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Revegetation after short-term trampling at subalpine heath vegetation

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We investigated how the timing and direction of low-pressure and short-term trampling influences revegetation of plant lifeforms at subalpine heath vegetation in northern Finland. Two trampling experiments were applied during summer 1999 to simulate the influence of unofficial trails that are common in popular recreation areas. Timing of trampling had no impact on the vegetation. Downward trampling reduced the total vegetation cover and the cover of evergreen dwarf shrubs more than did upward trampling, but only during the trampling year. The cover of vascular plants decreased directly after trampling, while the bryophytes showed a slower response to the treatment. Also the recovery of the vascular plants occurred more rapidly compared with the bryophytes. The cover of lichens increased in all treatments, apparently due to crumbling into smaller pieces. Although trampling impacts occur rapidly even under very low levels of use, revegetation is rapid if the trampling pressure is removed.

Key words: disturbance, recreation, regeneration, subalpine, trampling

Introduction

Recreational activities cause disturbance, which can be divided into killing of vegetation by trampling, and removal of vegetation and soil (Cole 1989, Hunter & Green 1995, Cole & Landers 1996). Trampling may change the species composition and reduce species richness (Chappell *et al*. 1971). Liddle (1975) suggests that the two major effects of trampling are: (1) direct mechanical pressure, which damages the plants; and (2) indirect effects on the physical and/or chemical characteristics of the soil, which cause damage to plant growth and reproduction. The impacts are related to the amount of disturbance (Cole 1987, Ikeda & Okutomi 1990). It is important to look at trampling thresholds and recreation carrying capacities, when developing principles of sustainable recreational use and the management of protected areas (Cole & McCool 1998). The overall tolerance of plants to trampling integrates the resistance and recovery after disturbance (Cole & Bayfield 1993). Resistance and recovery are connected with plant morphological characteristics and growth rate of species, which in turn vary between different site types (Whinam & Chilcott 2003). Also the topography greatly influences the vulnerability of a habitat to disturbances (Karjalainen & Verhe 1995).

We already have information on the impacts of trampling of various intensities on arctic and alpine vegetation (e.g. Tolvanen *et al*. 2001, Monz 2002). According to these studies, the negative impacts of hiking on vegetation show non-linear patterns and at some threshold the loss of vegetation is total. There is less information on the impact of the timing of trampling on vegetation (Holmström 1970) or the direction of trampling on slopes, however. Trampling early in the growing season may have greater effects on vegetation than trampling carried out later in the season. This is due to resources allocated to growing tissues, which would be lost if damaged early in the season. Later in the summer, resources are already transported to below-ground reserve meristems, which are protected from trampling (Zasada *et al.* 1994). The direction of trampling may influence the regeneration of vegetation on the slopes. The impacts of downward trampling on vegetation may be greater as compared with those of upward trampling, because the pressure of footsteps is greater when going down (Bayfield 1973).

In northern Finland, subalpine heath communities in protected areas are preferred habitats for recreation due to their easy accessibility and beautiful landscapes. Hiking in these habitats can have rapid negative consequences on vegetation. Depending on the vegetation type, visible trails form as soon as 10–25 persons have used a particular route (Tolvanen *et al*. 2001). Even though most hikers use formed trails, informal routes with lower trampling pressure are commonly formed in these environments. The regeneration of these trails is important for the environmental quality of the recreation areas.

In this study we investigated the regeneration of low-pressure trails that simulate trampling on untracked subalpine heath vegetation. The specific questions were: (1) Are there differences between trampling carried out in early, mid and late seasons? (2) Are there differences between trampling carried out in upward and downward directions on fjell slopes? (3) Are there differences between plant lifeforms in their responses to trampling? Although trampling is mainly bidirectional on formed trails, directional upward or downward trampling may occur especially on difficult terrains, such as slopes.

Material and methods

The study area

The study site was located at Pallas-Ounastunturi National Park, 30 km east of Muonio, Finland (68°05´N, 24°04´W, altitude 500–550 m a.s.l.). Pallas region is located near the northern limit of the boreal zone (Kalela 1961). Annual mean temperature during the study period 1999–2002 was –0.6 °C and ranged between –1.0 °C and 0.4 °C (Finnish Meteorological Institute 1999, 2000, 2001, 2002). The minimum and maximum temperatures were –47.2 °C and 28.1 °C, respectively. The ground was covered with snow from the middle of October to late May (ca. 220 days). Mean snow cover depth varied between 0 and 93 cm. Annual precipitation was 445–629 mm (Finnish Meteorological Institute 1999, 2000, 2001, 2002). Vegetation in the study area is treeless heath dominated by *Betula nana*, *Vaccinium vitis-idaea*, *Arctostaphylos alpina*, *A. uva-ursi* and *Juniperus communis* Beyond the upper limit of the treeless heath is the subalpine belt which consists mainly of low vascular plants, bryophytes and lichens. Since the 1950s, intense tourist pressure has led to heavy degradation of the site. Currently, the number of annual visitors is over 125 000 (Metsähallitus 2003).

Experimental design

Two separate experiments were carried out on a subalpine heath of the Pallaskero fjell in 1999, within an area of 20 000 m^2, located approximately 500 m from the nearest hiking trails. Experimental trails of 3 m × 0.3 m were placed on sites of similar vegetation, five replicates per treatment in each experiment, 3–5 m apart. The treatments were randomly assigned on the trails. In the first experiment, the influence of the timing of trampling was investigated by applying 150 passes on flat terrain either on 11 June, 8 July, or 27 September 1999. In the second experiment carried out on a slope, 25 passes were applied either upward or downward on 3 August 1999. Light trampling intensities were applied in order to imitate the trampling pressure on informal trails. The chosen trampling intensities were based on earlier observations, in which both 150 passes on flat terrain and 25 passes on the slopes reduced the vegetation cover by about 50% (J. Rautio pers. obs.). A pass was a one-way walk along a treatment trail by one person. Each treatment was trampled on the same day by persons weighing 60–65 kg and wearing heavy hiking boots. The inclination of slope trails, measured using the height meter, varied from 18° to 24°.

The experimental trails were divided into 100 cm^2 subplots, 90 per trail. Vegetation cover of individual plant species was measured in each subplot at 5% intervals. Cover analyses were carried out four times: (1) before trampling in June 1999, (2) 10 days after trampling in each treatment (3) in September 2001, and (4) in September 2002.

Data analyses

Plant resistance to trampling was defined as 50% cover relative to the initial level 10 days after trampling, while the plant tolerance indicates 75% of the initial level two years after trampling. The method is a modification of Cole and Bayfield (1993) who used 75% plant cover one year after trampling as an estimation of tolerance. Full recovery was assumed to have happened at the point where the plant cover did not differ significantly from the initial cover.

Plant species were pooled into six lifeforms; evergreen dwarf shrubs, deciduous dwarf shrubs, graminoids, herbs, bryophytes and lichens. The data were analysed separately for each group using the repeated measures ANOVAR. In the first experiment, the timing of trampling (June, July, September) was the between-subjects factor, while the time of the cover measurements was the within-subjects factor. Tukey's post hoc test was applied to compare the difference between the three trampling treatments. In the analysis of the second experiment, the direction of trampling was the between-subjects factor, and the time of cover measurements was the within-subjects factor. When the data did not directly satisfy the Mauchly's condition required for univariate testing in the repeated measures ANOVAR, the Huynh-Feldt-adjusted F values were used. Multiple comparisons among the cover analyses were made using the SIMPLE transformation, which compares the first cover analysis, i.e. the pre-treatment situation, with all other cover analyses. The initial cover is scaled to 1 in the figures. The analyses were carried out using SPSS 12 for Windows (SPSS 2003).

Results

Initial vegetation

Before trampling, the site on flat terrain was dominated by bryohytes (50.0% ± 4.9% cover), followed by evergreen and deciduous dwarf shrubs (33.0% ± 2.8%, and 10.3% ±1.5% respectively). The cover of lichens was 8.2% ± 1.1%. Herbs and graminoids represented only 3.1% ± 1.1% and 2.3% ± 0.5% of total cover, respectively. The sloping site consisted predominantly of evergreen dwarf shrubs (41.1% ± 2.9% cover) and bryophytes (15.39% ± 2.6% cover). The species list is presented in the Appendix.

Experiment I: Timing of trampling

There were no significant differences between the three trampling treatments, neither in the total plant cover nor in the cover of any plant lifeform (Table 1 and Fig. 1). During the trampling year, the treatment reduced the total plant cover to 0.59 ± 0.05 (59%) relative to the initial cover (Table 1 and Fig. 1A). Hence the vegetation cover remained above the resistance level after 150 passes. In 2001 however, the total cover reached the tolerance level only in treatments trampled June (Fig. 1A). By 2002, the tolerance level had been almost reached in all treatments (0.72 ± 0.03), but the difference with initial cover was still significant indicating that full recovery had not yet occurred ($p < 0.001$, Table 1). The cover of lichens remained just above the resistance level after trampling (Fig. 1B). The recovery occurred in 2001, after which the lichen cover increased above the original level ($p = 0.004$, Table 1 and Fig. 1C). Trampling most noticeably reduced the cover of bryophytes, evergreens and deciduous dwarf shrubs (reduction: 0.36 ± 0.02, 0.18 ± 0.01, and 0.25 ± 0.05 relative to the initial cover, respectively, Fig. 1C–E). The decline in cover of the bryophytes was slower than in the dwarf shrubs, however. Three years after trampling, the cover of bryophytes was still lower than their initial cover ($p < 0.001$, Table 1), whereas the evergreen dwarf shrubs had recovered to pre-trampling cover. Deciduous dwarf shrubs recovered in two years, as did the graminoids (Fig. 1E, F and Table 1). The herbs did not react significantly to trampling (Fig. 1G and Table 1). Although their cover decreased immediately after trampling, the original cover was reached by 2001.

Experiment II: Direction of trampling

The direction of trampling had no significant impact on the total plant cover or the cover of any plant lifeform (Table 2 and Fig. 2). However, the interaction between the direction of trampling and the time of cover measurements was significant for total plant cover ($p = 0.011$, Table 2). Immediately after treatment, downward trampling appeared to reduce the total plant cover more than did upward trampling (Fig. 2A). However, the resistance level of 50% was not broken in either treatment, as on average, the total plant cover was 0.66 ± 0.03 (66%) relative to initial cover. The cover of lichens showed a similar response as in experiment I: after a decrease during the first year, the lichen cover increased above the original level at the end of the experiment (Fig. 2B, $p = 0.019$, Table 2). Also bryophytes showed a similar delay in loss of cover as in experiment I (Table 2 and Fig. 2C). During the trampling year, the cover of evergreen dwarf shrubs was below the resistance level on trails trampled downwards but not on those trampled upwards (Fig. 2D). This was also indicated by a significant interaction between the timing of cover analyses and the direction of trampling (Table 2). The impact of the direction of trampling was not significant on deciduous dwarf shrubs, graminoids and herbs due to the high variation in their cover (Fig. 2E–G and Table 2).

Table 1. Relative changes in the total plant cover and the cover of plant lifeforms after three trampling times. Repeated measures ANOVAR, where the trampling time is the between factor (df = 3) and sampling time is the within-factor (df = 6). Interaction df = 1, $n = 5$.

Plant lifeform		Timing of trampling	Time of cover analyses	Timing of trampling × time of cover analyses	Initial cover *vs.* cover after trampling	Initial cover *vs.* cover 2001	Initial cover *vs.* cover 2002
Total cover	*F*	0.46	80.63	2.03	214.34	159.69	36.09
	p	n.s.	< 0.001	n.s.	< 0.001	< 0.001	< 0.001
Lichens	*F*	0.33	28.10	0.58	19.43	0.73	12.37
	p	n.s.	< 0.001	n.s.	0.001	n.s.	0.004
Bryophytes	*F*	0.22	66.14	1.42	7.12	113.77	70.01
	p	n.s.	< 0.001	n.s.	0.020	< 0.001	< 0.001
Evergreen dwarf shrubs	*F*	2.02	59.34	1.62	123.42	72.35	2.76
	p	n.s.	< 0.001	n.s.	< 0.001	< 0.001	n.s.
Deciduous dwarf shrubs	*F*	3.00	22.11	1.39	33.77	3.86	0.50
	p	n.s.	< 0.001	n.s.	< 0.001	n.s.	n.s.
Graminoids	*F*	1.13	7.88	0.38	16.50	2.32	1.66
	p	n.s.	0.001	n.s.	0.002	n.s.	n.s.
Herbs	*F*	0.79	2.38	0.71	5.54	4.59	0.86
	p	n.s.	n.s.	n.s.	0.037	0.053	n.s.

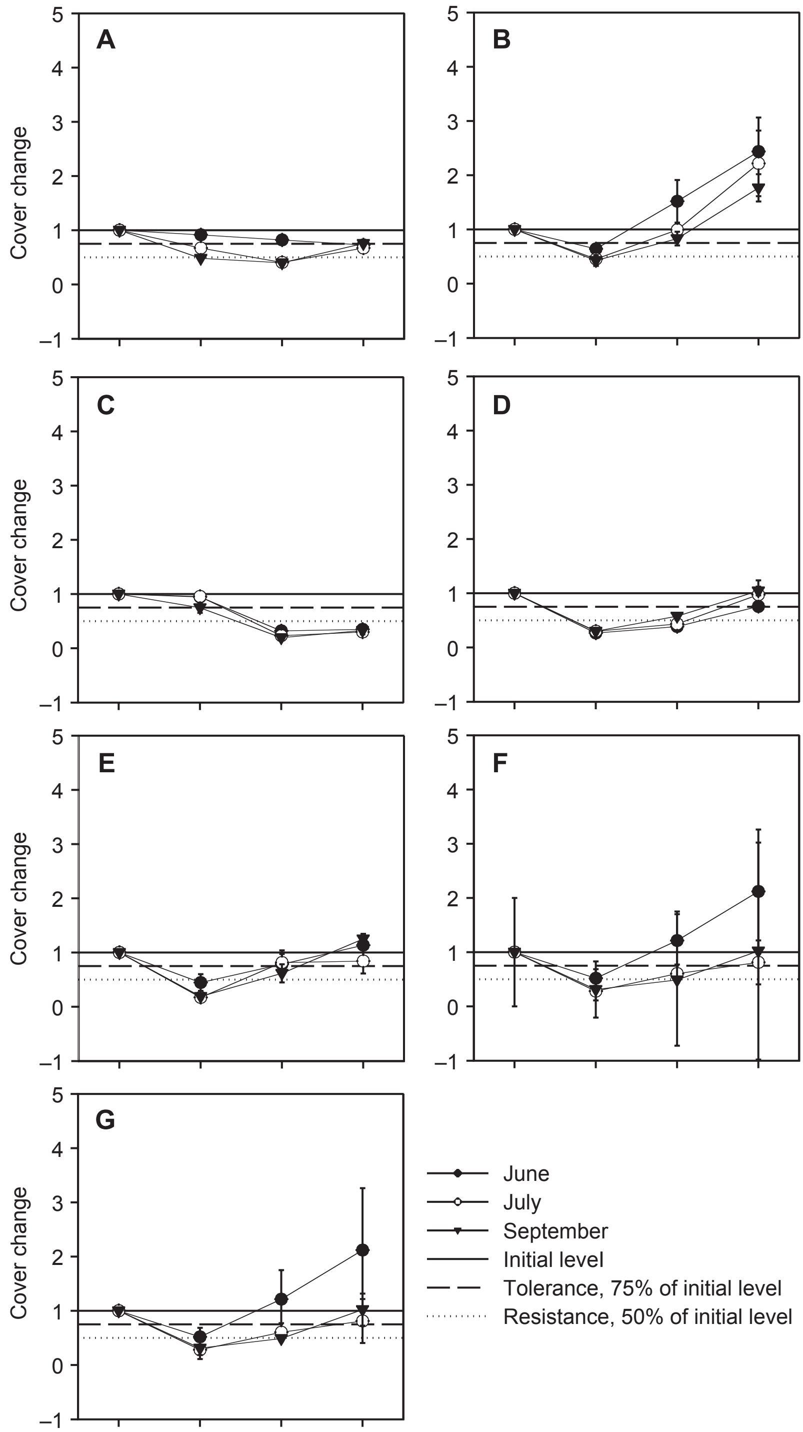

Fig. 1. Cover changes relative to the initial cover (± S.E.) after three trampling times: June, July and September 1999. Initial cover is scaled to 1. — **A**: Total vegetation. — **B**: Lichens. — **C**: Bryophytes. — **D**: Evergreen dwarf shrubs. — **E**: Deciduous dwarf shrubs. — **F**: Graminoids. — **G**: Herbs.

Discussion

The rate at which a plant community can sustain human use is a combination of its ability to resist trampling and its capacity to regenerate (e.g. Cole & Monz 2002). Our results support earlier studies and show that even low-level trampling pressure can cause a significant reduction in arctic and alpine heath vegetation (Tolvanen *et al*. 2001, 2004, Monz 2002). However, regeneration seems to be relatively rapid, as the disturbance is not prolonged. This kind of short-term trampling study may not fully imitate the natural state of low-pressure trails, on which the recreational pressure may be continuous (Monz 2002). However, the study gives information on the thresholds of damage. We observed that trampling decreased the total cover to 59% from the original level on flat terrain and to 66% on the slopes. Since the trampling levels were 150 and 25 passes, respectively, we can generalize that the impact of trampling was almost 6-fold on the slopes relative to that on flat terrain. However, this relationship will not hold in case of other trampling intensities, since the impact of trampling is not linear (Hammit & Cole 1998, Tolvanen *et al*. 2001, Monz 2002). Even though the species mix and lifeforms may not vary between flat and sloping terrains, environmental impacts between slopes and flat sites may be quite different. Trampling causes soil movement and erosion especially on the slopes, which can lead to frost and snow heave (Whinam & Chilcott 2003). Informal trails are therefore easily formed especially on slopes.

Contrary to our expectations we did not find any consistent response in the vegetation to the variation of the timing of trampling. The main reasons are apparently the short-term nature and low intensity of the trampling treatments and the great variation in plant cover between individual trails. Response to the direction of trampling was observed during the trampling year: downward trampling reduced the total cover and the cover of evergreen dwarf shrubs more than did upward trampling. The response was soon levelled out due to the recovery of vegetation, however, which indicates that the direction of low-level trampling has only a short-term impact on vegetation.

Lichens and bryophytes showed distinct responses to trampling. Lichens tolerated trampling quite well, and their cover increased above the original level, which might be a consequence of lichen tissue crumbling to smaller particles. When dry, lichens break very easily into small pieces and those pieces have an ability to grow (Jahns 1996). The cover of lichens has been observed to increase also on skiing trails (Tervo 2003). Despite the increasing cover, however, the growth of height and biomass may have been suppressed by trampling. Bryophytes showed a delayed response, which has been observed elsewhere both in bryophytes (Callaghan & Emanuelsson 1985, Pesonen 2003) and in other

Table 2. Relative changes in the total plant cover and the cover of plant lifeforms after downward and upward trampling. Repeated measures ANOVAR, where trampling direction is the between-factor (df = 1) and sampling timing is the within-factor (df = 3). Interaction df = 1, n = 5.

Plant lifeform		Direction of trampling	Time of cover analyses	Direction of trampling × time of cover analyses	Initial cover *vs.* cover after trampling	Initial cover *vs.* cover 2001	Initial cover *vs.* cover 2002
Total cover	*F*	0.68	15.53	5.01	206.36	0.09	0.98
	P	n.s.	< 0.001	0.011	< 0.001	n.s.	n.s.
Lichens	*F*	0.09	14.80	0.22	8.62	0.18	15.50
	P	n.s.	< 0.001	n.s.	0.019	n.s.	0.004
Bryophytes	*F*	0.09	5.08	0.47	3.11	0.59	28.15
	P	n.s.	0.021	n.s.	n.s.	n.s.	0.001
Evergreen dwarf shrubs	*F*	0.62	26.01	5.47	77.19	1.05	6.44
	P	n.s.	< 0.001	0.005	< 0.001	n.s.	0.035
Deciduous dwarf shrubs	*F*	0.52	3.75	1.07	6.09	2.01	0.42
	P	n.s.	0.033	n.s.	0.039	n.s.	n.s.
Graminoids	*F*	3.89	6.53	0.64	2.10	2.10	3.85
	P	n.s.	0.002	n.s.	n.s.	n.s.	0.025
Herbs	*F*	1.63	2.23	1.05	1.43	0.28	0.51
	P	n.s.	n.s.	n.s.	0.010	n.s.	n.s.

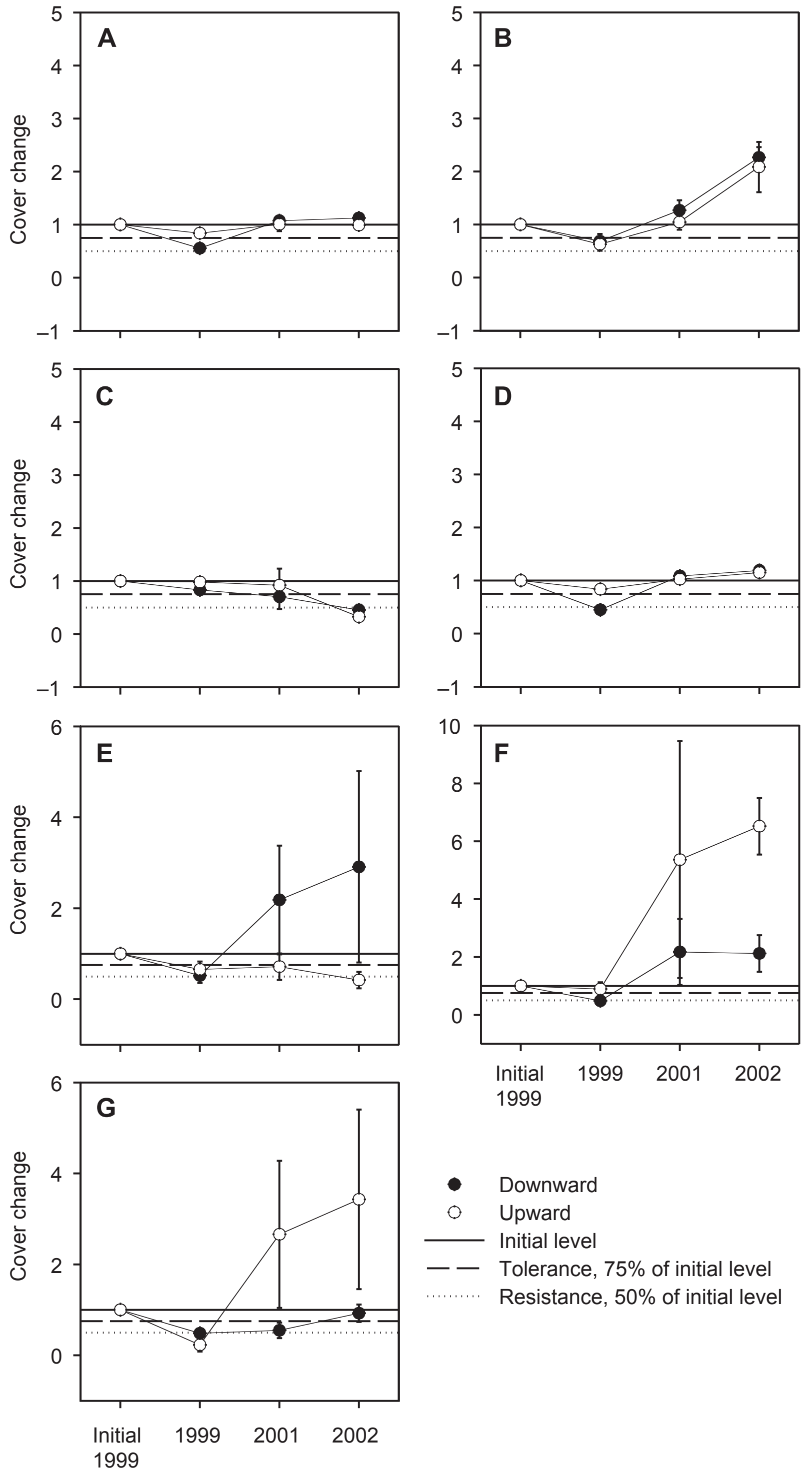

Fig. 2. Cover changes relative to initial cover (± S.E.) after two trampling directions. Initial cover is scaled to 1. — **A**: Total vegetation. — **B**: Lichens. — **C**: Bryophytes. — **D**: Evergreen dwarf shrubs. — **E**: Deciduous dwarf shrubs. — **F**: Graminoids. — **G**: Herbs. Note the different scales in panels **E**, **F** and **G**.

slow-growing species, such as an evergreen dwarf shrub *Empetrum nigrum* (Forbes *et al.* 2004). The delayed response of the bryophytes might be explained by the removal of protective vascular vegetation (Tolvanen *et al.* 2004), which changes the microclimate, especially moisture conditions. Bryophytes are the most susceptible group to disturbance (Ukkola 1995, Rydgren *et al*. 1998) apparently due to their slower growth relative to vascular plants.

The cover of vascular plants decreased quickly after trampling, but also their recovery had commenced in the second year after trampling. Since the cover was not measured during the first year after trampling, we do not know the starting date of recovery. It has been shown that the loss of vegetation cover continues after trampling (Cole & Bayfield 1993). Other studies show that it can take even 6–12 months after trampling before the vegetation reacts to treatment, and the greatest effect may be seen in the second year of study (Whinam & Chilcott 2003). The order of recovery of the vascular plants was similar to earlier herbivory studies in the arctic region where evergreen dwarf shrubs needed more time to recover than did the deciduous dwarf shrubs (Chapin & Chapin 1980). Herbs and graminoids thereby showed little response to short-term trampling, and their cover could even exceed the original level. The recovery rate is associated with the photosynthetic and growth rates, which are higher in graminoids, herbs and deciduous dwarf shrubs than in evergreen plants (Chapin & Chapin 1980, Karlsson 1989). However, the herbs disappear completely under prolonged trampling (Pesonen 2003), which indicates that their tolerance is lowered by their low resistance to trampling.

Although short-term and low-use trails regenerate relatively quickly, the formation of informal trails should be regarded with concern. Such trails have a tendency to increase in both number and size due to increasing recreational pressures. Since the degradation of nature decreases its value for recreation, a good way to protect the environment from further wear is the guidance of most recreationists. This could be done by using hand-made structures, such as stairs, duckboards, and trail covering, especially at the most sensitive sites such as steep slopes.

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Appendix. Species or genera observed in the trampling experiment trails: 'June, July and September' indicate the timing of trampling in the experiment I, while 'Down' and 'Up' indicate the direction of trampling in the experiment II.

Species	June	July	September	Down	Up
Antennaria dioica	–	–	–	x	x
Arctostaphylos alpina	x	x	x	x	x
Arctostaphylos uva-ursi	x	–	x	x	x
Betula nana	x	x	x	x	x
Calamagrostis sp.	x	–	–	–	–
Carex sp.	x	–	–	–	–
Cetraria ericetorum	x	x	x	x	x
Cetraria nivalis	x	x	x	x	x
Cladina arbuscula	x	x	x	x	x
Cladina rangiferina	x	x	x	x	x
Cladina stellaris	x	x	x	x	x
Cladonia sp.	x	x	x	x	x
Deschampsia flexuosa	x	x	x	x	x
Dicranum sp.	x	x	x	x	x
Diphasiastrum alpinum	–	–	–	x	x
Empetrum nigrum ssp. *hermaphroditum*	x	x	x	x	x
Festuca ovina	x	x	x	x	x
Hepaticeae sp.	x	x	x	x	–
Hieracium sp.	x	–	–	–	x
Icmadophila ericetorum	x	x	x	–	–
Juncus trifidus	x	x	x	x	–
Juniperus communis	x	–	–	x	x
Linnaea borealis	x	x	x	x	x
Loiseleuria procumbens	–	x	x	–	x
Nephroma arcticum	x	x	x	x	x
Orthilia secunda	–	–	–	–	–
Pedicularis lapponica	–	x	–	–	–
Peltigera aphthosa	x	x	x	–	–
Phyllodoce caerulea	–	x	–	–	–
Picea abies	x	x	x	x	–
Pleurozium schreberi	x	x	x	x	x
Poa sp.	x	x	x	x	x
Polytrichum sp.	x	x	x	x	x
Racomitrium sudeticum	x	–	–	–	–
Stereocaulon alpinum	x	x	x	x	x
Solidago virgaurea	–	–	–	x	x
Vaccinium myrtillus	x	x	x	x	x
Vaccinium uliginosum	–	x	x	x	x
Vaccinium vitis-idaea	x	x	x	x	x