mosses and lichens. Generally, only green photosynthetic material should be included in cover estimates. For example, it would be inappropriate to include the cover of surviving stems that had been defoliated by trampling. Cover should be recorded as 0 if there is no cover, as '+' if cover is less than 0.5%, or as the closest of the following values: 1, 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 90, or 100%.

(2) Visual estimates of the cover of bare ground (ground not covered by live vegetation). Bare ground can be either mineral soil or soil covered by organic horizons, including the litter of recently trampled plants. Use the same cover values as for cover of individual species.

(3) Measures of vegetation height, using a point quadrat frame with 5 pins (3 mm in diameter), located 5 cm apart within the 30 cm width of the subplot. The frame should be placed a minimum of 10 times, systematically, along the length of each subplot. The pins are dropped to the ground. Where the pin hits bare ground, a 0 is recorded. Where it hits live vegetation, the height of the pin strike is recorded to the nearest 1 cm, or as '+' if the strike is below 0.5 cm. **A** total of 50 pin drops and records are made in each subplot.

Recording also aims to assess both the damage and recovery responses of vegetation to trampling disturbance. Consequently, a complete set of measurements, two subplots per lane, should be taken immediately before trampling. Height measurements should be repeated immediately after trampling, when the greatest reduction in height occurs. Cover loss often continues to increase for some time after the trampling treatments, because it often takes a few days or weeks for trampled vegetation to die. Consequently, in most of our studies we have waited about two weeks after trampling to reassess vegetation cover. Finally, all measurements should be repeated on all subplots one year after trampling occurred. In communities with extremely rapid recovery, it may be desirable to repeat measurements three months after trampling, in addition to the one-year standard recovery period.

The total time required to set up a full set of plots, trample them, and take all requisite measurements is about three to four person-days per vegetation type.

DATA ANALYSIS

The two primary measures of vegetation change are relative cover (RC) and relative height (RH). In both cases, conditions after trampling are expressed as a proportion of initial conditions, with a correction factor (cf) applied to account for spontaneous changes on the control plots. This approach was originally developed by Bayfield (1979). Additional information can be derived from data for individual species and bare ground. Calculation of these measures and examples of analysis are presented below.

Relative cover

Relative cover is based on the sum of the coverages of all species, rather than a single estimate of total vegetation cover. This measure accounts for loss of overlapping layers of vegetation that may occur without a decrease in total cover. It is calculated in the following manner:

(1) sum the percent coverages of all vascular species, mosses, and lichens, for each subplot (a '+' is given a nominal value of 0·2%);

(2) derive the mean sum cover of the subplots on each lane;

(3) calculate relative cover:

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

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

Relative cover would be 100% in the absence of any change in cover caused by trampling. Therefore, the extent to which relative cover after trampling deviates from 100% provides a measure of the damage response to trampling. Relative cover one year after trampling can be compared with that shortly after trampling to provide a measure of the recovery response. The following example compares the response of three upper subalpine vegetation types to trampling disturbance:

(1) An *Abies lasiocarpa-Picea engelmannii/Valeriana sitchensis* forest at 1800 m in the Cascade Mountains of Washington, with an understorey dominated by a diverse mix of broad leaved herbs;

(2) A *Picea engelmannii-Abies 1asiocarpa/Vaccinium scoparium* forest at 3350 m in the Rocky Mountains of Colorado, with an understorey dominated by short shrubs.

(3) A *Carex nigricans* snowmelt meadow at 2050 m in the Cascade Mountains of Washington, with an understorey dominated by short, wiry sedges and rushes.

The relationship between relative cover and amount of trampling is depicted in graphs of mean relative cover after trampling and one year after trampling (Fig. 2). *The Carex nigricans* type had to be trampled more than 500 times to cause a 50% reduction in cover. In contrast, only 25 passes through the broadleaved forbs of the *Valeriana sitchensis* type *caused* a 50% reduction in cover. However, *in the Valeriana* type, cover increased substantially during the year following trampling. Although relative cover was only 2% after being trampled 500 times, it had increased to 66% within just one year. This contrasts with the *Vaccinium scoparium* type, in which cover continued to decrease

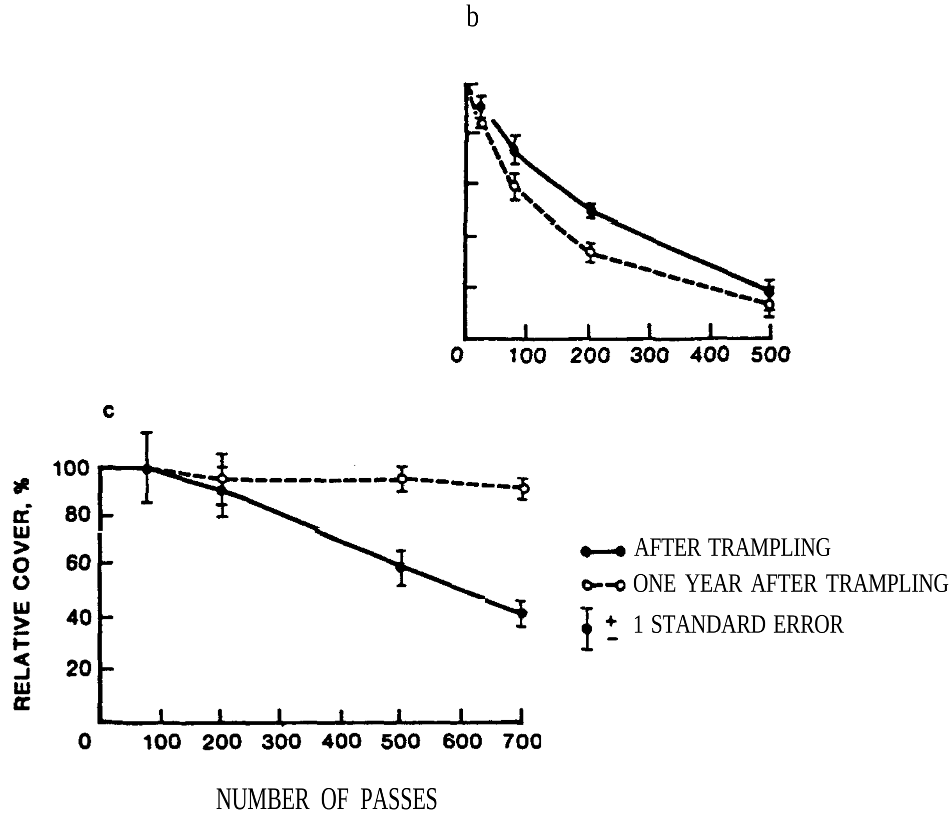


Fig. 2. Relative cover after trampling, and one year after trampling, in the (a) *Abies lasiocarpa-Picea engelmannii/ Valeriana sitchensis; (b) Abies lasiocarpa-Pica engelbannii/Vaccinium scoparium;* and *(c) Carex nigricans* vegetation types.

during the year after trampling. Delayed damage of *Vaccinium* sp.. has been reported elsewhere (Bayfield, 1979).

Relative height

Relative height is calculated in the following manner:

(1) sum the height measures, 50 records per subplot (a '+' is given a nominal value of 0·2 cm);

(2) divide this sum by the number of non-zero values to obtain the mean height of the surviving vegetation;

(3) derive the mean height of the two subplots on each lane;

(4) calculate relative height by substituting these mean height values for the cover values in the formula for cover loss given above.

Again, both damage and recovery can be assessed. In the *Valeriana* type (Fig. 3), height declines slightly more than cover, when subjected to equal levels of trampling, and recovery is less pronounced.

Bare ground

We have been reporting percent bare ground (the proportion of the ground surface not covered with live vegetation), before and after trampling, across the range of trampling intensities from 0 to 500 passes. In contrast to relative cover, coverages are neither relativised nor adjusted for changes on controls. Consequently, the bare ground data provide straightforward descriptive measures of the changes in ground cover that result from trampling disturbance. In the *Vaccinium* type, for example, bare ground was typically 15-20% before trampling (Fig. 4). Following trampling, bare ground varied from 26% after 25 passes, to 83% after 500 passes. Bare ground was more widespread one year later, increasing 45% on the control and 25 pass lane and 10-15% on the more heavily trampled lanes.

Response of individual species

For a few individual species it is possible to calculate relative cover in a manner similar to that for total vegetation cover. This is only possible, however, for species that (1) are present on all or most plots, and (2) have coverages on controls that are similar to those on treatment lanes prior to trampling. Most species will not meet these criteria, making it difficult to quantify their response.

We have been using the following procedure to

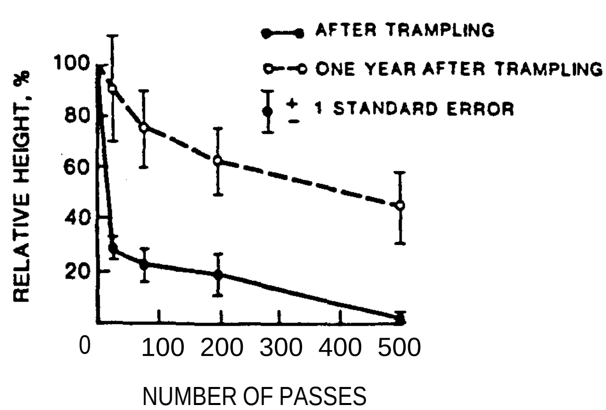


Fig. 3. Relative height immediately after trampling, and one year after trampling, in the *Abies lasiocarpo-Picea engelmannii/Valeriana sitchensis* vegetation type.

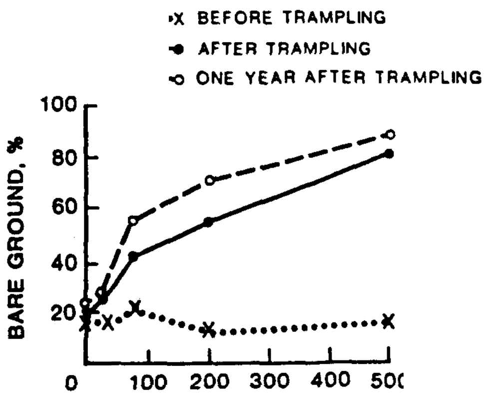


Fig. 4. Amount of bare ground before trampling, after trampling, and one year after trampling in *the Abies lasiocarpa-Picea engelmannii/vaccinium scoparium* vegetation type. Standard errors were all 1-6%.

analyze individual species data. First, variation between replications is reduced by treating replications as subsamples, calculating mean pre- and post-treatment cover measures for all replicates, and then calculating relative cover from these single cover estimates (instead of calculating relative cover for each replicate). These data are more likely to meet the requirements for analysis, but they have the drawback that confidence intervals cannot be calculated.

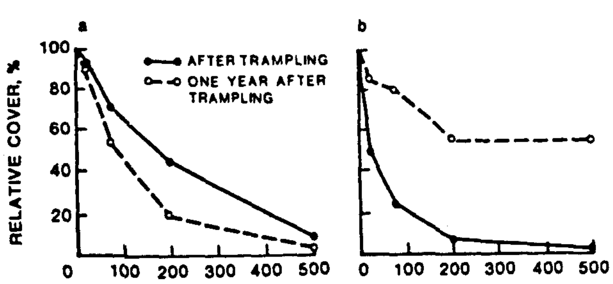
Second, the adequacy of controls is tested by calculating a second relative cover measure:

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

where cf = initial cover on control subplots - surviving cover on control subplots

This second measure uses a correction factor based on absolute rather than proportional differences on the control. It will provide the same result as the original formula when controls are similar, before treatment, to treated lanes. Where the two results are similar, we have been reporting relative cover for individual species, using the original formula. Where they are not similar, quantification of response could be misleading and we have merely classified species response (see Discussion).

The responses of *Valeriana sitchensis* and *Vaccinium scoparium*, the understorey dominants of their respective



NUMBER OF PASSES

Fig. 5. Relative cover after trampling and one year after trampling for (a) *Vaccinium scoparium* and (b) *Valeriana sitchensis.*

vegetation types, can be quantified (Fig. 5). In each case, the pattern of damage and recovery parallels that for the entire type, although the cover of *Valeriana* did not increase as much, during the year after trampling, as it did in the type as a whole.

DISCUSSION

One goal of experimental trampling research is to provide measures of the response of vegetation to different levels of trampling. In a wide variety of vegetation types, studies that follow the protocol we have described can generate reliable relative cover and height data. These data provide estimates of both damage and recovery that can be directly compared with estimates provided by other studies using the same design.

A second goal is to characterize the vulnerability of different vegetation types. The relative cover data generated by this procedure can be used to characterize vulnerability, but varied interpretations are possible. The concept of vulnerability has several distinct facets, there are several potential definitions of vulnerability, and there are many alternative ways that relative cover data can be used to assess vulnerability. The discussion that follows outlines several facets of vulnerability and suggests some ways that vulnerability might be assessed. In contrast to the experimental layout, treatments, measurements, and data analysis-which we feel should be standardized wherever possible-the most appropriate way to characterize vulnerability may vary between studies.

One important facet of vulnerability is the ability of a vegetation type to resist being altered by trampling. This characteristic, which has often been referred to as *resistance* (Webster *et al.*, 1975; Kelly & Harwell, 1990; Sun & Liddle, 1991), can be assessed on the basis of the level of trampling needed to cause a given amount of vegetation change. Liddle (1975), for example, suggested using the number of passes that reduces cover 50% as an indicator of resistance. Relative cover falls below 50% after about 650 passes in the *Carex* type, 200 passes in the *Vaccinium* type, and less than 25 passes in the *Valeriana* type.

Alternatively, resistance can be defined by the amount of damage caused by a given level of trampling or range of trampling intensities. An indicator suggested by Cole (1985) is the mean expected relative cover after trampling, for all possible levels of trampling between 0 and 500 passes. Although only five trampling intensities were applied, the resultant responses define a curve of expected relative cover values between 0 and 500 passes (Fig. 2). The mean of all these expected values is equal to the proportional area below the curve. This mean can be derived by calculating the area of a series of rectangles that together approximate the area under the curve and, then, dividing this area by the total area of the graph. For the *Valeriana* type, mean relative cover, for all possible trampling intensities between 0 and 500 passes, is only 16%. This index of resistance is 49% for *Vaccinium* and 85% for *Carex*. In the *Carex* type, only the portion of the graph from 0 to 500 passes on the x axis should be considered.

The index suggested by Liddle has more tradition but it does not use much of the available data and an anomalous result is more likely to introduce error. Either index provides a direct means of comparing vegetation types.

Another facet of vulnerability is the ability to recover from damage caused by trampling, once trampling ceases. This characteristic, which has often been referred to as *resilience* (Webster *et al.*, 1975; Kelly & Harwell, 1990; Kuss & Hall, 1991), can be assessed by estimating the amount of recovery that occurs after a given level of trampling disturbance. For example, one potential resilience index is the change in relative cover that occurs, during a one-year period, following a 50% reduction in cover caused by trampling. Expressed as a percent of the vegetation change caused by trampling (a 50% cover loss), this would be a 100% increase in cover in *Valeriana*, an 86% increase in *Carex*, and a 32% decrease in *Vuccinium* (Fig. 2). This index compares recovery from a common level of damage, but the levels of trampling that caused that damage were quite different. The 50% cover loss was caused by 25, 650, and 200 passes, respectively.

The other alternative is to estimate recovery after the curtailment of a given level of trampling or range of trampling intensities, regardless of how much vegetation loss that trampling caused. Again it is possible to calculate an index that integrates the effects of all possible trampling levels between 0 and 500 passes. The proportion of the graph in Fig. 2 that lies between the two curves is 64% for the *Valeriana* type. This means that, across the range from 0 to 500 tramples, relative cover increased 64% during the year of recovery. This index was 12% for *Carex*, and - 11% for *Vaccinium*. This index is misleading, however; because of high resistance, the *Carex* type had little potential to increase in cover. A better index is this value, expressed as a percent of the change caused by trampling (the proportion above the after-trampling curve). This is the ratio between the amount of recovery that did occur and the amount that could possibly have occurred-76% for *Valeriana*, 80% for *Carex*, and -22% for *Vaccinium*.

Vulnerability can also be defined on the basis of the similarity between original vegetative conditions and conditions after one complete cycle of damage and recovery. This characteristic, which we term *tolerance*, integrates both resistance and resilience. Tolerance could be assessed on the basis of the number of passes a vegetation type could tolerate and retain relative cover of at least 75% one year after trampling. This index would be more than 700 passes for *Carex*, *300* passes for *Valeriana*, and 75 passes for *Vaccinium*. An alternative index is the mean expected relative cover one year after trampling (the proportion of the graph below the relative cover curve one year after trampling). This tolerance index is 97% for *Carex*, 80% for *Valeriana*, *and 38%* for *Vaccinium*. Tolerance provides a single overall indication of vulnerability; however, it does not indicate whether a high level of tolerance results from an ability to resist damage, an ability to recover rapidly from damage, or both.

Table 1. Indices of resistance, resilience, and tolerance for three vegetation types

Index	Vegetation type		
	Valeriana	*Vaccinium*	*Carex*
Resistance			
Minimum no. of passes that cause a 50% cover loss	25	200	650
Mean relative cover after 0-500 passes	16	49	85
Resilience			
Percent increase in cover one year after 50% loss	100	-32	86
Mean increase in cover one year after O-500 passes, as a percent of the damage caused by trampling	76	-22	80
Tolerance			
Maximum number of passes that leave at least 75% cover one year after trampling	300	75	>700
Mean relative cover one year after O-500 passes	80	38	97

Indices of resistance, resilience, and tolerance for the three vegetation examples are provided in Table 1. These indices provide a means of quantifying the general response of each vegetation type to trampling disturbance, responses that are graphically evident in Fig. 2. These various facets of vulnerability can also be combined in a single graph (Fig. 6) that portrays resistance on one axis (mean relative cover after 0-500 passes) and tolerance on the other (mean relative cover one year after 0-500 passes). Resilience the perpendicular distance of the resulting data point from the diagonal line of equal resistance and tolerance. This shows the *Valeriana* type (broadleaved herbs) to be characterized by low resistance, high resilience, and relatively high tolerance. The *Vaccinium* type (short shrubs) has moderate resistance, very low resilience, and low tolerance. The *Carex* type (low, matted sedges) has very high resistance and tolerance. Resilience is relatively high, when expressed as a proportion of how much recovery could possibly occur, although the absolute increase in cover over the year was low.

Similar indices can be provided for individual species, provided that it is feasible to calculate relative

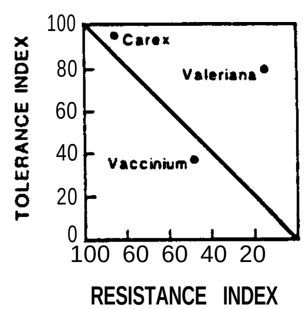


Fig. 6. Relative resistance and tolerance of three vegetation types to trampling disturbance. Refer to text for definitions.

cover values. Species for which this is not feasible can often be classified according to their relative resistance and tolerance. We have based these classifications on analysis of the species' mean cover before trampling, after trampling, and after one year of recovery. These values are used to estimate resistance on the basis of the minimum number of passes required to reduce clearly cover by at least 50%. Classes are high (500 passes or more), moderate (200 passes), and low (75 passes or less). For example, a species with a relative cover of 60% on the 75-pass lane and 40% on the 200-pass lane would be classified as moderately resistant. Tolerance is based on the maximum number of passes that can be endured and still have cover, one year after trampling, of at least 75% of original cover. Tolerance classes are high (500 passes or more), moderate (200 passes), and low (75 passes or less).

The protocol suggested here is a pragmatic approach to obtaining standardized information on vegetation responses to trampling. Although the details outlined have been derived from trials in contrasting situations, and much discussion, further modification and adaptation may be required for situations elsewhere. Some problems of data analysis have been identified and solutions suggested, but further solutions may become apparent with additional work. Two final caveats are (1) this protocol is only intended for studies of short-duration trampling effects and (2) it will not work well in some vegetation types. Investigators must weigh the relative benefits of utilizing standard techniques that permit comparison with other studies, and techniques adapted to maximize the efficiency of their specific study.

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