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Master thesis

Using turfs to facilitate recovery in a low-alpine environment. - What matters?

Master in Applied Ecology

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Abstract

Establishment and survival of plants in low-alpine ecosystems depend strongly on local environmental conditions, as for example nutrient availability and especially temperature. Some of these conditions are rather unpredictable in high-elevation environments, due to short and irregular growing seasons. To restore such harsh ecosystems is therefore most difficult. During the last two decades, the transplanting of whole vegetation turfs has been more frequently used in restoration of low-alpine ecosystems to facilitate vegetation recovery. This is due to ecological and functional advantages compared to seeding or fertilizing, which traditionally have been used to facilitate recovery in restoration. Few studies, however, did focus on the factors which are actually relevant for recovery around the turfs. The aim of this study is to find out how turf attributes contribute to vegetation recovery and which environmental factors at the turf receptor site are influencing the vegetation recovery in a low-alpine environment in the Dovrefjell mountain range, Norway. The study is part of Norway's largest nature restoration project so far, Hjerkinn PRO, with the restoration of a former military training area. Several turf attributes and environmental factors were tested, to ascertain the reasons for successful recovery around the turfs. In a multivariate approach LMM, GLMM and ANOVA have been used to analyze the data. Time is the most important factor for vegetation recovery, closely followed by conditions of the receptor site. Organic matter in the soil and a small grain size are very important to facilitate recovery around the turfs. Species richness of study plots at the turf receptor sites and of the turfs (as donor sites) were nearly equal after 14 years. Differences in species composition between donor and receptor site, as observed in several other experiments, were found only to a very low degree here. Neither turfs size nor distance to the next closest turf or species richness and vegetation cover of the turfs, seem to be important factors for vegetation recovery at the turf receptor site. The results of this study indicate that it is very important to prepare the receptor site thorough before turf transplantation, to achieve successful vegetation recovery around the turfs. As time is the most important factor, this should be communicated to project owners and to the public to adjust for different expectations on recovery rates.

Key words: Low-alpine ecosystems, vegetation restoration, turf transplants, Dovrefjell, ecosystem management.

Sammendrag

Etablering og overlevelse av arter og vegetasjon i lavalpine områder er sterkt påvirket av lokale miljøforhold, som for eksempel tilgjengelige næringsstoff og temperatur. Noe av disse forholdene er ganske uforutsigelig i slike miljøer, på grunn av korte og variable vekstsesonger. Dersom slike økosystemer eller områder blir forstyrret eller ødelagt vil det være vanskelig å gjenopprette dem. I løpet av de siste to tiår har transplantasjoner av hele vegetasjons-tuer vært brukt i restaurering av vegetasjon etter forstyrrelse i lavalpine økosystemer. Dette er en metode som har økologiske og funksjonelle fordeler sammenlignet med såing eller gjødsling, som tradisjonelt har vært brukt til å gjenopprette vegetasjon. Men få studier fokuserer på hvilke faktorene er avgjørende for å få vellykket gjenvekst rundt tuer. Formålet med denne studien er å finne ut hvordan egenskaper ved selve tuene bidrar til gjenvekst og hvilke miljøfaktorer på det stedet tuene plasseres som påvirker gjenvekst i et lavalpin område på Dovrefjell, Norge. Flere egenskaper av tuer og miljøfaktorer ble testet, for å finne ut årsakene til vellykket gjenvekst rundt tuer. LMM, GLMM og ANOVA ble bruket for å analysere dataene. Tid er den viktigste faktoren for gjenvekst, tett fulgt av tilstand av forholdene der tuene plasseres. Høyere innhold av organisk materiale i jord og liten kornstørrelse er svært viktige faktorer for å bedre gjenvekst rundt tuer. Etter 14 år er artsmangfoldet i tuene og i de analyserte rutene rundt tuene omtrent likt. Forskjeller i artssammensetning mellom tuene og rutene rundt tuene, som er observert i flere andre eksperimenter, ble i svært liten grad observert i denne studien. Hverken størrelse av tuer, eller avstand til nærmeste andre tuer eller artsmangfold og dekning av tuene er tilsynelatende viktige faktorer for å bedre gjenvekst rundt tuer. Resultatene av denne studie tyder på at det er svært viktig å klargjøre det stedet der tuene skal plasseres grundig før transplanteringen, for å oppnå vellykket gjenvekst rundt tuene. Ettersom tiden er den viktigste faktoren, bør dette gjøres klart for prosjekteiere og offentlige instanser slik at disse får realistiske forventninger om hvor sakte gjenveksten vil skje.

Stikkord: Lavalpin vegetasjon, restaurering, transplantasjon, gjenvekst, Dovrefjell, forvaltning.

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1. Introduction

Degradation and destruction of ecosystems by humans are increasing with a growing world population. To maintain and restore biodiversity in ecosystems, effective ecological restoration becomes more important than ever (Hobbs & Norton 1996). Ecological restoration aims to recover a degraded ecosystem to a degree of a natural stage. This is with respect to its health, intactness and long-term sustainability by preparing the ground for improved natural recovery and/or establishing or re-introducing flora and fauna (Hobbs & Norton 1996; Young, Petersen & Clary 2005; Falk, Palmer & Zedler 2006; Perring *et al.* 2015).

The establishment and survival of plants is highly depending on resources (radiant energy, CO_2, O_2, mineral nutrients) available at the potential growing site and direct physical or chemical effects as extreme temperatures and disturbance (e.g. toxins, water stress, removal of vegetation cover and soil) (Fitter & Hay 2002). Additional important factors are species traits as the ability to deal with limitations and variability in these abiotic factors (Hagen & Skrindo 2010; Kempel *et al.* 2013). As a first step for establishment, the seed germination is a vital process for some plants to establish. To germinate, seeds need basic resources as water, oxygen, light and suitable temperatures, as well as safe sites, which are also decisive to a successful germination process. In these safe sites, the seeds can be trapped and get shelter from adverse environmental conditions until, with the factors already mentioned, they are eventually able to germinate (Fitter & Hay 2002; Urbanska & Chambers 2002; Finch-Savage & Leubner-Metzger 2006).

Alpine and low-alpine ecosystems have shorter growing seasons, lower temperatures and often less water and nutrient availability compared with lower-altitude ecosystems, which makes it difficult for many plants to establishment and survive (Urbanska & Chambers 2002; Bay & Ebersole 2006; Krautzer, Uhlig & Wittmann 2012; Hagen & Evju 2013). Additional challenges in alpine and low alpine ecosystems are frequently strong winds, extensive snow cover during winters and a with the altitude increasing light intensity (Urbanska & Chambers 2002; Krautzer, Uhlig & Wittmann 2012; Hagen & Evju 2013). Furthermore, the diaspore production and the germination process of plants in high-altitude ecosystems is strongly depending on local environmental conditions as e.g. temperature, which are rather unpredictable due to the short and irregular growing seasons (Fitter & Hay 2002; Urbanska & Chambers 2002; Cooper *et al.* 2004; Bay & Ebersole 2006). Therefore, most plants in high-altitude ecosystems use both seeds and clonal growth as dispersal technics, to increase the chance of distribution and survival (Urbanska & Chambers 2002).

The restoration of harsh alpine ecosystems is most difficult, due to the above mentioned factors and the limited number of species adapted to the given conditions (Urbanska & Chambers 2002; Bay & Ebersole 2006; Krautzer, Uhlig & Wittmann 2012). Typical measures for restoration of vegetation in general are 1) restoring soil conditions, 2) adding nutrients, 3) seeding and 4) transplanting (Conlin & Ebersole 2001; Hagen & Evju 2013), and all of them have over time been tried out in several projects in alpine ecosystems with varying success.

Particularly, the transplanting of individuals of plant species or whole vegetation turfs has been applied more frequently during the last two decades, to protect communities, re-introduce species and for restoration in general (Bruelheide & Flintrop 2000; Kiehl *et al.* 2010; Aradottir 2012). Vegetation turfs, or turf transplants, are pieces of the upper layer of soil, extracted with all plant material growing in it, including parts of the root-system. Turf transplantation is believed to facilitate vegetation recovery. The size and the shape of turfs vary greatly, depending on the purpose of application (Good *et al.* 1999; Bruelheide & Flintrop 2000; Conlin & Ebersole 2001; Krautzer, Uhlig & Wittmann 2012; Hagen & Evju 2013). Vegetation turfs in general can act as source for both diaspores and clonal growth organs, as well as seed traps and safe sites for plant dispersal and establishment (Conlin & Ebersole 2001; Urbanska & Chambers 2002; Klimeš *et al.* 2010; Krautzer, Uhlig & Wittmann 2012; Hagen & Evju 2013). The soil-seedbank may also work as a long-term seed source (Urbanska & Chambers 2002; Krautzer, Uhlig & Wittmann 2012), though according to Klimeš *et al.* (2010) at least the short-term effect is negligible. Mycorrhiza and soil biota on the other hand, also transferred within the soil of turfs, may support establishment of target plant species, by maintaining the soil conditions the plants are accustomed to (Conlin & Ebersole 2001; Klimeš *et al.* 2010).

There are several ecological advantages of using turfs for restoration instead of seeding with either commercial seed mixtures or seeds gained from local plants. Seeding might be a cheaper and easier applied method for revegetation in general (Kiehl *et al.* 2010), but has some ecological and functional disadvantages. Seeding can function very well to establish a vegetation cover in short time, also in alpine ecosystems, though the success in the latter can be limited due to strong winds and erosion in exposed landscapes (Bay & Ebersole 2006; Krautzer, Uhlig & Wittmann 2012). Furthermore, species used for seeding are often grasses, in some extant non-native, which can be very successful on freshly prepared soil and establish very fast. However, this can lead to a lower species diversity and less native species over time, as less species might be able to colonize the community due to an extensive grass cover (Aradottir & Oskarsdottir 2013; Hagen & Evju 2013; Hagen *et al.* 2014). For smaller-scale restoration, turfs can be considered as a highly relevant restoration method, which promotes establishment of a diverse native plant community (Hagen & Evju 2013).

Transplanting turfs with native species provides greater advantages on ecological level compared to transplants with non-native species (Conlin & Ebersole 2001; Urbanska & Chambers 2002; Bochet, Tormo & García-Fayos 2010; Klimeš *et al.* 2010; Krautzer, Uhlig & Wittmann 2012; Aradottir & Oskarsdottir 2013). First, native species are adapted to grow in the given conditions, so they can establish and preserve local plant communities and thus biodiversity of the area (Conlin & Ebersole

2001; Bochet, Tormo & García-Fayos 2010; Kiehl *et al.* 2010; Aradottir 2012; Krautzer, Uhlig & Wittmann 2012; Aradottir & Oskarsdottir 2013; Hagen & Evju 2013). Furthermore, a decrease in local genetic diversity, which might occur when using non-native plants, is prevented through the use of native species, carrying native genotypes (Klimeš *et al.* 2010). Moreover, native animals do also benefit of a suitable habitat created by native vegetation, which in turn can be an improvement for the establishment of a well-working ecosystem (Bochet, Tormo & García-Fayos 2010).

So far, the transplantation of turfs in restoration has been to a greater or lesser extent successful (Bullock 1998; Bruelheide & Flintrop 2000; Bay & Ebersole 2006; Kiehl *et al.* 2010; Aradottir 2012; Krautzer, Uhlig & Wittmann 2012; Aradottir & Oskarsdottir 2013; Hagen & Evju 2013). The turf size might be of importance and, for a successful transplantation, turf size is depending on the vegetation of the donor site, the growth form, size and abundance of target species as well as on the conditions of the receptor site (Bullock 1998; Aradottir 2012; Krautzer, Uhlig & Wittmann 2012; Aradottir & Oskarsdottir 2013). Success can be measured as for example, sufficient protection against erosion (Krautzer, Uhlig & Wittmann 2012), difference in total cover and species richness between donor and receptor site, and difference in occurrence of rare species between donor and receptor site (Conlin & Ebersole 2001; Bay & Ebersole 2006; Klimeš *et al.* 2010; Aradottir 2012; Aradottir & Oskarsdottir 2013; Mudrák *et al.* 2017).

However, few studies did focus on the factors which are actually responsible for the success of the recovery around the turf transplants. Therefore it is highly important that the methods of turf transplantation for restoration and the reasons of their success or failure are studied more detailed (Aradottir 2012; Krautzer, Uhlig & Wittmann 2012; Hagen & Evju 2013).

This master project is part of Norway's largest nature restoration project so far, Hjerkinn PRO, with the restoration of a former military training area in Hjerkinn, Dovrefjell, in alpine-central Norway, led by the Norwegian Defence Estates Agency (NDEA) in cooperation with Norwegian Institute for Nature Research (NINA) (Norwegian Defence Estates Agency 2017). The goal of the project is to "Restore the ecosystem to original state and for future nature conservation (National park)" by using only native plant material of adjacent, undisturbed sites and hence promoting natural recovery of the native vegetation (Fig. 2) (Norwegian Defence Estates Agency 2017). Turf transplants have been used on former roads in the military area, to facilitate recovery of the vegetation. (Hagen & Evju 2013; Hagen & Evju 2014).

The aim of this study is to find out how turf attributes contribute to vegetation recovery and which environmental factors at the turf receptor site are influencing the vegetation recovery.

In order to achieve this, I will test if 1) vegetation cover of the receptor site is influenced by turf size and total vegetation cover of the turfs, by environmental conditions at the receptor site or a combination of those, and 2) species richness of the receptor site is influenced by turf size and species richness of the turfs, and by environmental conditions at the receptor site. Environmental conditions at the receptor site were represented by the following variables: distance to the next turf, distance to intact vegetation, organic matter in the soil, and soil grain size.

2. Methods

2.1 Study area

The study area is located north-west of Hjerkinn in the Dovrefjell mountain range in central Norway (62°14’59” N, 9°27’48” E; 1070 m a.s.l.) and is situated within a former military training area (Hjerkinn firing range) and surrounded by the Dovrefjell-Sunndalsfjella National Park (Fig. 1).

The surrounding national park has a high level of biodiversity and is the last high mountain area in Europe where for example populations of wild reindeer, musk ox, wolverine, mountain fox and golden eagle can be found living in the same area. It also sustains a highly divers mountain flora (Norwegian Environment Agency 2013).

Figure 1. (A) Position of the study area (star) in central Norway. (B) The study sites (stars) in the Hjerkinn firing range in the Dovrefjell mountain range, surrounded by national parks (green color). P1 = Pilot I, P2 = Pilot II, T = Tverfjellvegen, H1 = Haukberget I, H2 = Haukberget II. Map material © Google 2017.

Hjerkinn firing range is 165 km^2 and was actively used as military training area from 1923 – 2005. The decision to restore the area to its natural state was made by the Norwegian Parliament in 1999. All infrastructure should be removed and the area be prepared for nature restoration (Hagen & Evju 2013; Norwegian Defence Estates Agency 2017). According to a plan for restoration, the overall goal of the project is to “Restore the ecosystem to original state and for future nature conservation (National park)”. This broad formulation was narrowed down over specific targets and ecological attributes to actions (Fig. 2). In 2002 a pilot study was started to test different vegetation restoration treatments (Hagen & Evju 2013). The full large scale restoration project started in 2009 and is planned to be finished in 2020 with removing over 100 buildings, butts, gravel pits and 90 km of roads (Norwegian Defence Estates Agency 2017).

The mean annual temperature (1961-1999) at the closest weather station (Fokstugu, 973 m a.s.l.) is 0.8° C with a mean annual precipitation of 450 mm (Norwegian Meteorological Institute 2017; Norwegian Meteorological Institute & Norwegian Broadcasting Corporation 2017). The bedrock is primarily metamorphic rock covered mostly with till (Norwegian Geological Institute 2017). The vegetation at the study sites is of dry and medium dry alpine heathland, partly with tall herbaceous vegetation and mire (Norwegian Institute of Bioeconomy Research (NIBIO) 2017).

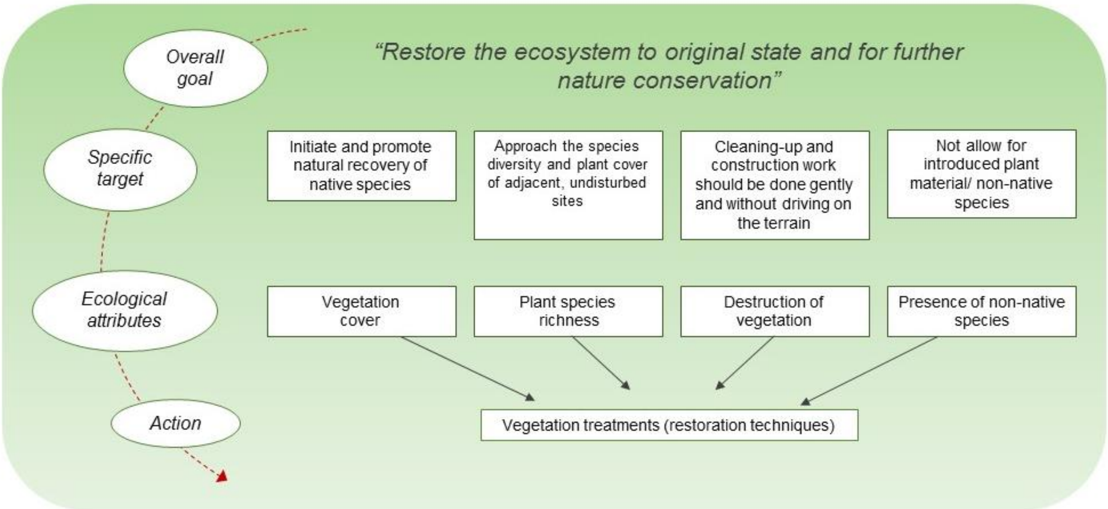

Figure 2. The link between the overall goal, specific targets, ecological attributes, and the actions in the plan for restoration. The overall goal for HjerkinnPRO is narrowed down into specific targets, ecological attributes and action(s). Ecological attributes are measureable surrogates for each of the specific targets. Figure based on Hagen and Evju (2013).

2.2 Study design

2.2.1 Study sites

The study was conducted at five study sites within the study area, with different years of restoration, and different numbers of roads (Table 1).

Haukberget I: This site was restored in 2013. The turfs for this road were extracted both from the edge of the roadside before road removal and from adjacent mire vegetation. The extraction was done with a remotely controlled digger due to updated security regulations set from the Defense Estate Agency. From this road system, I included four roads and a total of 40 turfs (Table 1). The site is dominated by heath-mire vegetation.

Haukberget II: This site was restored in 2010. The turfs for this road were extracted both from the edge of the roadside before road removal and from adjacent mire vegetation. The extraction was done with a remotely controlled digger due to updated security regulations set from the Defense Estate Agency. From this road system, I included four roads and a total of 40 turfs (Table 1). The site is dominated by heath-birch vegetation.

Tverfjellvegen: This site was restored in 2009. The turfs were extracted from the edge of the roadside before road removal. The extraction was done with a remotely controlled digger due to updated security regulations set from the Defense Estate Agency. From this road system, I included two road sections and a total of 20 turfs (Table 1). The site is dominated by willow vegetation.

Pilot I: This site was restored in 2002. The turfs were extracted from the ridge at the roadside by regular diggers, before the road was removed. From this road system, I included one road sections and a total of five turfs (Table 1). Because large parts of this road had other treatment as well, only a short section was available for the study design of this experiment. The site is dominated by heath-willow vegetation.

Pilot II: This site was restored in 2002. The turfs were extracted from the ridge at the roadside by regular diggers, before the road was removed. From this road system, I included one road sections and a total of four turfs (Table 1). Because large parts of this road had other treatment as well, only a short section was available for the study design of this experiment. The site is dominated by heath-willow vegetation.

Pilot I and Pilot II were confounded in the analysis, as the number of turfs was low in both sites and they have been restored in the same year.

Table 1. Study sites with the average length in meter of each of the roads in the study site, year of restoration, the number of roads per study site and the number of turfs per study site.

Study site	Average length of the roads (m)	Year of restoration	Number of roads	Number of turfs
Haukberget I	~ 138	2013	4	40
Haukberget II	~ 129	2010	4	40
Tverfjellveg	~ 157	2009	2	20
Pilots I	~ 50	2002	1	5
Pilot II	~ 40	2002	1	4
Total		/	12	109

2.2.2 Study design

During the restoration measure in 2009-2014 the predefined turf size for transplanting was 1 m^2. This had been difficult to achieve in field, so the turf sizes upon completion of the transplantation ranged between 0.35 and 5.76 m^2. The planting distance of the turf transplants varied between and within roads and sites due to logistic and available turfs.

All restored roads for this experiment in 2016 were selected from the sections restored during 2009 – 2012, plus the roads from the pilot-study restored in 2002.

On each road, turfs were systematically selected. Starting at the beginning of the road, 10 m were measured and a line was drawn across the road (Fig. 3). From there the closest turf was selected and checked for meeting the following requirements 1) area surrounding the turf should not be too wet (no puddles), 2) minimum distance of 110 cm between turfs and between turf and intact vegetation (requirement was neglected for some roads), 3) clear definable outline of the single turf. If not all the requirements were met, I continued to the next closest turf and so on.

A total of 109 turfs have been selected and all turf positions were marked with Global Positioning System (Garmin GPSmap 62s).

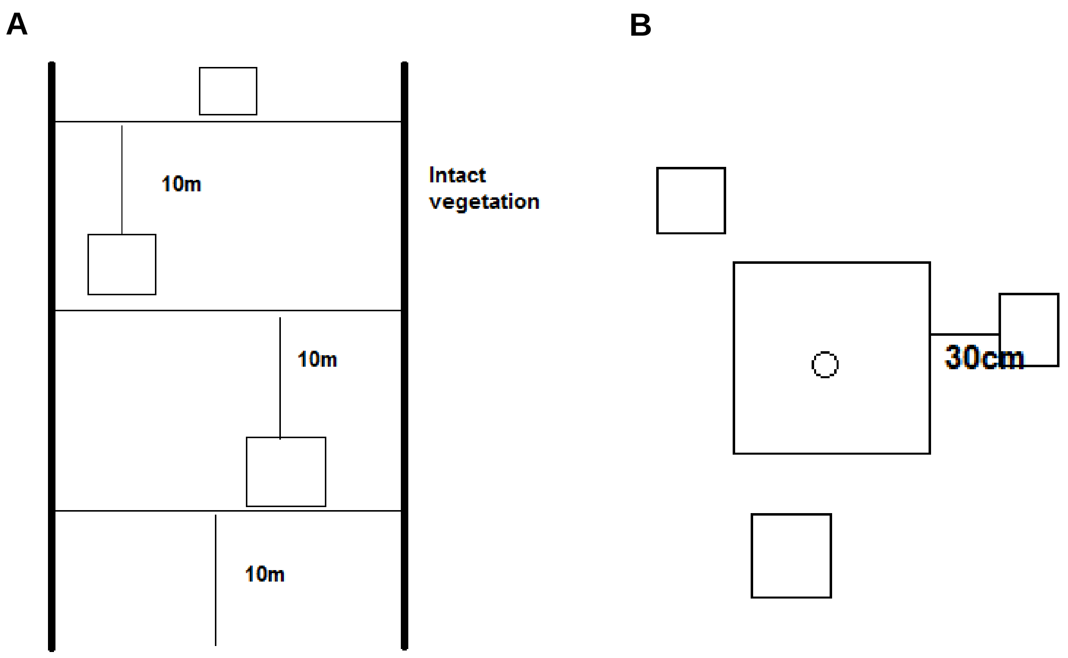

Figure 3. Study design: (A) Road with turfs (squares) and intact vegetation on the sides. (B) Turf (large square) with compass in the center (circle) and the three plots around (small squares).

2.3 Data collection

2.3.1 General for turfs and plots

The fieldwork was carried out from the 27.06.16 – 17.07.16. The nomenclature of all vascular plants is according to the "Gyldendals store nordiske Flora" (Mossberg & Stenberg 2014), which was also used for plant identification.

All vascular plants in each of the selected turfs and plots were identified to species level, if possible. If identification was not possible in the field, a sample was taken for later identification. Moss and lichens were only identified to species group.

2.3.2 Turfs

For every vascular plant species and for moss and lichens the cover was recorded, using a slightly altered Braun-Blanquet scale (Table 2) for better use in data processing software. The total vegetation cover and the cover of dead vegetation of the turf were estimated. The distance to intact vegetation (roadside) left and right of the turf, as well as length and breadth of the turf were measured. To have an overview about the surrounding vegetation types, a reference vegetation stating the dominant vegetation type of the intact vegetation to each site of the turfs (Table 3) was roughly judged by eye.

Table 2. Braun-Blanquet cover scale (left), and slightly modified Braun-Blanquet cover scale (right).

Scale	Cover	Scale	Cover
0.1	Less than 1 %	1	Less than 1 %
1	1-5 %	2	1-5 %
2	6-25 %	3	6-25 %
3	26-50 %	4	26-50 %
4	51-75 %	5	51-75 %
5	76-100 %	6	76-100 %

Table 3. Vegetation types of the reference vegetation around the turfs. Willow, birch and juniper were only present in the growth form of shrubs and bushes.

Vegetation type
mire
mire-willow
heath
heath-mire
heath-birch
heath-willow
birch
birch-juniper
willow
willow-birch

2.3.3 Plots

To record the vegetation around the turf I did a vegetation analysis in three plots (each 50 x 50 cm) surrounding each turf (Fig. 3) and did a subplot frequency analysis using 16 subplots within each plot (Fig. 4).

Figure 4. Turf with three plastic sticks at the angular degrees (0°, 120°, 240°) and the vegetation survey frame (bottom right corner) with the 16 subplots.

The positions of the three plots were determined by using the angular degrees 0°, 120° and 240° from the center of the turf using a compass. At each of these angular degrees, I measured 30 cm away from the edge of the turf and marked that point (Fig. 3). At these points, the frame was placed always with the same alignment (right upper corner to the stick, always left of the stick) (Fig. 4).

Abundance of species was recorded as presence/absence of each species in each of the 16 subplots in the 50 x 50 cm frame beginning in the upper left corner continuing in reading direction. Only plants rooted in the subplots were recorded. Furthermore, total vegetation cover within the frame (including overhanging vegetation), grain size and the occurrence of organic matter in the soil were recorded. Animal presence was recorded in terms of tracks, feces and grazing. Finally, I measured the distance to the next turf and to the closest intact vegetation (Table 4). The grain size was recorded according to the “Natur i Norge (NiN)” identification system (Halvorsen *et al.* 2015) (Table 5).

Table 4. Variables recorded in each plot with the scale and unit they were recorded.

Variable	Scale	Unit
total vegetation cover	ordinal	%
grain size	ordinal	
organic matter	binary	0/1
animal presence/absence	binary	0/1
distance to closest other turf	ordinal	cm
distance to closest intact vegetation	ordinal	cm

Table 5. Grainsize scale after the “Natur i Norge” identification system (Halvorsen *et al.* 2015).

Scale	Explanation
c	cobbles
d	coarse pebbles
e	fine and medium pebbles
f	coarse sand
g	fine and medium sand
h	silt-dominated

2.4 Data analysis

2.4.1 Species richness

The species richness for the turfs and for the plots were calculated using the package “vegan” (Oksanen *et al.* 2017) in the software R (R Core Team 2016).

2.4.2 Statistical analysis vegetation recovery

The statistical analysis was conducted in two parts, as vegetation recovery was measured as 1) “total vegetation cover of plots” and 2) “species richness of plots”. Linear mixed effects models (LMM) have been used to analyze the data of part 1) with “total vegetation cover” as response. Generalized linear mixed effects models (GLMM) with a Poisson error distribution have been used to analyze the data of part 2) with “species richness” as response.

To select the random component structure for the models (both analysis parts), I started with a model that in the fixed component contained all explanatory variables, called the beyond optimal model. With this model I tested different random component structures. These nested models were run with restricted maximum likelihood estimation (REML) and compared by using the Akaike information criterion (AIC) (Zuur *et al.* 2009).

For the random structure of both analysis parts, turf nested in road nested in site, turf nested in road and turf alone were tested. Additionally a model with site in the fixed structure and turf nested in road was tested (Table C + D appendix). Study site and years since restoration are confounded in the dataset. The best fitting model for the random structure for both analysis parts was turf nested in road with site in the fixed structure (Fig. 5).

year + (1|road/turf)

Figure 5. Best fitting random structure for both analysis parts.

As explanatory variables for the fixed structure for part 1) I selected distance to next turf, distance to intact vegetation, organic matter in the soil, soil grain size, and cover of turf, turf size and years since restoration. The same explanatory variables were selected for part 2), only cover of turf was replaced by species richness of turf.

To select the fixed component structure for the models, I used a forward selection and then compared competing models with analysis of variance (ANOVA) (Zuur *et al.* 2009). For part 1) I first tested each of the explanatory variables alone and selected the ones with the highest *t-value* (Table E appendix). Further, I built another model with these explanatory variables. Finally, I compared these candidate models with ANOVA (Table F appendix). The models were run with maximum likelihood estimation (ML) and the best fitting model is presented with REML. Model validation for linear mixed effect models was performed and the assumptions for normal distribution of residuals and homoscedasticity were met. For part 2) I first tested each of the explanatory variables and then selected the ones with the lowest *p-value* (Table G appendix). Further, I built other models with these explanatory variables and compared these candidate models using ANOVA (Table H appendix). The models were run with maximum likelihood estimation (ML). Model validation for generalized linear mixed effect models was performed and the assumptions were met, there was no over-dispersion.

Only the most parsimonious models are shown. All analyses were conducted in R (R Core Team 2016), using the package "lme4" (Bates *et al.* 2015).

3. Results

3.1 Species and cover

In total 120 vascular plant species were found, of these 104 were identified to species level, 13 to genus and one to family. Seedlings were identified as dicotyledonous and monocotyledonous plants. Moss and lichens were identified to species groups, unidentifiable very small grasses as well (Table A appendix).

Nineteen species were solely found in the plots, whereas 25 species were solely found in the turfs (Table B appendix). Furthermore, one red-list species (*Comastoma tenellum*) was recorded in the turfs, but none in the plots. One species (*Deschampsia cespitosa*), non-native for the vegetation type of alpine heath vegetation was recorded, both in turfs and plots. *Deschampsia cespitosa* was found in 187 plots and 70 turfs and is thereby one of the most abundant species (Table A appendix).

Both mean species richness and mean total vegetation cover of the plots were increasing over the different years since restoration (Table 6). A similar trend could be shown for the turfs, though species richness and cover decreased slightly after six respectively seven years and increased again afterwards (Table 6).

Table 6. Recorded species richness and total vegetation cover of plots and turfs over the different years of restoration, mean with standard deviation.

Years since restoration	Mean species richness plots	Mean species richness turfs	Mean total vegetation cover plots	Mean total vegetation cover turfs
3	5.53±0.21	15.98±0.49	4.18±0.62	85.71±1.13
6	5.37±0.21	11.86±0.32	21.18±1.87	94.49±0.86
7	9.14±0.83	14.90±0.54	38.54±2.99	91.61±1.10
14	11.89±0.50	12.22±0.84	47.41±4.36	97.78±0.68

3.2 Vegetation recovery

3.2.1 Total vegetation cover

The model fitting the “total vegetation cover” data best included organic matter in the soil, soil grain size and years since restoration as explanatory variables (Table 7, fig. 6, Table E appendix). Total vegetation cover was higher when there was organic matter in the soil and the soil grain size was small (Fig. 7). Furthermore, the more years since restoration, the higher was the total vegetation cover (Fig. 7).

Turf size, total vegetation cover of the turfs, distance to the next turf and distance to intact vegetation had no significant effect on the total vegetation cover (Table E appendix, fig. A appendix).

Table 7. Coefficients of the best fitting model for analysis part 1) "Total vegetation cover", parameter estimates for random effects are not shown.

Model: lmer(total.cover ~ org.soil + grain size + year + (1|road.x/turf.x), data = fulldata, REML = TRUE)			
	Estimate	Std. Error	t value
(Intercept)	1.078	3.482	0.310
Organic material present	12.340	1.841	6.704
Fine and medium coarse pebbles	-6.768	2.878	-2.351
Coarse pebbles	-1.579	2.769	-0.570
Coarse sand	-1.999	2.373	-0.843
Silt-dominated	20.951	4.416	4.745
Cobbles	0.320	4.831	0.066
Years since restoration 6	14.633	3.986	3.671
Years since restoration 14	40.858	5.442	7.508
Years since restoration 7	37.412	4.872	7.679

3.2.2 Species richness

The model fitting the "species richness" data best included organic matter in the soil and years since restoration as explanatory variables (Table 8, fig. 6, Table G appendix). Species richness was higher, when there was organic matter in the soil (Fig. 8). Furthermore, the more years since restoration had passed, the higher was the species richness (Fig. 8). The alternative models 10 and 12 showed that species richness was significantly lower with large soil grain size and that there is a tendency that a shorter distance to intact vegetation increases species richness (Table G appendix, fig. B appendix).

Turf size, species richness of the turf and distance to the next turf had no significant effect on the species richness (Table G appendix, fig. A appendix).

Table 8. Coefficients of the best fitting model for analysis part 2) "Species richness", parameter estimates for random effects are not shown.

Model: glmer(SR.ruter ~ org.soil + year + (1|road.x/turf.x), data = fulldata, family = poisson())				
	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.653	0.065	25.515	< 0.001
Organic material present	0.138	0.049	2.796	0.005
Years since restoration 6	-0.063	0.089	-0.710	0.478
Years since restoration 14	0.741	0.114	6.515	< 0.001
Years since restoration 7	0.504	0.102	4.928	< 0.001

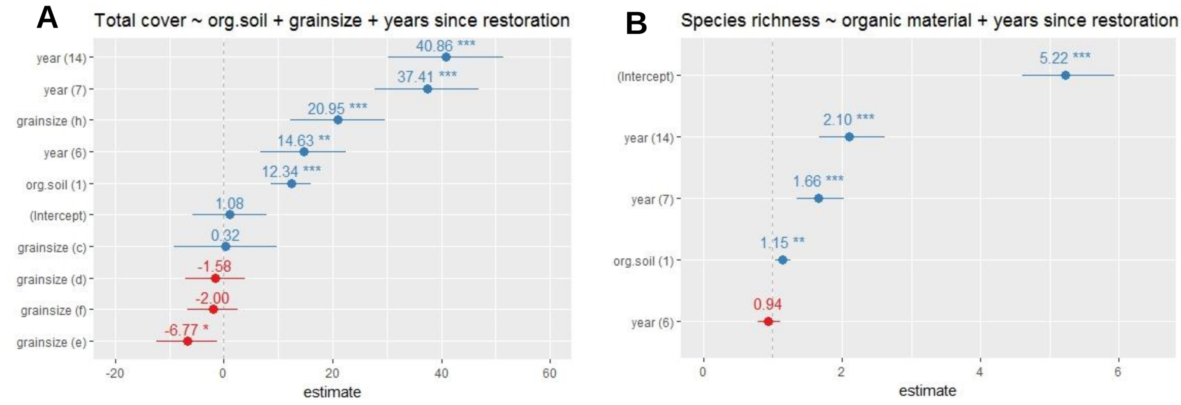

Figure 6. (A) Estimates of fixed effects of the best fitting model for analysis part 1) “Total vegetation cover” and (B) estimates of fixed effects of the best fitting model for analysis part 2) “Species richness”. On the y-axis the model parameters are shown, on the x-axis the estimates for the parameters. See table 5 for the grain size scale.

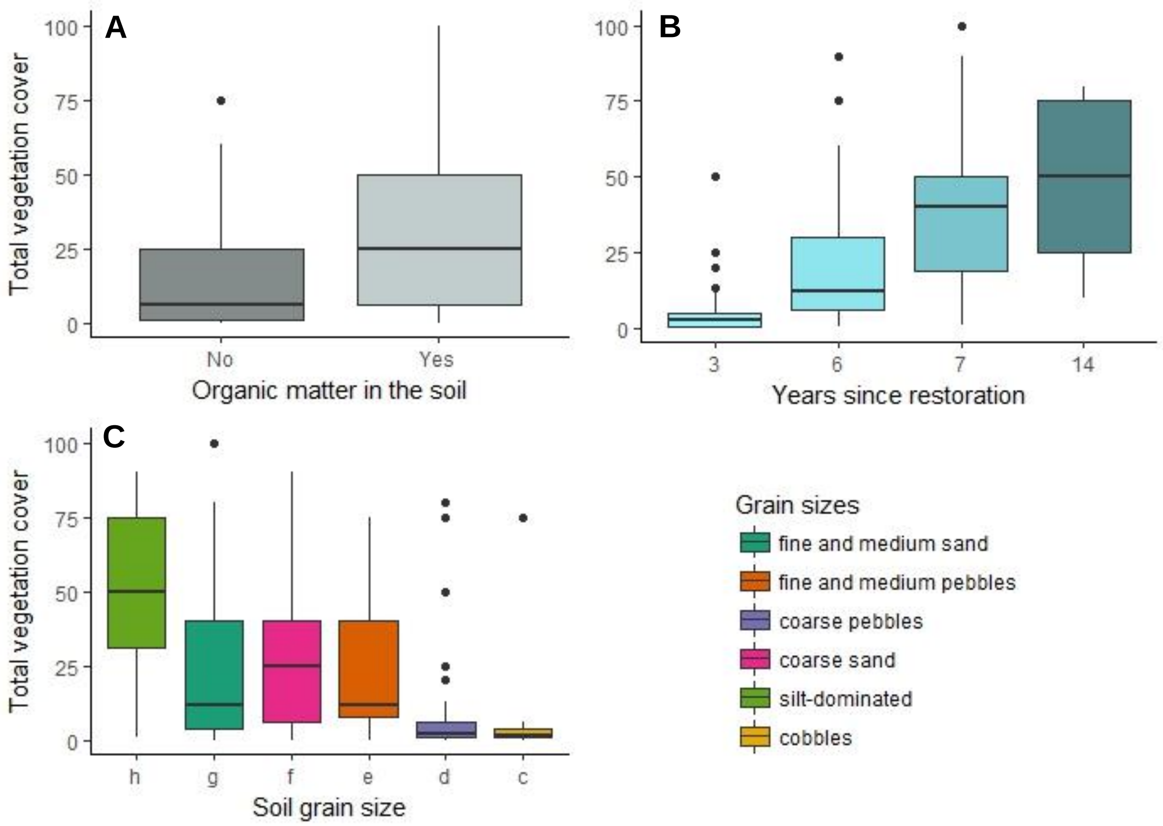

Figure 7. Parameters effecting total vegetation cover of the plots. (A) Effect of organic matter in the soil on total vegetation cover, (B) effect of years since restoration on vegetation cover, (C) effect of soil grain size on total vegetation cover, grain size is shown from smallest to largest.

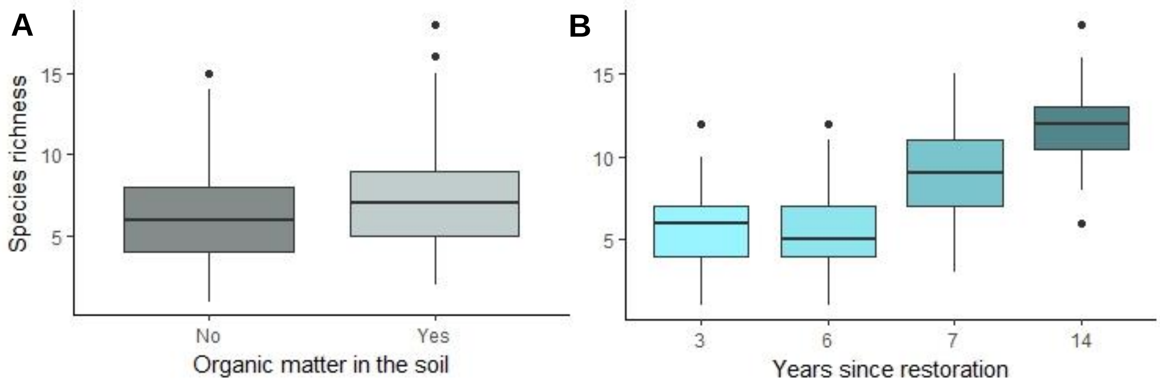

Figure 8. Parameters effecting species richness of the plots. (A) Effect of organic matter in the soil on species richness, (B) effect of years since restoration on species richness.

4. Discussion

4.1 Vegetation recovery

After fourteen years since restoration the species richness of the plots nearly matches the species richness of the turfs. Thus, if I consider the turfs as “original vegetation” or reference vegetation, my results indicate that species richness is restored after fourteen years, although the species composition differs slightly between plots and turfs. Both species richness and total vegetation cover of the plots increased over the years since restoration. In the turfs, however both parameters decreased slightly after six to seven years, but had increased again after fourteen years since restoration. The slight decline could be explained by difficulties in surviving the transplantation.

One of the most abundant species in both plots and turfs was *Deschampsia cespitosa*. This species is native to Norway and rather common in disturbed high-altitude ecosystems. But it is non-native to the alpine heath vegetation which we find in Hjerkinn. This grass species is a strong competitor and has the undesirable characteristics of invasive species, traditionally used when seeding for restoration (Aradottir & Oskarsdottir 2013; Hagen & Evju 2013; Hagen *et al.* 2014). Thus *Deschampsia cespitosa* is undesirable in this restoration project.

My results show that time is the factor that matters most for the recovery of the vegetation around the transplanted turfs. The most significant development of total vegetation cover and species richness was observed over time. Both total vegetation cover and species richness of the plots surrounding the turfs increased over the years since restoration. These findings are consistent with Hagen and Evju (2013), who observed a similar effect. This development is comprehensible, as in low-alpine vegetation the environmental conditions are harsher than in lower-altitude ecosystems. Shorter growing seasons, lower temperatures, strong winds and furthermore, often less resource availability lead to a more difficult germination and establishment process and hence the vegetation needs longer to recover (Urbanska & Chambers 2002; Bay & Ebersole 2006; Krautzer, Uhlig & Wittmann 2012; Hagen & Evju 2013). But the turfs seem to promote a quicker establishment of a vegetation cover in their surroundings, than it would have been without (Bay & Ebersole 2006; Klimeš *et al.* 2010; Aradottir & Oskarsdottir 2013; Hagen & Evju 2013; Mudrák *et al.* 2017). Thus, my findings show that the turfs and their surroundings offer the conditions needed for vegetation recovery, otherwise the recovery process would not have started or it would have been too slow to be crucial after this short time frame of 14 years.

As further suggested, both total vegetation cover and species richness are to a great extend depending on conditions of the receptor site. The presence of organic matter in the soil and a small soil grain size were very important parameters for a higher total vegetation cover and a higher species richness in the plots. Soil grain size, however, was less important for the species richness than it was for the total vegetation cover. Both factors provide ecological advantages for plant establishment. Soil with organic matter contains more nutrients than soil without and a small grain size can keep the water better, so both factors might provide the plants with better growing conditions during establishment. Furthermore, the plants have better possibilities to fasten small root in the soil when the grain size is smaller. Thus, as suggested among others, e.g. Kiehl *et al.* (2010) and Aradottir (2012) it is very important for a successful turf transplantation and also vegetation recovery of the surroundings, that the preparation of the receptor site should be done thoroughly (e.g. remove gravel, stir topsoil). Both studies mentioned above, stress the importance of a well prepared receptor site, specific to the needs of the target vegetation and hence support my results concerning the importance of the conditions at the receptor site.

The distance to the next turf did not influence the species richness significantly, as observed by Hagen and Evju (2013). However, I observed a tendency of increasing species richness with shorter distance to intact vegetation. Differences between my results and the monitoring data of another study of the Pilot-roads (Hagen & Evju 2013) might occur due to differences in study design. The plots in the pilot-monitoring-study were placed randomly, with randomly varying distances to the turfs, while they were placed systematically around the turfs in my experiment, so that all plots were always in close proximity to a turf. As in the pilot-study the monitoring plots were randomly dispersed, the closeness to a turf might have been less frequent and hence more important for a higher species richness than in my study. Another explanation could be that, in most occasions, the next turf was too far away to contribute to species richness of a plot and that most plants dispersed and colonized from the turf belonging to the plot and not from the next closest turf. The dispersal distance and colonization of plants in alpine ecosystems can vary to a great degree temporal and spatial but is believed to be rather short, which could explain this (Stöcklin & Bäumler 1996; Urbanska & Chambers 2002). On the other hand, as the distance to intact vegetation shows the tendency to increase species richness, and the intact vegetation in my study was mostly further away from the plots than the next closest turf, the dispersal distance might have been longer than expected. Following this, as the influence of distance to both next turf and intact vegetation on species richness of the surroundings of transplanted turfs is still not clear, I stress the need for more detailed studies to clarify this point.

Furthermore, neither total vegetation cover of the turfs nor species richness of the turfs have a significant influence on total vegetation cover and species richness of the plots. The reason for this could as well be associated with complications in dispersal distance and colonization of the plants (Stöcklin & Bäumler 1996; Urbanska & Chambers 2002) or by the same suggestion as for the last point, that the influence of the intact vegetation is greater than that of the next closest turf. But as the species richness of the plots and the turfs were nearly equal after 14 years since restoration, I assume that there have been events of dispersal, also from the turfs into the surroundings. Though, it is possible that total vegetation cover and species richness of the turfs are just not the most important factors to vegetation recovery around the transplants, but that the distance to intact vegetation is more important. This might especially be relevant as the roads in my study are quite narrow. In an experiment on a larger area, the vegetation recovery might depend much more on the turfs.

Based on the facts that I observed a good recovery, in terms of an increasing total vegetation cover and species richness over the years since restoration, I assume that the turfs did serve as seed source and/or safe sites for their proximate surroundings. Several other studies demonstrated the function of turfs as seed source for near surroundings or as safe sites where seeds are able to establish in the immediate vicinity of turfs (Klimeš *et al.* 2010; Hagen & Evju 2013) and these studies are therefore supporting my results.

Differences in species composition between donor and receptor sites have been observed in several turf transplantation experiments (Bullock 1998; Klimeš *et al.* 2010; Aradottir & Oskarsdottir 2013). With this study, I cannot confirm nor reject this, as it was not part of the study to survey the reference vegetation in detail. The turfs in my study, however, can be seen to represent the donor site at least to some extent, as they have been taken from the close intact vegetation along the roads. As most of the vascular plants (76 species, table A appendix) were found both in the turfs and in the plots, I assume that the species composition did not differ much between receptor site and original vegetation.

The turf size was not significant for the recovery of the vegetation around the transplants in my study. However, Aradottir (2012) states that the turf size is important for survival of transplantation, at least for some functional groups of plants. The optimal turf size is depending on growth form and abundance of the target species, and is decreasing in size in line with the size of the species. According to that, dwarf-shrubs need larger turfs (20-30 cm diameter) to survive the transplantation than e.g. grasses and mosses (Aradottir 2012). One explanation why the turf size was not important in my study could be that there is a tipping point when turfs are large enough to transfer “enough” species with the ability to survive and to contribute to vegetation recovery around the turfs, and that this is the case in my study. Compared to Aradottir (2012), who used smaller turfs (up to 30 cm diameter), the turfs in my study were mostly larger (between 0.35 and 5.76 m^2).

4.2 Management implications

The results of my study indicate that, whenever there is a restoration project where turfs are going to be used, it is highly important to prepare the receptor site thoroughly. The significant importance of the presence of organic matter in the soil and a small soil grain size in my study show this clearly. Thorough preparations of the receptor site include removing of all crushed stones, gravel and other materials all the way down to the original terrain surface. Furthermore, if the surface is very compressed, the soil top layer should be stirred down to ~20 cm, so that it is easier for the plants to root (Hagen & Evju 2013). Afterwards, with organic matter in the soil and a small soil grain size, it will be much easier for plants to establish themselves and grow in the new environment (Urbanska & Chambers 2002). My results further indicate that, in such narrow disturbed areas as these roads, the size and placing (distance between turf transplants) is not too crucial. Nevertheless, the most important factor for vegetation recovery, in this case, is time. This should be considered in planning and implication of this kind of restoration measures and could also be helpful to communicate to project owners and the public to adjust for different expectations on recovery rates, which might seem slow to non-specialists.

When extracting turfs, it is very important not to destroy other communities and ecosystems (Kiehl *et al.* 2010; Aradottir 2012; Aradottir & Oskarsdottir 2013; Hagen & Evju 2013). This can be easy to some degree in cases where work is in progress, because here the turfs can be taken from the construction site, or were turfs are available due to other reasons (Bay & Ebersole 2006; Kiehl *et al.* 2010; Aradottir & Oskarsdottir 2013; Mudrák *et al.* 2017). But when it comes to restoration or preservation of a site where turfs are not easily accessible, it is very important to extract turfs with no or little native vegetation disturbed (Krautzer, Uhlig & Wittmann 2012; Aradottir & Oskarsdottir 2013) and with greatest care and biological knowledge (Hagen & Evju 2013).

4.3 Conclusion

In conclusion, I can say that the use of turfs as a restoration measure insured a quick establishment of vegetation cover and the introduction of native species on the former roads. A process which, without facilitation with turfs, would have taken much longer, particularly in a low-alpine environment. Therefore, and in agreement with previous published studies, I can recommend the use of turfs to facilitate recovery in restoration, in this case in low-alpine environment. There are still several factors, for example the influence of distance to turf and intact vegetation on vegetation recovery, which need to be studied further to ensure an even better implication of turfs for restoration.

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Appendix

Table A. Species found, the number of plots and turfs they were found in and their mean abundance with standard deviation for plots and turfs. The abundance scales differ between turfs and plots. For the turfs a slightly altered Braun-Blanquet (BB) cover scale has been used, while the abundance in the plots was recorded as presence/absence (p/a) of each species in each subplot.

Species	No. of plots species was recorded in	No. of turfs species was recorded in	Mean abundance (p/a) in the plots ± SD			Mean abundance (BB) in the turfs ± SD		
Achillea multifolium	10	4	5.90	±	3.78	1.8	±	1.26
Agrostis capillaris	-	1	-	-	-	1.0	±	1.54
Andromeda polyfolia	-	12	-	-	-	0.7	±	1.09
Antennaria dioica	24	18	3.08	±	2.32	0.7	±	0.54
Anthoxanthum nipponicum	1	3	2.00	±	NA	0.4	±	1.23
Arctostaphylos uva-ursi	6	6	2.00	±	1.67	1.2	±	1.05
Astragalus alpinus	6	8	3.67	±	2.50	1.5	±	0.37
Astragalus fridigus	-	3	-	-	-	1.7	±	0.99
Avenella flexuosa	17	23	1.47	±	0.80	1.7	±	1.36
Bartsia alpina	13	32	2.23	±	1.54	0.6	±	0.42
Betula nana	37	90	2.78	±	2.72	2.2	±	0.52
Betula pubescens	4	14	1.00	±	0.00	0.4	±	0.69
Bistorta vivipara	43	44	3.28	±	3.03	1.1	±	0.65
Botrychium lunaria	3	2	1.00	±	0.00	0.1	±	0.90
Calluna vulgaris	-	11	-	-	-	1.3	±	0.40
Campanula rotundifolia	7	6	2.57	±	1.72	0.3	±	0.62
Carex atrofusca	2	-	1.50	±	0.71	-	-	-
Carex bigelowii	22	33	2.95	±	2.66	1.0	±	0.37
Carex brunnescens	11	3	1.91	±	0.83	0.4	±	0.62
Carex capillaris	-	2	-	-	-	0.6	±	0.56
Carex cf. dioica	1	6	1.00	±	NA	1.4	±	0.42
Carex cf. panicea	-	1	-	-	-	1.0	±	NA
Carex dioica	-	2	-	-	-	3.0	±	0.77
Carex norvegica	4	1	1.25	±	0.50	1.0	±	0.52
Carex trifidus	1	-	1.00	±	NA	-	-	-
Carex vaginata	-	10	-	-	-	0.6	±	0.95
Cerastium alpinum	25	8	1.96	±	1.74	0.3	±	1.37
Cerastium fontanum	17	1	2.29	±	1.86	1.0	±	0.79
Coeloglussum virvide	-	1	-	-	-	1.0	±	NA
Comastoma tenellum	-	1	-	-	-	0.1	±	0.52
Deschampsia cespitosa	187	70	4.13	±	3.49	2.1	±	1.69
Diphasiastrum alpinum	-	2	-	-	-	0.1	±	0.94
Empetrum nigrum	25	68	2.08	±	1.26	1.9	±	0.75
Epilobium angustifolium	2	4	1.50	±	0.71	0.3	±	1.13
Epilobium davuricum	10	-	3.00	±	2.91	-	-	-
Epilobium palustre	2	-	2.50	±	2.12	-	-	-
Equisetum arvense	14	2	7.64	±	5.92	1.5	±	0.88
Equisetum cf. arvense	1	-	14.00	±	NA	-	-	-
Equisetum palustre	30	5	6.80	±	5.71	1.4	±	0.42
Equisetum variegatum	2	1	2.50	±	0.71	0.1	±	0.95
Erigeron cf. uniflorus	-	2	-	-	-	0.1	±	1.23
Eriophorum angustifolium	1	5	6.00	±	NA	1.1	±	0.56
Eriophorum vaginatum	2	6	1.00	±	0.00	1.2	±	0.00
Festuca ovina	149	93	4.26	±	3.83	2.9	±	1.07
Festuca pratensis	1	-	2.00	±	NA	-	-	-
Festuca rubra	62	6	2.13	±	1.60	0.7	±	0.73
Galium boreale	1	10	2.00	±	NA	1.8	±	0.42
Gentiana nivalis	2	1	1.00	±	0.00	0.1	±	0.00
Geranium sylvaticum	5	15	1.60	±	0.89	1.3	±	0.80

Species	nr of plots species was recorded in	nr of turfs species was recorded in	mean abundance (p/a) in the plots ± SD			mean abundance (BB) in the turfs ± SD		
Geum rivale	-	1	-	-	-	0.1	±	0.76
Gymnadenia conopsea	-	1	-	-	-	0.1	±	0.56
Hieracium sek Alpina	1	15	1.00	±	NA	1.1	±	0.91
Juncus arcticus	61	10	2.92	±	2.30	1.4	±	0.66
Juncus castaneus	19	4	4.16	±	3.69	0.6	±	1.11
Juncus trifidus	7	1	3.00	±	2.00	1.0	±	1.00
Juncus triglumis	13	3	3.08	±	3.62	1.0	±	0.72
Juniperus communis	4	15	1.25	±	0.50	2.2	±	NA
Kalmia procumbens	-	4	-	-	-	1.5	±	0.96
Leontodon autumnalis	5	3	2.00	±	1.22	0.1	±	0.46
Loiseleuria procumbens	1	1	1.00	±	NA	2.0	±	0.52
Luzula multiflora	108	48	2.88	±	2.98	0.5	±	0.37
Luzula spicata	44	5	2.07	±	2.44	0.3	±	0.00
Melampyrum sylvaticum	-	8	-	-	-	1.2	±	0.85
Minuartia stricta	1	-	4.00	±	NA	-	-	-
Nardus stricta	2	17	1.50	±	0.71	1.4	±	0.64
Omalotheca supina	1	-	1.00	±	NA	-	-	-
Oxyria diguna	-	1	-	-	-	0.1	±	1.48
Pedicularis lapponica	2	29	4.50	±	4.95	0.7	±	NA
Pedicularis oederi	-	2	-	-	-	1.5	±	0.79
Phleum alpinum	-	6	-	-	-	0.3	±	1.47
Phyllodoce caerulea	1	4	1.00	±	NA	0.6	±	0.85
Pinguicula vulgaris	30	35	5.07	±	5.77	0.5	±	1.34
Poa alpina	40	19	2.15	±	1.55	0.5	±	0.52
Poa pratensis	1	1	1.00	±	NA	0.1	±	NA
Potentilla crantzii	2	1	1.00	±	0.00	2.0	±	0.00
Primula stricta	1	1	7.00	±	NA	1.0	±	0.00
Ranunculus acris	2	4	2.50	±	2.12	1.0	±	0.99
Rubus chamaemorus	-	1	-	-	-	1.0	±	NA
Rumex acetosa	5	3	3.40	±	4.28	0.7	±	NA
Rumex acetosella	3	4	11.00	±	4.00	0.3	±	1.47
Sagina nivalis	30	-	4.40	±	4.87	-	-	-
Salix glauca	47	83	3.11	±	2.79	2.4	±	0.78
Salix herbacea	5	3	2.40	±	2.07	0.7	±	1.67
Salix myrsinifolia	-	1	-	-	-	1.0	±	NA
Salix phylicifolia	37	36	4.03	±	3.62	1.8	±	0.00
Salix reticulata	1	8	3.00	±	NA	0.3	±	NA
Saussurea alpina	-	7	-	-	-	0.9	±	0.00
Saxifraga aizoides	6	2	2.50	±	3.21	1.1	±	NA
Saxifraga oppositifolia	1	-	1.00	±	NA	-	-	-
Saxifraga stellaris	5	-	1.40	±	0.55	-	-	-
Silene cf. dioica	1	-	1.00	±	NA	-	-	-
Silene dioica	-	1	-	-	-	2.0	±	0.71
Solidago virgaurea	12	61	2.25	±	2.18	1.1	±	NA
Spergularia rubra	1	-	2.00	±	NA	-	-	-
Stellaria borealis	5	6	1.40	±	0.89	0.3	±	0.52
Thalictrum alpinum	3	18	1.33	±	0.58	0.7	±	0.71
Tofieldia pusilla	10	27	3.30	±	3.92	0.7	±	0.64
Trientalis europaea	2	19	1.00	±	0.00	1.3	±	NA
Vaccinium myrtillus	-	33	-	-	-	0.7	±	NA
Vaccinium uliginosum	2	15	1.50	±	0.71	0.6	±	NA
Vaccinium vitis-idaea	7	57	3.29	±	3.04	0.7	±	NA
Viscaria alpina	10	2	1.30	±	0.95	0.1	±	NA
Carex sp.	50	42	1.40	±	0.76	1.6	±	0.44
Epilobium sp.	1	-	15.00	±	NA	-	-	-
Equisetum sp.	18	2	9.28	±	5.00	1.0	±	0.71
Eriophorum sp.	23	16	2.65	±	2.48	1.2	±	NA

Species	nr of plots species was recorded in	nr of turfs species was recorded in	mean abundance (p/A) in the plots ± SD	mean abundance (BB) in the turfs ± SD
Festuca sp.	1	-	1.00 ± NA	- - -
Juncus sp.	2	2	1.00 ± 0.00	1.5 ± NA
Luzula sp.	98	3	3.60 ± 3.81	0.4 ± NA
Lycopodium sp.	5	-	1.40 ± 0.89	- - -
Poa sp.	-	1	- - -	0.1 ± 0.45
Pyrola sp.	2	8	1.00 ± 0.00	0.3 ± NA
Sagina sp.	7	-	1.57 ± 0.79	- - -
Salix sp.	86	1	3.84 ± 3.22	0.1 ± NA
Taraxacum sp.	1	2	2.00 ± NA	0.6 ± 0.96
Cyperaceae	5	4	1.60 ± 0.55	0.8 ± 0.00
fungi	21	5	1.62 ± 1.36	0.1 ± 1.18
grass	37	-	2.19 ± 1.22	- - -
lichens	51	69	9.61 ± 6.05	2.2 ± 1.17
moss	262	108	10.14 ± 5.55	2.7 ± 0.45
dicotyledonous plants	34	-	3.18 ± 2.17	- - -
monocotyledonous plants	178	-	5.36 ± 4.56	- - -

Table B. Species solely found in plots (left) and turfs (right).

	Species solely found in plots
1	*Carex atrofusca*
2	*Carex trifidus*
3	*Epilobium davuricum*
4	*Epilobium palustre*
5	*Equisetum cf. arvense*
6	*Festuca pratensis*
7	*Minuartia stricta*
8	*Omalotheca supina*
9	*Sagina nivalis*
10	*Saxifraga oppositifolia*
11	*Saxifraga stellaris*
12	*Silene cf. dioica*
13	*Spergularia rubra*
14	*Epilobium sp.*
15	*Festuca sp.*
16	*Lycopodium sp.*
17	*Sagina sp.*
18	grass
19	monocotyledonous plants

	Species solely found in turfs
1	*Agrostis capillaris*
2	*Andromeda polyfolia*
3	*Astragalus fridigus*
4	*Calluna vulgaris*
5	*Carex capillaris*
6	*Carex cf. panicea*
7	*Carex dioica*
8	*Carex vaginata*
10	*Comastoma tenellum*
11	*Diphasiastrum alpinum*
12	*Erigeron cf. uniflorus*
13	*Geum rivale*
14	*Gymnadenia conopsea*
15	*Kalmia procumbens*
16	*Melampyrum sylvaticum*
17	*Oxyria diguna*
18	*Pedicularis oederi*
19	*Phleum alpinum*
20	*Rubus chamaemorus*
21	*Salix myrsinifolia*
22	*Saussurea alpina*
23	*Silene dioica*
24	*Vaccinium myrtillus*
25	*Poa sp.*

Table C. AIC table of random component structure selection for analysis part 1) "Total vegetation cover", left column shows the different random structures tested, best fitting random structure in bold , K = number of parameters.

	K	AIC	Delta_AIC	ModelLik	AICWt	Res.LL	Cum.Wt
year + (1|road/turf)	**18**	**2651**	**0**	**1.00**	**1.00**	**-1307.51**	**1.00**
(1|year/road/turf)	16	2675	24	7.04E-06	7.04E-06	-1321.37	1.00
(1|road/turf)	15	2687	36	1.35E-08	1.35E-08	-1328.63	1.00
(1|turf)	14	2766	115	9.38E-26	9.38E-26	-1369.14	1.00

Table D. AIC table of random component structure selection for analysis part 2) "Species richness", left column shows the different random structures tested, best fitting random structure in bold , K = number of parameters.

	K	AIC	Delta_AIC	ModelLik	AICWt	LL	Cum.Wt
year + (1|road/turf)	**17**	**1499**	**0.00**	**1.00**	**1.00**	**-732.71**	**1.00**
(1|year/road/turf)	15	1511	11.29	0.00	0.00	-740.36	1.00
(1|road/turf)	14	1517	17.13	0.00	0.00	-744.28	1.00
(1|turf)	13	1561	62.04	3.37E-14	3.36E-14	-767.74	1.00

Table E. Fixed component structure selection for analysis part 1) "total vegetation cover", shown are coefficients for all tested models (single explanatory and more complex models), significant parameters in bold, except for "year" which is significant in every model, parameter estimates for random effects are not shown.

Model 1: lmer(total.cover ~ distance.turf + year + (1|road.x/turf.x), data = fulldata, REML = FALSE)

	Estimate	Std. Error	t value
(Intercept)	4.448	3.800	1.170
distance.turf	-0.001	0.010	-0.127
year6	16.858	4.680	3.602
year14	43.286	6.419	6.743
year7	35.012	5.691	6.152

Model 2: lmer(total.cover ~ distance.veg + year + (1|road.x/turf.x), data = fulldata, REML = FALSE)

	Estimate	Std. Error	t value
(Intercept)	5.962	3.921	1.521
distance.veg	-0.005	0.006	-0.814
year6	16.714	4.634	3.607
year14	43.314	6.391	6.778
year7	34.747	5.667	6.131

Model 3: lmer(total.cover ~ org.soil + year + (1|road.x/turf.x), = fulldata, REML = FALSE)

	Estimate	Std. Error	t value
(Intercept)	-0.149	2.819	-0.053
org.soil1	**13.537**	**1.836**	**7.373**
year6	14.817	3.911	3.789
year14	40.532	5.472	7.407
year7	35.012	4.774	7.334

Model 4: lmer(total.cover ~ grain size + year + (1|road.x/turf.x), data = fulldata, REML = FALSE)

	Estimate	Std. Error	t value
(Intercept)	8.377	3.398	2.465
grain sizee	-9.209	2.999	-3.071
grain sized	-6.148	2.831	-2.172
grain sizef	-3.820	2.476	-1.543
grain sizeh	**21.666**	**4.635**	**4.675**
grain sizec	-6.296	5.006	-1.258
year6	14.845	4.049	3.666
year14	42.023	5.609	7.492
year7	35.832	4.942	7.251

Model 5: lmer(total.cover ~ cover.turf + year + (1|road.x/turf.x), data = fulldata, REML = FALSE

	Estimate	Std. Error	t value
(Intercept)	8.767	10.118	0.866
cover.turf	-0.053	0.112	-0.477
year6	17.411	4.741	3.673
year14	43.987	6.546	6.719
year7	35.268	5.718	6.168

Model 6: lmer(total.cover ~ tsize + year + (1|road.x/turf.x), data = fulldata, REML = FALSE)

	Estimate	Std. Error	t value
(Intercept)	5.229	3.883	1.347
tsize	-0.477	1.030	-0.463
year6	16.970	4.506	3.766
year14	43.046	6.304	6.829
year7	35.245	5.553	6.347

Model 7: lmer(total.cover ~ year + (1|road.x/turf.x), data = fulldata, REML = FALSE)

	Estimate	Std. Error	t value
(Intercept)	4.202	3.269	1.285
year6	16.944	4.624	3.664
year14	43.347	6.396	6.778
year7	34.948	5.661	6.173

Model 8: lmer(total.cover ~ org.soil + grain size + year + (1|road.x/turf.x), data = fulldata, REML = FALSE)

	Estimate	Std. Error	t value
(Intercept)	0.961	3.074	0.313
org.soil1	**12.507**	**1.806**	**6.925**
grain sizee	-6.637	2.837	-2.339
grain sized	-1.563	2.729	-0.573
grain sizef	-1.994	2.338	-0.853
grain sizeh	**21.644**	**4.346**	**4.980**
grain sizec	0.554	4.751	0.117
year6	14.609	3.289	4.441
year14	40.771	4.674	8.723
year7	37.427	4.017	9.318

Table F. ANOVA result tables of competing models from analysis part 1) “Total vegetation cover”, significant models in bold.

Models:
Model3: total.cover ~ org.soil + year + (1 | road.x/turf.x)
Model4: total.cover ~ grain size + year + (1 | road.x/turf.x)

	Df	AIC	BIC	logLik	deviance	Chisq	Chi Df	Pr(>Chisq)
Model3	8	2710	2740	-1346.80	2693.61			
Model4	12	2725	2770	-1350.51	2701.02	0	4	1

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Models:
Model3: total.cover ~ org.soil + year + (1 | road.x/turf.x)
Model8: total.cover ~ org.soil + grain size + year + (1 | road.x/turf.x)

	Df	AIC	BIC	logLik	deviance	Chisq	Chi Df	Pr(>Chisq)
Model3	8	2710	2740	-1346.80	2693.61			
Model8	**13**	**2683**	**2733**	**-1328.64**	**2657.27**	**36.34**	**5**	**8.13E-07*****

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Models:
Model4: total.cover ~ grain size + year + (1 | road.x/turf.x)
Model8: total.cover ~ org.soil + grain size + year + (1 | road.x/turf.x)

	Df	AIC	BIC	logLik	deviance	Chisq	Chi Df	Pr(>Chisq)
Model4	12	2725	2770	-1350.51	2701.02			
Model8	**13**	**2683**	**2733**	**-1328.64**	**2657.27**	**43.75**	**1**	**3.74E-11*****

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table G. Fixed component structure selection for analysis part 2) “Species richness”, shown are coefficients for all tested models (single explanatory and more complex models), significant parameters in bold, except for “year” which is significant in every model, parameter estimates for random effects are not shown.

Model 9: glmer(SR.ruter ~ distance.turf.std + year + (1|road.x/turf.x), data = fulldata, family = poisson())

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.689	0.066	25.698	0.0000
distance.turf.std	0.034	0.026	1.344	0.1789
year6	-0.018	0.095	-0.190	0.8496
year14	0.788	0.120	6.579	0.0000
year7	0.487	0.108	4.499	0.0000

Model 10: glmer(SR.ruter ~ distance.veg.std + year + (1|road.x/turf.x), data = fulldata, family = poisson())

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.702	0.069	24.527	0.0000
distance.veg.std	**-0.046**	**0.024**	**-1.884**	**0.0595**
year6	-0.054	0.099	-0.548	0.5840
year14	0.770	0.125	6.140	0.0000
year7	0.494	0.115	4.303	0.0000

Model 11: glmer(SR.ruter ~ org.soil + year + (1|road.x/turf.x), data = fulldata, family = poisson())

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.653	0.065	25.515	0.0000
org.soil1	**0.138**	**0.049**	**2.796**	**0.0052**
year6	-0.063	0.089	-0.710	0.4777
year14	0.741	0.114	6.515	0.0000
year7	0.504	0.102	4.928	0.0000

Model 12: glmer(SR.ruter ~ grain size + year + (1|road.x/turf.x), data = fulldata, family = poisson())

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.827	0.083	22.003	0.0000
grain sizee	-0.035	0.078	-0.445	0.6565
grain sized	**-0.199**	**0.081**	**-2.468**	**0.0136**
grain sizef	-0.044	0.067	-0.652	0.5146
grain sizeh	0.014	0.122	0.117	0.9068
grain sizec	**-0.274**	**0.144**	**-1.909**	**0.0562**
year6	-0.125	0.095	-1.319	0.1872
year14	0.695	0.120	5.813	0.0000
year7	0.414	0.110	3.767	0.0002

Model 13: glmer(SR.ruter ~ SR.turf.std + year + (1|road.x/turf.x), data = fulldata, family = poisson())

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.708	0.071	23.976	0.0000
SR.turf.std	-0.018	0.032	-0.554	0.5798
year6	-0.065	0.106	-0.616	0.5379
year14	0.761	0.125	6.093	0.0000
year7	0.492	0.115	4.285	0.0000

Model 14: glmer(SR.ruter ~ tsize + year + (1|road.x/turf.x), data = fulldata, family = poisson())

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.672	0.088	18.970	0.0000
tsize	0.012	0.025	0.472	0.6368
year6	-0.043	0.099	-0.431	0.6661
year14	0.779	0.126	6.157	0.0000
year7	0.497	0.116	4.276	0.0000

Model 15: glmer(SR.ruter ~ year + (1|road.x/turf.x), data = fulldata, family = poisson())

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.697	0.068	25.037	0.0000
year6	-0.042	0.096	-0.435	0.6638
year14	0.771	0.123	6.284	0.0000
year7	0.504	0.112	4.503	0.0000

Model 16: glmer(SR.ruter ~ distance.veg.std + org.soil + year + (1|road.x/turf.x), data = fulldata, family = poisson())

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.660	0.066	25.032	0.0000
distance.veg.std	-0.035	0.025	-1.403	0.1605
org.soil1	**0.125**	**0.050**	**2.479**	**0.0132**
year6	-0.070	0.091	-0.767	0.4430
year14	0.743	0.116	6.384	0.0000
year7	0.497	0.105	4.733	0.0000

Model 17: glmer(SR.ruter ~ distance.veg.std + grain size + year + (1|road.x/turf.x), data = fulldata, family = poisson())

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.823	0.085	21.538	0.0000
distance.veg.std	-0.038	0.024	-1.561	0.1185
grain sizee	-0.028	0.079	-0.351	0.7256
grain sized	**-0.189**	**0.081**	**-2.328**	**0.0199**
grain sizef	-0.040	0.067	-0.592	0.5540
grain sizeh	0.008	0.122	0.067	0.9465
grain sizec	**-0.248**	**0.145**	**-1.715**	**0.0864**
year6	-0.130	0.098	-1.336	0.1815
year14	0.699	0.123	5.696	0.0000
year7	0.410	0.113	3.624	0.0003

Model 18: glmer(SR.ruter ~ org.soil + grain size + year + (1|road.x/turf.x), data = fulldata, family = poisson(), control = glmerControl(optimizer= "optimx", optCtrl = list(method="nlminb")))

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.762	0.085	20.640	0.0000
org.soil1	**0.112**	**0.051**	**2.192**	**0.0284**
grain sizee	-0.009	0.079	-0.110	0.9121
grain sized	**-0.159**	**0.082**	**-1.931**	**0.0534**
grain sizef	-0.028	0.067	-0.419	0.6752
grain sizeh	0.015	0.121	0.124	0.9016
grain sizec	-0.221	0.144	-1.529	0.1262
year6	-0.129	0.090	-1.434	0.1517
year14	0.682	0.113	6.056	0.0000
year7	0.426	0.103	4.134	0.0000

Table H. ANOVA result tables of competing models from analysis part 2 “Species richness”, significant models in bold.

Models:
Model10: SR.ruter ~ distance.veg.std + year + (1 | road.x/turf.x)
Model11: SR.ruter ~ org.soil + year + (1 | road.x/turf.x)

	Df	AIC	BIC	logLik	deviance	Chisq	Chi Df	Pr(>Chisq)
Model10	7	1492	1519	-739.07	1478.14			
Model11	**7**	**1488**	**1515**	**-737.06**	**1474.12**	**4.02**	**0**	**<2.20E-16*****

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Models:
Model10: SR.ruter ~ distance.veg.std + year + (1 | road.x/turf.x)
Model12: SR.ruter ~ grain size + year + (1 | road.x/turf.x)

	Df	AIC	BIC	logLik	deviance	Chisq	Chi Df	Pr(>Chisq)
Model10	7	1492	1519	-739.07	1478.14			
Model12	11	1495	1537	-736.54	1473.08	5.07	4	2.81E-01

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Models:
Model11: SR.ruter ~ org.soil + year + (1 | road.x/turf.x)
Model12: SR.ruter ~ grain size + year + (1 | road.x/turf.x)

	Df	AIC	BIC	logLik	deviance	Chisq	Chi Df	Pr(>Chisq)
Model11	7	1488	1515	-737.06	1474.12			
Model12	11	1495	1537	-736.54	1473.08	1.05	4	9.03E-01

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Models:
Model11: SR.ruter ~ org.soil + year + (1 | road.x/turf.x)
Model16: SR.ruter ~ distance.veg.std + org.soil + year + (1 | road.x/turf.x)

	Df	AIC	BIC	logLik	deviance	Chisq	Chi Df	Pr(>Chisq)
Model11	7	1488	1515	-737.06	1474.12			
Model16	8	1488	1518	-736.06	1472.11	2.01	1	0.16

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Models:
Model11: SR.ruter ~ org.soil + year + (1 | road.x/turf.x)
Model17: SR.ruter ~ distance.veg.std + grain size + year + (1 | road.x/turf.x)

	Df	AIC	BIC	logLik	deviance	Chisq	Chi Df	Pr(>Chisq)
Model11:	7	1488	1515	-737.06	1474.12			
Model17	12	1495	1540	-735.30	1470.60	3.53	5	0.62

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Models:
Model11: SR.ruter ~ org.soil + year + (1 | road.x/turf.x)
Model18: SR.ruter ~ org.soil + grain size + year + (1 | road.x/turf.x)

	Df	AIC	BIC	logLik	deviance	Chisq	Chi Df	Pr(>Chisq)
Model11	7	1488	1515	-737.06	1474.12			
Model18	12	1492	1538	-734.19	1468.37	5.75	5	0.33

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

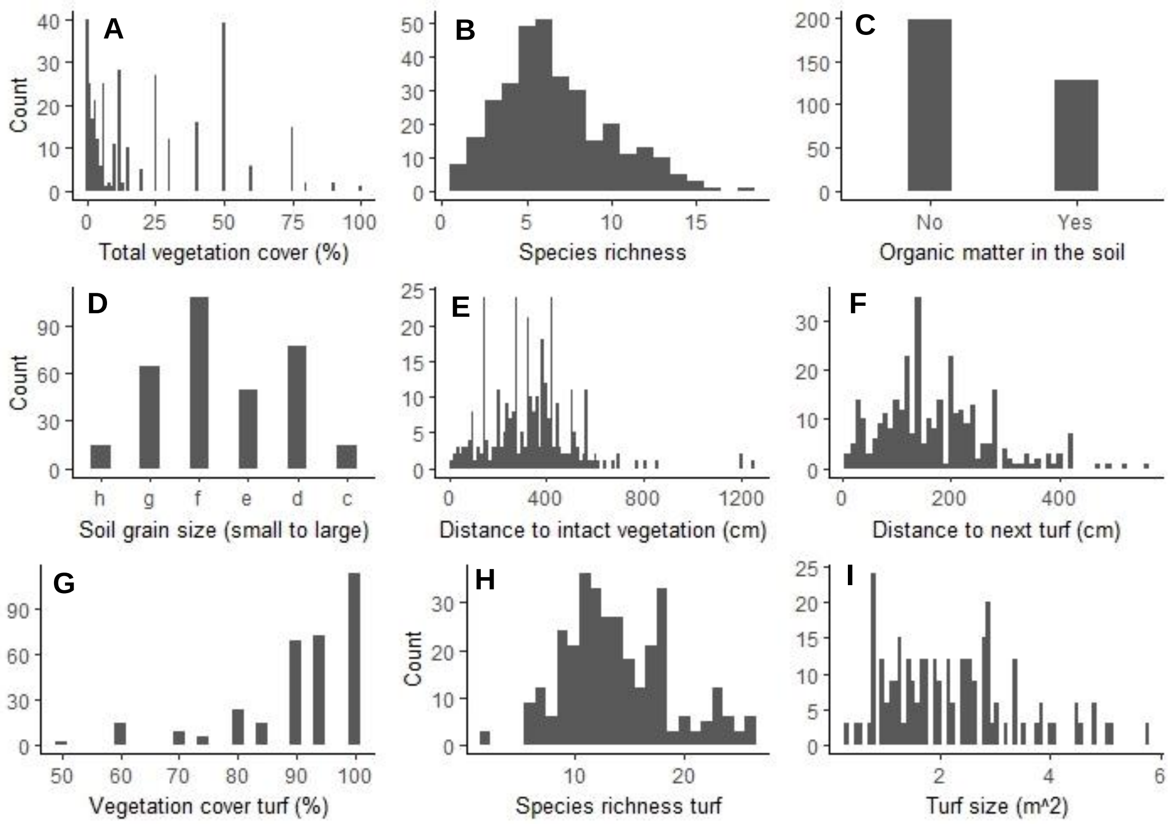

Figure A. Distribution of each parameter used in the analysis. On the y-axis is the count, on the x-axis the parameter. A-F = plot parameters, G-I = turf parameters. See table 5 for the grain size scale.

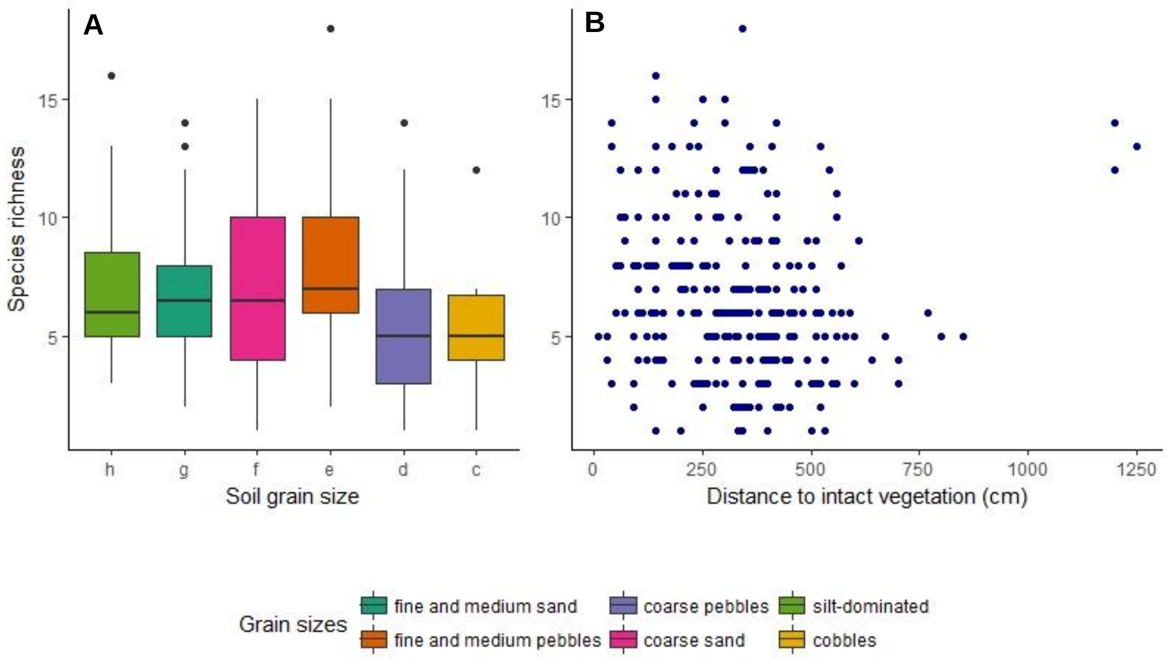

Figure B. Alternative models for analysis part 2 “Species richness”. (A) Effect of soil grain size on species richness. (B) Parameter distance to intact vegetation, with the tendency to effect species richness of the plots.