



Visitors off the trail: Impacts on the dominant plant, bryophyte and lichen species in alpine heath vegetation in sub-arctic Sweden



Monika Rawat^a, Annika K. Jägerbrand^b, Ulf Molau^c, Yang Bai^d, Juha M. Alatalo^{a,*}

^a Environmental Science Center, Qatar University, PO Box 2713, Doha, Qatar

^b Department of Environmental and Biosciences, Rydberg Laboratory of Applied Science (RLAS), School of Business, Engineering and Science, Halmstad University, P.O. Box 823, SE-301 18 Halmstad, Sweden

^c Department of Biological and Environmental Sciences, University of Gothenburg, PO Box 461, SE-405 30 Gothenburg, Sweden

^d Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Menglun, Mengla, Yunnan 666303, China

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ABSTRACT

Alpine ecosystems are under increasing pressure due to tourism and recreational activities. When leaving designated trails as is frequently observed, visitors can cause unintentional damage to vegetation. This study investigated the effect of human trampling on the dominant species of vascular plants, bryophytes and lichens along an infrequently used hiking trail in an alpine ecosystem in sub-arctic Sweden. The hypothesis tested was that proximity to the trail (as an effect of more people leaving the trail for a short distance compared to a longer distance) causes a decrease in species with low resistance to trampling. With a greater decrease in taller forbs and shrubs than in graminoids and prostrate plants, a greater decrease in lichen than in bryophyte species, and a change in vegetation composition. The results showed that proximity to the trail did not cause a decrease in the majority of dominant species, with none of the eight most dominant vascular plants showing any significant effects of proximity to the trail. One bryophyte species (*Dicranum elongatum*) among the six most commonly found decreased with proximity to the trail. Three lichen species (*Cladonia arbuscula*, *Cladonia uncinata*, *Ochrolechia frigida*) among the eight most common species decreased with proximity to the trail. There was no evidence that taller species decreased with proximity to the trail, although the deciduous shrub *Betula nana* showed a tendency for a decrease. Proximity to the trail caused a greater decrease in lichen species than in bryophyte species. Multivariate analyses showed that distance from trail and transect direction had significant effects on overall vegetation composition. The level of low-intensity trampling recorded indicates that current numbers of hikers at the site can be sustained for longer periods with minimum impact on vascular plant species, but to get a more general understanding of the impact of low-intensity trampling data from additional sites are needed.

1. Introduction

Recreational and tourism activities are causing disturbances in natural ecosystems worldwide (Atik et al., 2009; Mcdougall and Wright, 2004; Perevoznikova and Zubareva, 2002; Whinam et al., 1994). In particular, these human-related activities are increasing the pressure on alpine ecosystems (Monz, 2002; Pickering and Hill, 2007; Zhang et al., 2015). Activities such as hiking, mountain biking, snowmobile touring and horse riding affect alpine vegetation (Barros and Pickering, 2015; Pescott and Stewart, 2014; Pickering and Hill, 2007; Whinam et al., 1994). In addition, visitors often stray away from the designated trails and cause trampling damage to the vegetation (Barros et al., 2020; Goh, 2020; Park et al., 2008). Human disturbances

have been shown to affect the vegetation of alpine ecosystems in a number of ways, such as decreasing biomass, cover, litter, species composition and richness (Ballantyne et al., 2014; Monz, 2002; Pickering and Hill, 2007). The most common threat to vascular plants in Europe is tourism and recreational activities, which are threatening 42% (194 species) of vascular plant species across 50 families (mostly herbs, 70 %) on the IUCN Red List (Ballantyne and Pickering, 2013). More specifically, these activities can alter the cover and dominance hierarchies of bryophytes, lichens and vascular plants (Gheza et al., 2018; Jägerbrand and Alatalo, 2015; Törn et al., 2006). Furthermore, human disturbances can cause reductions in biomass and vegetation height, changes in species composition, formation of informal trails and an increase in weeds and plant pathogens in the vegetation (Barros et al., 2013; Farrell and Marion, 2001; Pickering et al., 2010). However, the impacts are not always negative, as proximity to trails has been shown to have a positive effect on species richness in grassland (Kostrakiewicz-

* Corresponding author.

E-mail address: jalatalo@qu.edu.qa (J.M. Alatalo).

Gieralt et al., 2020). Disturbances caused by tourism have been shown to have stronger effects on plant communities than physiographical factors (i.e. elevation, slope) in forest vegetation, with disturbed areas having different species composition distinguished by unique indicator species (Niu and Cheng, 2019). Trampling disturbance not only changes the dominant vegetation, but can also cause soil erosion, soil compaction, changes in soil hydrology, trail widening, and exposure of roots, rocks and bedrocks in existing trails (Dunne and Dietrich, 2011; Mcdougall and Wright, 2004). Apart from human disturbances, alpine areas are also frequently affected by grazing activities by the natural fauna (Czortek et al., 2018b; Pauler et al., 2019), and by semi-domesticated reindeers and pack animals in regions such as Fennoscandia and the Andes (Barros and Pickering, 2015).

Tundra plant communities may be able to tolerate moderate levels of hiking, but extreme situations can result e.g. in substantial reductions in plant cover (Monz, 2002). Under harsh climate conditions with poor soil development, low productivity and a short growing season, the process of vegetation recovery due to trampling in sensitive tundra regions may be slow (Jägerbrand and Alatalo, 2015). This indicates that the plant communities in more sensitive areas, such as alpine and sub-arctic to arctic tundra, may have only moderate tolerance to human disturbances (Pickering and Growcock, 2009; Czortek et al., 2018a). Hence, site management can play an important role in counteracting the effects of tourism and human disturbance (Kuba et al., 2018). This creates a need to evaluate the impact of hiking on the surrounding vegetation, to confirm whether human disturbances cause detrimental changes to the plant communities. Important factors for determining the response of vegetation to trampling disturbance are the intrinsic properties of plants, such as morphological characteristics and Raunkiaer life form (Pescott and Stewart, 2014; Raunkiaer, 1905, 1934). Moreover, in response to experimental trampling, plant morphological characteristics such as plant height, erectness and plant functional groups have been found to be more important than site characteristics such as altitude or canopy cover (Cole, 1995). In general, graminoids, short plants and prostrate plants are more resistant to trampling than shrubs and taller forbs (Ballantyne et al., 2014; Bernhardt-Römermann et al., 2011; Yorks et al., 1997), with erect forbs being the most vulnerable group to trampling (Cole, 1995). However, some studies have found lichens and deciduous shrubs to be the most vulnerable to long-term low intensive trampling, as their incidence decreases with proximity to trails (Jägerbrand and Alatalo, 2015).

In a previous study, we described the impact of proximity to trails on the abundance and diversity of vascular plants, bryophytes and lichens as groups on community level (Jägerbrand and Alatalo, 2015). Except for deciduous shrubs, we found no change in overall (canopy) plant cover. However, there were significant changes in the understory cover, and both lichen cover and diversity decreased (Jägerbrand and Alatalo, 2015). Certain plant functional groups can be expected to be more tolerant to trampling than others, for example grasses and sedges should be more resistant to trampling than lichens (Cole, 1995). However, as the vulnerability of plant functional groups has been shown to differ between studies, the responses may be partly species-specific and not related to functional group. Thus, the aim in this study was to investigate the effect of visitors leaving the designated trail (which is frequently observed) on species level of the most dominant vascular plants, bryophytes and lichens along a hiking trail in an alpine ecosystem in northern Sweden. This happens when people walk side by side talking with each other, stray of the trail to look at a plant, rock, a specific view, or something else that catch their interest, or when the trail is very muddy during wet conditions (snow melt or during/after rainfall).

The overall hypothesis was that proximity to the trail causes a decrease in species with low resistance to trampling (as a function of more people leave the trail for shorter distance compared to longer distance). Specific hypotheses were that proximity to the trail causes: (1) a greater decrease in taller forbs and shrubs than in graminoids and prostrate

plants; (2) a greater decrease in lichen than in bryophyte species; and (3) an overall change in vegetation composition.

2. Materials and methods

2.1. Study area

The study was conducted at Latnjajaure Field Station, sub-arctic northern Sweden (68°21'N, 18°29'E, elevation 1000 m a.s.l.). The physical conditions in the Latnjavagge valley vary from dry to wet and poor and the soils range from acidic to base-rich, with a large variation in plant communities (Alatalo et al., 2017; Björk et al., 2007; Lindblad et al., 2006). This study was conducted on a dry, poor heath community through which the trail runs (for more details, see Jägerbrand and Alatalo 2015). The Kungsleden, a 440 km long hiking trail that runs between Abisko in the north and Hemavan in the south, has a side-trail through the Latnjavagge valley. In the period 1999–2002, the number of hikers in the valley during the summer months varied between 281 and 399 per year (Beylich et al., 2005).

2.2. Measurements

This study followed a similar approach to that applied previously to examine the impact of hiking and tourism along established trails (Cole, 2004; Crisfield et al., 2012; Grabherr, 1982). Ten transects (nos. 1–10) were placed randomly perpendicular to the trail and 5–20 m apart, with three plots at 0.5 m, 2 m and 5 m distance from the trail along each transect, giving in total 30 plots (Jägerbrand and Alatalo, 2015). Transects 1, 2, 3, 5, 9 and 10 were placed in a “westward” direction from the trail, while transects 4, 6, 7 and 8 were placed in an “eastward” direction (Jägerbrand and Alatalo, 2015).

Vegetation analyses were carried out using a 1 m x 1 m quadrat point-frame with 100 gridpoints (Walker, 1996), and measuring first intercepts (abundance) at the bottom (ground) and canopy layer. Thus, maximum number of intercepts (or abundance) possible in each canopy layer per plot is 100. The fieldwork was conducted during the peak vegetation period in 2013 (29 July–6 August).

2.3. Data analyses

To test for the impact on vegetation from people leaving the designated trail, plots at different distances from the trail were compared. Abundance of species was calculated per plot and separated into canopy and understory. Only species with more than 46 hits in total were included in analyses of trail impact (but all species were included when analysing species community structure). The study included eight vascular plants (*Betula nana*, *Carex bigelowii*, *Empetrum nigrum*, *Juncus trifidus*, *Phyllodoce caerulea*, *Salix herbacea*, *Vaccinium vitis-idaea* and *Harimanella hypnoides*), six bryophyte species (*Dicranum elongatum*, *Gymnomitron* sp., *Kiaeria starkei*, *Polytrichum juniperinum*, *Polytrichum piliferum* and *Ptilidium ciliare*) and eight lichen species (*Cetrariella delisei*, *Flavocetraria cucullata*, *Flavocetraria nivalis*, *Cladonia arbuscula*, *Cladonia uncialis*, *Sphaerophorus globosus*, *Stereocaulon alpinum* and *Ochrolechia frigida*).

Prior to analysis, the data were tested for normality of distribution by the Shapiro–Wilks test (Shapiro and Wilk, 1965) and variables not meeting the normality assumption were log-transformed. Variables meeting the normality assumption were then analysed by generalised linear models (GLM), which test how one or more predictors can explain a target variable. The predictor variables used were distance from trail (0.5 m, 2 m, 5 m), direction of transect (west or east) and their interactions as fixed factors and the significance of explaining the response variables (i.e. species abundances) was tested. GLM with an identity-link function was used assuming a linear scale response with maximum likelihood estimation. Variables not meeting the normality assumption were analysed for response trends to distance from the trail by the non-parametric

Table 1

List of vascular plants, bryophytes and lichens found along the hiking trail in the Latnjavagge valley, sub-arctic Sweden. Vascular and non-vascular plants divided into functional growth forms. Vascular plant growth forms: Cushion plants, Deciduous shrubs, Evergreen dwarf shrubs, Evergreen shrubs, Forbs, Grasses, Rushes, and Sedges. Non-vascular plants: Lichens, Acrocarp bryophytes, Pleurocarp bryophytes, and Liverworts (bryophytes). Hits = total number of “hits” from all plots using point frame abundance data.

| Species in the canopy layer | Type | Abb. | Total hits |
|---|-----------------------|-------------|------------|
| <i>Agrostis mertensii</i> Trin. | Grass | Agm | 3 |
| <i>Antennaria alpina</i> (L.) Gaertn. | Forb | Ant | 9 |
| <i>Betula nana</i> L. | Deciduous shrub | Bn | 202 |
| <i>Calamagrostis lapponica</i> (Wahlenb.) Hartm. | Grass | Cagla | 14 |
| <i>Cassiope tetragona</i> (L.) D. Don. | Evergreen shrub | Cast | 7 |
| <i>Carex bigelowii</i> Torr. ex Schwein. | Sedge | Cxb | 62 |
| <i>Empetrum nigrum</i> L. | Evergreen shrub | Emp | 185 |
| <i>Equisetum arvense</i> L. | Forb | Eqarv | 1 |
| <i>Erigeron uniflorus</i> L. | Forb | Erig | 9 |
| <i>Festuca ovina</i> L. | Grass | Fov | 13 |
| <i>Festuca vivipara</i> (L.) Sm. | Grass | FVI | 3 |
| <i>Hieracium</i> L. sect. <i>Alpina</i> (Griseb.) Gremli | Forb | Hiera | 11 |
| <i>Juncus trifidus</i> L. | Rush | Jtr | 131 |
| <i>Luzula arcuata</i> (Wahlenb.) Sw. | Rush | Lzarc | 2 |
| <i>Luzula spicata</i> (L.) DC. | Rush | Lzsp | 1 |
| <i>Minuartia biflora</i> (L.) Schinz & Thell. | Forb | Mibi | 1 |
| <i>Poa alpina</i> L. | Grass | Palp | 12 |
| <i>Phyllodoce caerulea</i> (L.) Bab. | Evergreen shrub | Phyl | 152 |
| <i>Pedicularis lapponica</i> L. | Forb | PI | 2 |
| <i>Bistorta vivipara</i> (L.) Gray | Forb | PV | 11 |
| <i>Salix herbacea</i> L. | Deciduous shrub | Sh | 270 |
| <i>Sibbaldia procumbens</i> L. | Forb | SIBB | 4 |
| <i>Trisetum spicatum</i> (L.) K. Richter | Grass | Tris | 2 |
| <i>Taraxacum</i> sect. <i>Taraxacum</i> | Forb | TX | 1 |
| <i>Vaccinium uliginosum</i> L. | Deciduous shrub | Vu | 7 |
| <i>Vaccinium vitis-idaea</i> L. | Evergreen shrub | Vvi | 165 |
| Species in the bottom layer | Type | Abb. | |
| <i>Alectoria nigricans</i> (Ach.) Nyl. | Lichen | Alni | 10 |
| <i>Alectoria ochroleuca</i> (Hoffm.) A. Massal. | Lichen | Aloc | 11 |
| <i>Aulacomnium turgidum</i> (Wahlenb.) Schwägr. | Acrocarp | Autu | 25 |
| <i>Cetraria</i> sp. | Lichen | Cet | 1 |
| <i>Flavocetraria cucullata</i> (Bellardi) Kärnefelt & A. Thell | Lichen | Cetc | 46 |
| <i>Cetrariella delisei</i> (Bory ex Schaer.) Kärnefelt & A. Thell | Lichen | Cetd | 55 |
| <i>Cetraria islandica</i> (L.) Ach. | Lichen | Cetis | 2 |
| <i>Flavocetraria nivalis</i> (L.) Kärnefelt & A. Thell | Lichen | Cetn | 50 |
| <i>Cladonia arbuscula</i> (Wallr.) Flot. | Lichen | Clarb | 268 |
| <i>Cladonia</i> sp. | Lichen | Cld sp | 25 |
| <i>Cladonia gracilis</i> (L.) Willd. | Lichen | Cldg | 15 |
| <i>Cladonia uncialis</i> (L.) F. H. Wigg. | Lichen | Clunc | 158 |
| <i>Diapensia lapponica</i> L. | Cushion evergreen | DI | 19 |
| <i>Dicranum elongatum</i> Schleich. ex Schwägr. | Acrocarp | Dicrel | 109 |
| <i>Dicranum groenlandicum</i> Brid. | Acrocarp | Dicrg | 16 |
| <i>Dicranella subulata</i> (Hedw.) Schimp. | Acrocarp | Disub | 25 |
| <i>Gymnomitrium</i> sp. | Liverwort | Gym | 104 |
| <i>Harrimanella hypnoides</i> (L.) D. Don | Evergreen dwarf shrub | Cah | 179 |
| <i>Hylocomium splendens</i> (Hedw.) Schimp. | Pleurocarp | HS | 40 |
| <i>Icmadophila ericetorum</i> (L.) Zahlbr. | Lichen | Icm | 1 |
| <i>Kiaeria starkei</i> (F. Weber & D. Mohr) I. Hagen | Acrocarp | Kias | 66 |
| <i>Loiseleuria procumbens</i> (L.) Desv. | Evergreen shrub | Lois | 26 |
| <i>Lophozia lycopodioides</i> (Wallr.) Cogn. | Liverwort | Lopl | 1 |
| <i>Nephroma arcticum</i> (L.) Torss. | Lichen | Nefa | 15 |
| <i>Pertusaria dactylina</i> (Ach.) Nyl. | Lichen | Pedact | 36 |
| <i>Peltigera aphthosa</i> (L.) Willd. | Lichen | Pela | 5 |
| <i>Peltigera scabrosa</i> Th. Fr. | Lichen | Pels | 4 |
| <i>Pleurocladula albescens</i> (Hook.) Grolle | Liverwort | Plalb | 3 |
| <i>Pleurozium schreberi</i> (Willd. ex Brid.) Mitt. | Pleurocarp | Pls | 4 |
| <i>Polytrichum alpinum</i> Hedw. | Acrocarp | Polya | 14 |
| <i>Polytrichum juniperinum</i> Hedw. | Acrocarp | Polyj | 75 |
| <i>Polytrichum piliferum</i> Hedw. | Acrocarp | Polyp | 56 |
| <i>Polytrichum sexangulare</i> Floerke ex Brid. | Acrocarp | Polysex | 9 |
| <i>Pohlia nutans</i> (Hedw.) Lindb. | Acrocarp | Ponu | 3 |
| <i>Psoroma hypnorum</i> (Vahl) Gray | Lichen | Pso | 1 |
| <i>Ptilidium ciliare</i> (L.) Hampe | Liverwort | Ptc | 102 |
| <i>Racomitrium lanuginosum</i> (Hedw.) Brid. | Acrocarp | Racla | 1 |
| <i>Solorina crocea</i> (L.) Ach. | Lichen | Solo | 22 |
| <i>Sphaerophorus globosus</i> (Huds.) Vain. | Lichen | Spgl | 66 |
| <i>Stereocaulon alpinum</i> Laurer | Lichen | Stea | 398 |
| <i>Stereocaulon</i> sp. | Lichen | Stesp | 1 |
| <i>Sanionia uncinata</i> (Hedw.) Loeske | Pleurocarp | Sunc | 18 |
| <i>Tetraplodon mnioides</i> (Hedw.) Bruch & Schimp. | Acrocarp | Tetra | 1 |
| <i>Thamnomia vermicularis</i> (Sw.) Schaer. | Lichen | Tv | 25 |
| <i>Ochrolechia frigida</i> (Sw.) Lynge | Lichen | X1 | 356 |

Table 2

Results from the generalised linear model (GLM) showing Wald chi-square and significance levels for tests of model effects type III. Responses explain significant effects on species abundance (count number per plot) at different distances from the trail and directions of transect in the Latnjavagge valley, sub-arctic Sweden, and their interactions. Only significant results on the species are shown. Df = degrees of freedom, P=significance level, n=10.

| Species | Intercept | | | Distance | | | Direction | | | Distance x Direction | | |
|----------------------------|-----------------|----|--------|-----------------|----|-------|-----------------|----|-------|----------------------|----|-------|
| | Wald chi-square | df | P | Wald chi-square | df | P | Wald chi-square | df | P | Wald chi-square | df | P |
| Vascular plants | | | | | | | | | | | | |
| <i>Empetrum nigrum</i> | 24.6 | 1 | <0.001 | 4.3 | 2 | 0.12 | 6.1 | 1 | 0.014 | 5.8 | 2 | 0.056 |
| <i>Phyllodoce caerulea</i> | 43.0 | 1 | <0.001 | 0.06 | 2 | n.s | 6.7 | 1 | 0.010 | 0.6 | 2 | n.s |
| Bryophytes and lichens | | | | | | | | | | | | |
| <i>Cladonia arbuscula</i> | 128.5 | 1 | <0.001 | 13.2 | 2 | 0.001 | 10.8 | 1 | 0.001 | 0.3 | 2 | n.s |
| <i>Cladonia uncialis</i> | 160.3 | 1 | <0.001 | 12.0 | 2 | 0.002 | 9.7 | 1 | 0.002 | 1.0 | 2 | n.s |
| <i>Dicranum elongatum</i> | 70.6 | 1 | <0.001 | 7.5 | 2 | 0.024 | 0.3 | 1 | n.s | 0.9 | 2 | n.s |
| <i>Ochrolechia frigida</i> | 224.8 | 1 | <0.001 | 15.0 | 2 | 0.001 | 1.4 | 1 | n.s | 7.0 | 2 | 0.031 |
| <i>Ptilidium ciliare</i> | 40.4 | 1 | <0.001 | 0.001 | 2 | n.s | 5.9 | 1 | 0.015 | 0.0 | 2 | n.s |

Table 3

Significant results from the generalised linear model (GLM) showing coefficients and significance levels, explaining effects on species abundances (count number per plot) at different distances from the hiking trail and different transect directions in the Latnjavagge valley, sub-arctic Sweden. Coef= coefficient, P=significance level, n=10.

| Species | Intercept | | Distance from trail (m) | | | | Direction | | Dist x dir | | Dist x dir | |
|----------------------------|-----------|--------|-------------------------|-------|------|-------|-----------|-------|------------|------|------------|------|
| | Coef | P | 0.5 | | 2 | | East | | 0.5 x E | | 2 x E | |
| | | | Coef | P | Coef | P | Coef | P | Coef | P | Coef | P |
| Vascular plants | | | | | | | | | | | | |
| <i>Empetrum nigrum</i> | 3.8 | n.s | | | | | | | 16.2 | 0.02 | | |
| <i>Phyllodoce caerulea</i> | 0.5 | <0.001 | | | | | | | | | | |
| Bryophytes and lichens | | | | | | | | | | | | |
| <i>Cladonia arbuscula</i> | 14.0 | <0.001 | -7.2 | 0.002 | | | -5.0 | 0.053 | | | | |
| <i>Cladonia uncialis</i> | 0.7 | <0.001 | -0.3 | 0.004 | | | | | | | | |
| <i>Dicranum elongatum</i> | 0.6 | <0.001 | -0.4 | 0.006 | | | | | | | | |
| <i>Ochrolechia frigida</i> | 16.0 | <0.001 | -8.5 | 0.001 | -5.7 | 0.023 | | | | | 10.2 | 0.01 |

Kruskal–Wallis test (Sokal and Rohlf, 1995). The Shapiro–Wilks normality test, GLM and Kruskal–Wallis tests were all performed using IBM® SPSS® Statistics v. 22.0.0.1.

Plant community composition was first analysed by detrended correspondence analysis (DCA), based on all species occurrences. DCA showed that the axes were relatively long, i.e. over four standard deviation units for species turnover. This indicated that a unimodal technique would be more appropriate for extracting the variation in the data. However, to check for the most appropriate constrained gradient method for our dataset, we performed both constrained CCA (canonical correspondence analysis) and RDA (Ter Braak and Šmilauer, 2002), and found that the CCA extracted more variation from the data. Consequently, in order to investigate whether plant community composition was influenced by the variables trail distance, direction and transect number, CCA was selected for use. Significance of constraining factors was analysed by Monte Carlo permutation tests (1000 permutations) on non-transformed data and default settings. DCA, CCA and RDA were all performed in CANOCO 4.5 (Ter Braak and Šmilauer, 2002).

3. Results

Empetrum nigrum and *Phyllodoce caerulea* showed significant changes in abundance with direction of the transect, and *E. nigrum* also showed a significant interaction effect of distance from trail and direction of transect (Fig. 1, Tables 2 and 3). No other significant responses by vascular plants on species level to distance from the hiking trail or direction of transect were detected. However, *E. nigrum* tended to decrease with distance from the trail.

For bryophytes, the abundance of acrocarpous species in general tended to increase with distance from the trail (Figs. 2A, 2C, 2D and 2E), but only *Dicranum elongatum* showed significant responses (Tables 2 and 3). *Dicranum elongatum* had significantly lower abundance at 0.5

m distance from the trail than at 2 and 5 m distance (Tables 2 and 3). The two liverworts (*Gymnocola* sp. and *Ptilidium ciliare*) showed contrasting responses to proximity to the trail. No significant response was found for *Gymnocola* sp., but there was a significant change in *P. ciliare*, which peaked in abundance at 2 m distance from the trail (Figs. 2B and 2F, Table 2). Three species of lichens (*Cladonia arbuscula*, *Cladonia uncialis*, *Ochrolechia frigida*) showed a significant decrease with proximity to the trail (Figs. 3B, 3C and 3F). *Cladonia arbuscula* (Fig. 3B) and *C. uncialis* (Fig. 3C) showed a significant decrease at 0.5 m from the trail, but also a relationship with the direction of the transect in tests of model effects (Table 2). However, this was not significant when variables were tested in the full GLM (Table 3). *Ochrolechia frigida* (Fig. 3F) had significantly lower abundance at 0.5 and 2 m distance from the trail (Tables 2 and 3), but also showed a significant interaction effect between distance and direction of the transect (Table 3). *Cetrariella delisei*, *Flavocetraria cucullata*, *Flavocetraria nivalis*, *Sphaerophorus globosus* and *Stereocaulon alpinum* did not show any significant abundance change due to distance from the trail or direction of the transect.

Multivariate analysis (CCA) explained 41.9% of the total variation, with CCA1 explaining 33.1% and CCA 2 explaining 8.8% (Fig. 4 and Table 4). Cumulative percentage variance in the species–environment relationship was in total 100% for the two first CCA axes. The CCA results showed that distance from the trail and transect direction both significantly explained this variance. The permutation test showed a total fit for all variables of 0.42, although direction was omitted as a constraining variable due to negligible variance. Distance from the trail showed a model fit of 0.11 (F-ratio 1.69, P=0.0100) and transect showed a model fit of 0.31 (F-ratio 4.89, P=0.0010). The higher model fit by the transect indicates that the study area has somewhat heterogeneous species composition. For example, *P. ciliare* may have a heterogeneous distribution, as indicated by the increase at 2 m distance from the trail (Fig. 2F), and

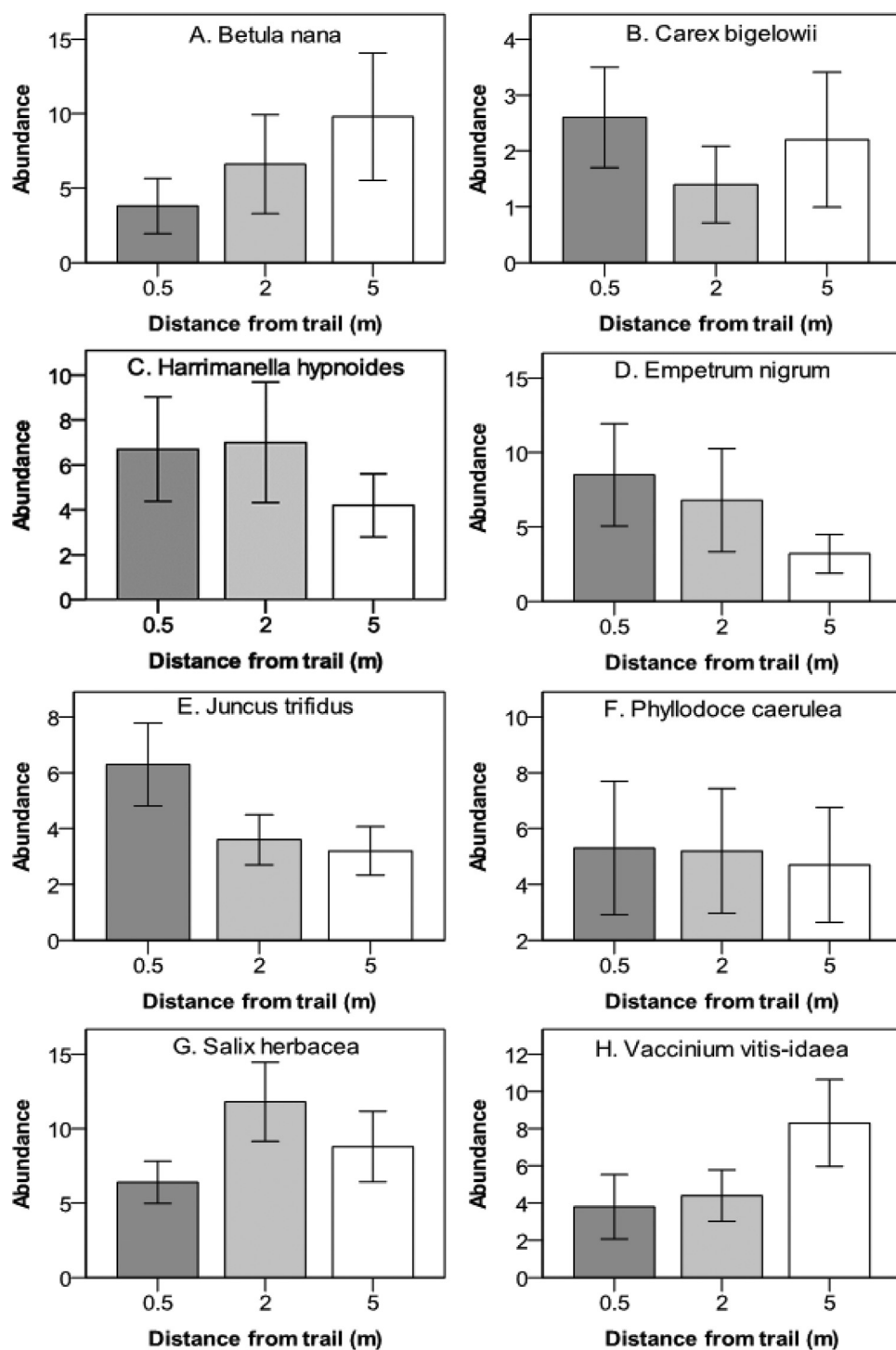


Fig. 1. (A-H). Abundance of the eight most dominant vascular plants at different distances from the hiking trail at Latnjajaure, sub-arctic Sweden (mean \pm 1 S.E, n =10).

Table 4
Results of canonical correspondence analysis (CCA).

| Axes | 1 | 2 | 3 | 4 | Total inertia |
|--|-------|-------|-------|-------|---------------|
| Eigenvalues | 0.331 | 0.088 | 0.249 | 0.198 | 2.110 |
| Species-environment correlations | 0.907 | 0.820 | 0.000 | 0.000 | |
| Cumulative percentage variance of species data | 15.7 | 19.9 | 31.7 | 41.1 | |
| of species-environment relation | 79.0 | 100.0 | 0.0 | 0.0 | |
| Sum of all eigenvalues | | | | | 2.110 |
| Sum of all canonical eigenvalues | | | | | 0.419 |

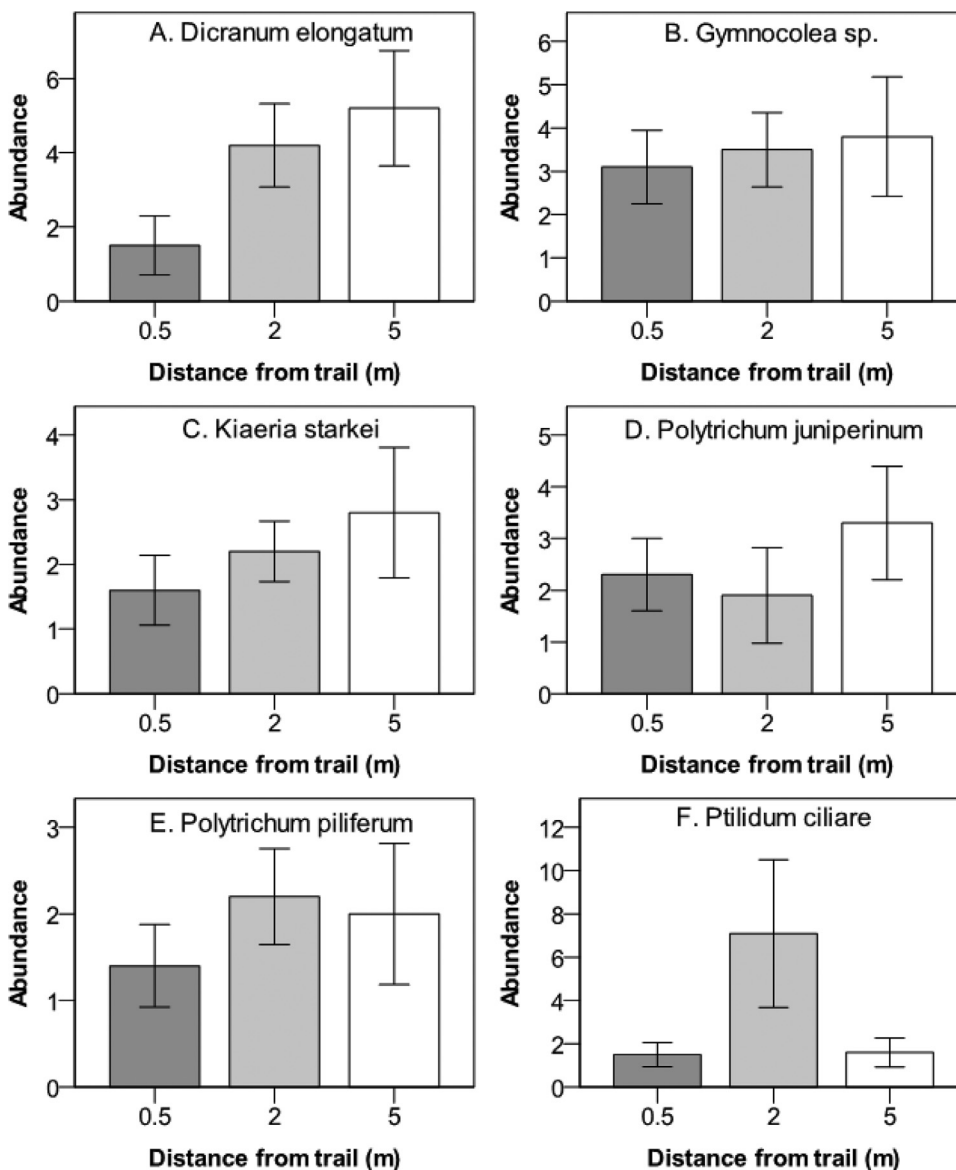


Fig. 2. (A-F). Abundance of the six most dominant bryophyte species at different distances from the hiking trail at Latnjajaure, sub-arctic Sweden (mean \pm 1 S.E, n = 10). *Dicranum elongatum* (Acrocarp), *Gymnocolea* sp. (Liverwort), *Kiaeria starkei* (Acrocarp), *Polytrichum juniperinum* (Acrocarp), *Polytrichum piliferum* (Acrocarp), *Ptilidium ciliare* (Liverwort).

also by the close correlation with the transect arrow in the ordination diagram of the CCA (Fig 4).

4. Discussion

Field studies along a hiking trail in sub-arctic Sweden provided no support for the hypothesis that proximity to the trail (caused by off-trail visitor trampling) causes a decrease in species with the lowest resistance to trampling. None of the eight most dominant vascular plants showed any significant effects of proximity to the trail. One bryophyte species (*Dicranum elongatum*) among the six most commonly found decreased with proximity to the trail. Three lichen species (*Cladonia arbuscula*, *Cladonia uncinatis*, *Ochrolechia frigida*) of the eight most common species detected decreased with proximity to the trail. Similarly, the hypothesis that taller species decrease with proximity to the trail was not supported, although abundance of the deciduous shrub *Betula nana* tended to decrease with proximity to the trail. As hypothesised, more lichen species decreased with proximity to the trail than bryophyte species, and multivariate analyses showed that proximity to the trail had a significant negative effect on overall vegetation composition.

While no dominant vascular plant species showed any significant effects of proximity to the trail in this study, other studies have shown considerable variation among vascular plants in their resistance and resilience to trampling (Cole, 1995). For example, in contrast to our results indicating higher abundance of *Empetrum nigrum* closer to the trail, in a study in Denmark trampling was found to have a negative effect on cover of *Empetrum nigrum* (Hylgaard and Liddle, 1981). A study in alpine Argentina found negative effects on *Adesmia aegiceras*, *Poa* sp., *Stipa* sp., *Tropaeolum polyphyllum* and *Gayophytum micranthum*, while abundance of *Acaena magellanica* and *Hypsela reniformis* increased (Barros et al., 2013). A study in sub-antarctic Marion Island found that trampling had a negative impact on *Azorella stolonifera*, *Blechnum pennamarina* and *Uncinia compacta*, and a positive effect on *Juncus scheuchzerioides* (Gremmen et al., 2003). This variation in responses can partly be related to the growth form of the plants, with taller shrubs and forbs being more vulnerable to trampling than graminoids, short plants and prostrate plants (Ballantyne et al., 2014; Bernhardt-Römermann et al., 2011; Gremmen et al., 2003; Yorks et al., 1997). In sub-antarctic Marion Island, trampling was found to lead to cushion dicots and shrubs being replaced by graminoids (Gremmen et al., 2003). While not significant, our results provide some support for these previous findings, as the graminoids *Carex bigelowii*, *Juncus trifidus* and prostrate *Harrimanella*

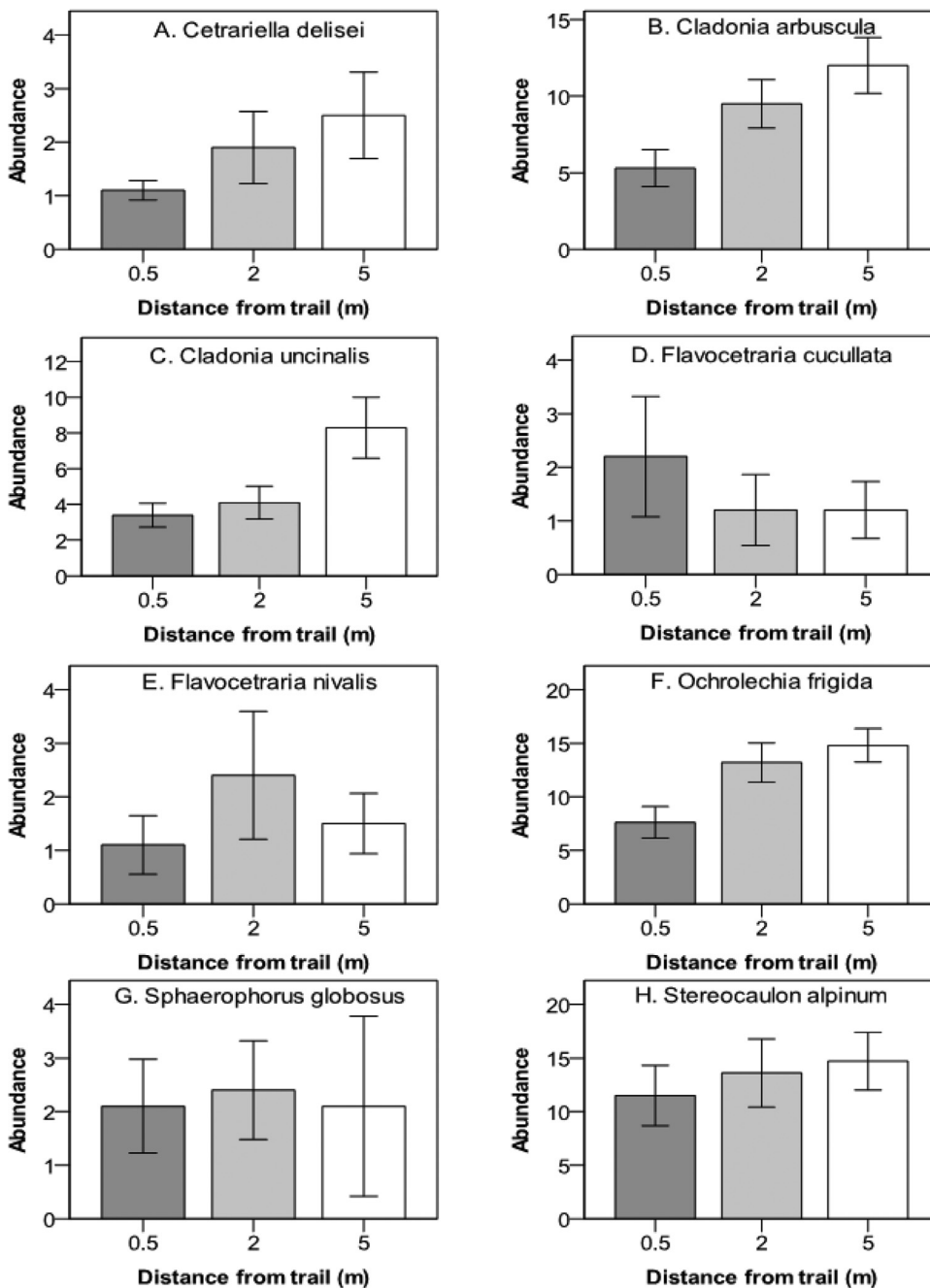


Fig. 3. (A-H). Abundance of the six most dominant lichen species at different distances from the hiking trail at Latnjajaure, sub-arctic Sweden (mean \pm 1 S.E., n=10).

hypnoides and *Phyllodoce caerulea* were all unaffected by proximity to the trail, whereas the taller *Betula nana* tended to increase with distance from the trail.

The lack of significant impact on vascular plant species at our study site may be because the trail has very few visitors on an annual basis (300-400 hikers in summer) (Beylich et al., 2005). If the side-trail of the Kungsleden Way between Abisko and Hemavan that runs through the Latnjavagge valley were to become more popular with hikers, the pressure would increase. This would probably lead to a significant negative impact on the abundance of vascular plant species present, similar to that reported in other studies following an increase in trampling intensity (Barros and Pickering, 2015; Cole, 1995; Hylgaard and Liddle, 1981; Whinam and Chilcott, 1999, 2003). For example, a study at alpine and sub-alpine sites in Tasmania showed that having 500 annual passes caused a drastic increase in species decline during the second year of trampling treatment, while having less than 100 annual passes did not cause an increase in species decline after the first year

(Whinam and Chilcott, 2003). Similarly, other studies in alpine and polar regions have shown that the natural vegetation can tolerate low levels of trampling, but that if the intensity of disturbance exceeds a certain threshold the damage to the vegetation is considerably larger (Monz, 2002; Tolvanen et al., 2001). The threshold for sustainable numbers of hikers at the Latnjavagge valley has not yet been determined, but the level of low-intensity trampling recorded indicates that current numbers of hikers can be sustained for longer periods with minimum impact on vascular plant species. The negative impact of visitors leaving the designated trail could potentially be mitigated by management practices to keep people on the trail (Rowe et al., 2018). Due to the Covid outbreak, which limited international travel, local tourism in the study area increased significantly in summer 2020, with local authorities and companies reporting a record number of visitors to sub-arctic Sweden (Lind, 2020). Further studies are needed to evaluate whether this increase in tourism caused the plant damage threshold for sustainable numbers of hikers to be exceeded.

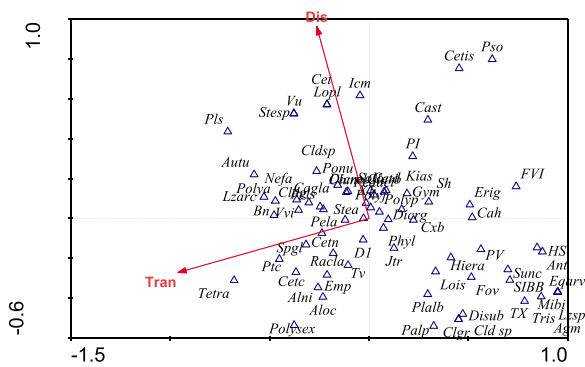


Fig. 4. Ordination diagram of canonical correspondence analysis (CCA) showing the variation in species community with distance from the trail (Distance) and direction of transect (Transect) ($n = 10$) in the Latnjavagge valley, sub-arctic Sweden. For species abbreviations, see Table 1.

As found in previous studies in Tasmania (Whinam and Chilcott, 2003), the Australian Alps (Pickering and Growcock, 2009), Australia and USA (Pickering et al., 2010), sub-antarctic Marion Island (Gremmen et al., 2003) and China (Niu and Cheng, 2019), multivariate analysis showed that distance from the trail and direction of transect both had a significant impact on the vegetation composition. Some vascular plant species (*E. nigrum* and *P. caerulea*) showed significant changes in abundance with direction of the transect. A general decrease in abundance of vascular plants with transect direction has been reported previously (Törn et al., 2006). This might be due to changes in soil properties due to human trampling activities (Chardon et al., 2018; Lucas-Borja et al., 2011; Ros et al., 2004), or to trampling occurring down a slope (Törn et al., 2006). In the present study, the transects were set mainly on more or less flat areas (without apparent slope), and thus it is more likely that the effect of direction was a random effect, rather than an effect of topography. Others have found that trampling can have contrasting effects on cushion plants along an altitudinal gradient, with e.g. trampling having a positive effect at lower altitudes and negative or neutral effect at higher altitudes (Chardon et al., 2019). The positive effect at lower altitudes is suggested to be due to trampling decreasing competition between plants (Chardon et al., 2019; Gremmen et al., 2003). At higher altitudes the abiotic stress is already high, so additional disturbance can have a negative effect (Chardon et al., 2019). The impact may also vary depending on soil conditions, with moister soils experiencing a larger negative effect than drier mineral soils that suffer less structural damage from trampling (Gremmen et al., 2003).

In the case of bryophytes, of the six bryophytes included in the present analysis (four acrocarps and two liverworts), only *Dicranum elongatum* (acrocarp) showed a significant response, increasing in abundance with distance from the trail (i.e. it was negatively affected by trampling). In contrast, in a study on sub-antarctic Marion Island, trampling had a negative effect on the cover of acrocarp and liverwort species, while pleurocarps were more resistant (Gremmen et al., 2003). In the present study, trampling had no effect on the two liverworts (*Gymnocolea* sp., *Ptilidium ciliare*). At the study site, liverworts often grow beneath and intermingled with the stems of vascular plants and could therefore be more protected against trampling than other bryophytes. Others have found that bryophytes are not affected by trampling activities, but that they are influenced by changes in the soil physical-chemical properties, such as increased soil pH, and by climate conditions, such as annual rainfall (Gheza et al., 2018). In addition, bryophyte cover has been shown to be negatively correlated with vascular plant cover in heaths (Jägerbrand et al., 2012), and specifically with deciduous shrubs more broadly across vegetation communities (Alatalo et al., 2020). Thus, a decrease in vascular plants, or specifically the deciduous shrub *B. nana*, in the heath community due to trampling could potentially indirectly

lessen the competition between bryophytes and vascular plants in areas closer to the trail (Alatalo et al., 2020; Gremmen et al., 2003; Jägerbrand et al., 2012).

Previous studies have found a negative effect of trampling on lichens in alpine ecosystems and maritime Antarctica (Czortek et al., 2018a; Grabherr, 1982; Jägerbrand and Alatalo, 2015; Pertierra et al., 2013). Similarly, in the present study three of the eight most common lichen species included in the analysis showed a significant decrease with proximity to the trail. Two species, *Cladonia arbuscula* and *Cladonia uncinata*, showed a significant decrease at 0.5 m from the trail and a relationship with direction of transect. *Ochrolechia frigida* showed significantly lower abundance at 0.5 m and 2 m, and also showed a significant interaction effect between distance from the trail and direction of transect. In contrast, human trampling has been found not to affect the lichen pattern in lichen-rich grasslands in Italy (Gheza et al., 2018) and to increase lichen cover an alpine heath community in northern Finland (Törn et al., 2006). In the latter case, the increase was caused by regeneration of lichens after trampling.

5. Conclusions

Proximity to the trail did not cause a decrease in the majority of dominant species, with none of the eight most dominant vascular plants showing any significant effects of proximity to the trail. However, multivariate analyses showed that distance from trail and transect direction had significant effects on overall vegetation composition. The level of low-intensity trampling recorded indicates that current numbers of hikers can be sustained for longer periods with small impact on dominant vascular plant species. To limit future trampling damage to sensitive alpine ecosystems in sub-arctic Sweden, visitors should be encouraged to keep to the designated trails and visitor numbers could be regulated in busy periods. To get a more general understanding of impact of low-intensity trampling, it would be necessary to include data from several contrasting sites.

Authors' contributions

AKJ and JMA planned the study. UM did the field work. AKJ carried out the analyses and prepared figures. AKJ, MR and JMA drafted the manuscript. All authors read and approved the final manuscript.

Declaration of Competing Interest

The authors declare that they have no competing interests.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.envc.2021.100050.

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