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

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Abstract

Questions: Restoration of disturbed alpine ecosystems is difficult due to harsh environmental conditions. Transplanting of vegetation turfs into disturbed areas has been used as a restoration method in disturbed alpine sites. The aim of this study is to investigate which environmental factors influence the vegetation recovery in turf surroundings and how turf attributes contribute to vegetation recovery.

Location: Restored roads in a former military training area at the Dovrefjell mountain range, Central Norway.

Methods: We recorded species richness, vegetation cover and soil characteristics of transplanted turfs and turf surroundings in roads restored between three and fourteen years ago. Linear and generalized linear mixed models were used to investigate the relative importance of turf attributes and soil factors for recovery of turf surroundings.

Results: Time was the most important factor for vegetation recovery, but soil conditions in turf surroundings were also highly important. Species richness and vegetation cover in turf surroundings were almost twice as high on silt-dominated soil and with presence of soil organic matter compared to on coarser soils and without organic matter. Species richness in turfs and turf surroundings was almost equal after 14 years, and the similarity of the species composition was high. Neither turf size, distance to the second closest turf or species richness and vegetation cover of the turfs were important factors for vegetation recovery in the turf surroundings.

Conclusion: This study demonstrates the importance of preparing the restoration sites before using turf transplants in road and infrastructure restoration. Of particular importance is ensuring soil organic content and a fine soil grain size to increase rates of vegetation recovery in short time-scales. Time is the most important factor for recovery in this ecosystem, and this should be communicated to project owners and to the public to ensure realistic expectations on recovery time.

Keywords: Low-alpine ecosystems, vegetation restoration, turf transplants, ecosystem management, vegetation recovery.

Nomenclature: Mossberg and Stenberg (2014) for vascular plants.

Running head: Turf transplants in restoration.

Introduction

Degradation and destruction of ecosystems by humans are increasing with a growing world population. To maintain and restore biodiversity and maintain functions of soil retention, effective ecological restoration becomes more important than ever (Hobbs & Norton 1996; Suding 2011). Ecological restoration aims to recover a degraded ecosystem to a degree of a natural stage with respect to its health, intactness and long-term sustainability. This also includes preparing disturbed ground for improved natural recovery and establishment of native flora and fauna (Hobbs & Norton 1996; Society for Ecological Restoration Science & Policy Working Group 2002; Young et al. 2005; Falk et al. 2006; Perring et al. 2015).

The restoration of alpine ecosystems is increasingly important, as these habitats are under strong pressure and degradation from changing land-use, infrastructure and hydropower development, and at the same time they harbour unique diversity of habitat types, flora and fauna (Suding 2011). Restoration in alpine areas is challenging due to short growing seasons, low temperatures and often less water- and nutrient availability compared with lower-altitude ecosystems (Urbanska & Chambers 2002; Bay & Ebersole 2006; Krautzer et al. 2012; Hagen & Evju 2013), and hence, it is particularly difficult to find successful restoration methods.

Typical measures for alpine vegetation restoration after soil and habitat degradation include 1) restoring terrain surface conditions, 2) adding nutrients, 3) seeding and 4) transplanting turfs or plants (Conlin & Ebersole 2001; Hagen & Evju 2013). All these measures have over time been tried out in several projects, with varying success (Kiehl et al. 2010; Krautzer et al. 2012; Hagen & Evju 2013).

Particularly, the transplanting of individuals of plant species or whole vegetation turfs has been applied more frequently during the last two decades, to conserve 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. 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 et al. 2012; Hagen & Evju 2013). Turf transplantation is believed to facilitate vegetation recovery by providing a 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 et al. 2012; Hagen & Evju 2013). The soil seedbank may also work as a long-term seed source (Urbanska & Chambers 2002; Krautzer et al. 2012), although according to Klimeš et al. (2010) at least the short-term effect is negligible. Mycorrhiza and soil biota, 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 local turfs for restoration instead of seeding with either commercial seed mixtures or local seeds. Seeding might be less costly and easier applied but success, especially in alpine ecosystems, can be limited because of strong winds and erosion (Bay & Ebersole 2006; Kiehl et al. 2010; Krautzer et al. 2012). Furthermore, species in seed-mixtures are often fast establishing grasses which can outcompete other species, leading to a lower species diversity over time (Aradottir & Oskarsdottir 2013; Hagen & Evju 2013; Hagen et al. 2014). 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 et al. 2010; Klimeš et al. 2010; Krautzer et al. 2012; Aradottir & Oskarsdottir 2013). Native species are adapted to grow in the given conditions, they maintain local genetic diversity and hence can establish and preserve local plant communities and thus biodiversity of the area (Conlin & Ebersole 2001; Bochet et al. 2010; Kiehl et al. 2010; Klimeš et al. 2010; Aradottir 2012; Krautzer et al. 2012; Aradottir & Oskarsdottir 2013; Hagen & Evju 2013).

Turf transplants have been used in restoration projects in alpine hiking trails (Conlin & Ebersole 2001; Bay & Ebersole 2006), coalfields and opencast coal extraction sites (Bullock 1998; Good et al. 1999), species rich meadows and grasslands (Good et al. 1999; Klimeš et al. 2010) and road sides (Aradottir & Oskarsdottir 2013), however, the definitions of success criteria vary. Turf transplanting has been evaluated as a successful measure in terms of protection against erosion (Krautzer et al. 2012), development of vegetation cover and species richness, difference from intact vegetation (Hagen & Evju 2013) and occurrence of rare species in the transplants (Conlin & Ebersole 2001; Bay & Ebersole 2006;

Aradottir 2012; Aradottir & Oskarsdottir 2013; Mudrák et al. 2017). Nevertheless, when comparing species composition and occurrence of red list species between donor site and turfs after transplantation, turf transplants show limitations (Bullock 1998; Klimeš et al. 2010).

However, few studies have focused on the surroundings of the turf and particularly on the factors responsible for recovery of sites adjacent to turfs (Klimeš et al. 2010). Studies of turf transplantation should thus also include detailed investigations of both the turfs themselves, and the surroundings of turfs, to evaluate the relative importance of different environmental factors. This is critical for the development of efficient methods for applied ecological restoration (Aradottir 2012; Krautzer et al. 2012; Hagen & Evju 2013).

In this study we use roads restored between three to fourteen years ago in an alpine area to investigate the relative importance of environmental factors at sites adjacent to turfs and turf attributes for vegetation recovery, recorded as vegetation cover and species richness of the turf surroundings. We predict that recovery 1) increases with age of restoration, 2) is positively affected by turf size, vegetation cover of turf, and turf species richness, 3) increases with closeness to intact vegetation and turf density, and that 4) soil characteristics of the turf surroundings, such as organic matter content and soil grain size increase recovery rates.

Methods

Study area

The study area is located in the Dovrefjell mountain range in central Norway (62°14’59” N, 9°27’48” E; 1070 m a.s.l.), surrounded by the Dovrefjell-Sunndalsfjella National Park which sustains a highly diverse mountain flora (Fig. 1) (Norwegian Environment Agency 2013).

The mean annual temperature (1961-1999) at the closest weather station (Fokstugu, 973 m a.s.l.) is 0.8° C with a total precipitation of 295 mm during May – October (lowest in September with 34.8 mm, highest in July with 72.3 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 type at the study sites is dry and medium dry alpine heathland, partly with tall herbaceous vegetation and mire (Norwegian Institute of Bioeconomy Research (NIBIO) 2017).

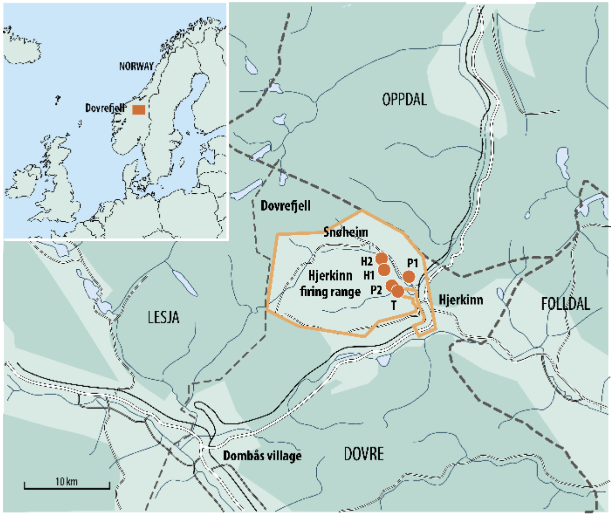

Fig. 1: The study area situated in Hjerkinn firing range at the Dovrefjell mountain range, central Norway (orange line), surrounded by protected areas (dark green colour). The study sites are marked as orange dots. P1 = Pilot I, P2 = Pilot II, T = Tverfjellvegen, H1 = Haukberget I, H2 = Haukberget II.

The study area is located within Hjerkinn firing range, a former military training area, covering 165 km^2. The decision to restore the area to its natural state was made by the Norwegian Parliament in 1998 (Ministry of Defence 1998), with an overall goal to “Restore the ecosystem to original state and for future nature conservation (National park)”. The restoration involves removing all infrastructure, including more than 90 km of roads (Hagen & Evju 2013; Norwegian Defence Estates Agency 2017). In 2002 a pilot study was established to test different vegetation restoration treatments, while the large scale restoration project started in 2009 and will be finished in 2020 (Hagen & Evju 2013; Norwegian Defence Estates Agency 2017).

Restoration method

The roads in the area were built during the 1960s to 1980s, partly by redistribution of on-site local soil, and partly by supply of gravel from a nearby quarry simply added on top of the original vegetation and terrain. The method used to remove the roads was to reshape the original surface, either by redistribution of local soil or by removing the added gravel down to the original surface, leaving almost only mineral soil. In both cases, vegetation turfs from road verges were placed on the mineral soil of the restored roads and then pressed onto the surface to ensure a better contact between soil and turf (Appendix S1). This was mainly done with remote-operated excavators due to the risk of undetonated explosives from the military activity. The turf transplant size and planting density varied between and within roads due to logistic and available turfs. The turfs were between 15 and 40 cm thick, depending on vegetation type of the intact vegetation they were taken from, and mostly had an intact O horizon.

Sampling design

Five study sites were established (Fig. 1). We used all restored roads and thus covered the entire restoration time range (2009–2013), in addition to the roads restored in the pilot-study in 2002. Within each road we chose 20 turfs for each main vegetation type (except for the pilot sites where the roads were short) (Table 1). The turfs selected for vegetation analysis in this study ranged between 0.35 and 5.76 m^2 in size.

Table 1: Overview over the sampling sites and their attributes. Dominant vegetation refers to the surrounding intact vegetation.

Sampling site	Average length of the road sections (m)	Year of restoration	Number of turfs	Dominant vegetation of the surroundings
Haukberget I	~ 140	2013	40	Heath with *Vaccinium myrtillus* and *Empetrum nigrum.*
Haukberget II	~ 130	2010	40	Dry heath with *Juniperus communis* and *Betula nana.*
Tverfjellvegen	~ 160	2009	20	Willow heath and tall herb meadow.
Pilot I	~ 50	2002	5	Heath with *Vaccinium myrtillus* and *Empetrum nigrum*, tall herb meadow and low herb meadow.
Pilot II	~ 40	2002	4	Heath with *Vaccinium myrtillus* and *Empetrum nigrum*, tall herb meadow.
Total	/	/	109	/

On each road, we systematically selected turfs according to the following procedure: Starting at the beginning of the road, 10 m were measured, and a line was drawn across the road (Fig. 2a). From there the closest turf was selected and checked for meeting the following requirements 1) no puddles in the area surrounding the turf, 2) minimum distance of 110 cm between turfs and between turf and intact vegetation (requirement was neglected for some roads, because of narrow roads and a higher turf density), 3) clear definable outline of the single turf. If not all the requirements were met, we continued to the next closest turf. We repeated this to select all turfs, starting to measure 10 meters from the current turf, not from the beginning of the road (Fig. 2a). A total of 109 turfs were selected.

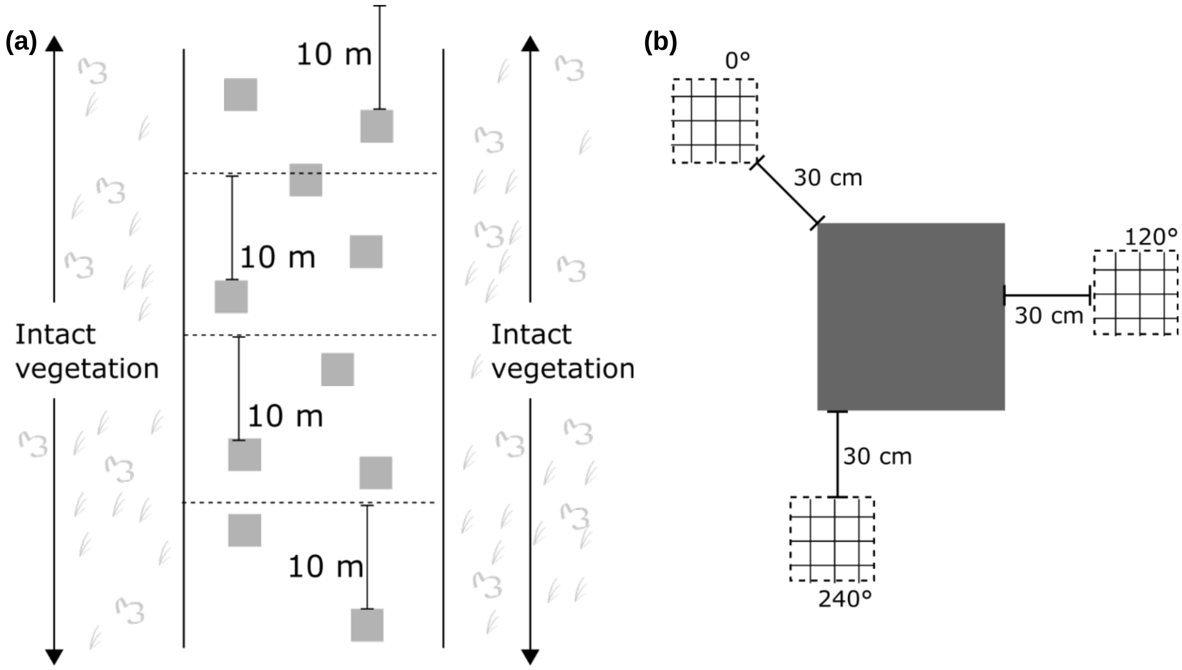

Fig. 2: Sampling design: (a) Road section with turfs (grey squares) and intact vegetation on the road sides. The dotted lines indicate the 10 m measurement lines. (b) Turf-plot group: Centre turf (large square) and the three plots adjacent to the turf (Small squares with 16 subplots, 50 x 50 cm).

Around each turf we placed three plots (50 x 50 cm) by the angular degrees 0°, 120° and 240° from the centre of the turf and 30 cm away from the edge of the turf (Fig. 2b). A total of 327 plots were established, hereafter referred to as “plots adjacent to the turfs” or “turf surroundings”.

Sampling of turfs

We recorded the presence of all vascular plant species, whereas bryophytes and lichens were identified to group. The total vegetation cover of the turfs was estimated in percent. We measured the distance to intact vegetation (roadside) left and right of the turf, as well as turf size (length x breadth in cm). The recording was always done on the whole turf, despite different turf sizes.

Sampling of turf surroundings

To record the vegetation in the turf surroundings we analysed three plots around each turf (Fig. 2b), using a frame (50 x 50 cm) with 16 subplots. Vascular plants were identified to species level, and bryophytes and lichens were identified to group. The total vegetation cover was estimated in percent. For each plot, we measured the distance to the second closest turf and to the closest intact vegetation at the roadside. We recorded the occurrence of organic matter in the soil as presence/ absence and the soil grain size by touch. Soil grain size was categorized into six classes, from coarse to fine (cobbles 1, course pebbles 2, fine and medium pebbles 3, fine and medium sand 4, course sand 5, silt-dominated 6).

Statistical analysis

The statistical analysis was conducted in three parts. Vegetation recovery was measured as 1) total vegetation cover of plots and 2) species richness of plots. In addition, we calculated Bray-Curtis dissimilarity of the communities of turf-plot groups (Fig. 2b) and used these values as a response to investigate the dissimilarity in species composition between turfs and their adjacent three plots. The species richness of turfs and of plots adjacent to the turfs, as well as Bray-Curtis dissimilarity, were calculated using the package "vegan" (Oksanen et al. 2017) in the software R (https://www.r-project.org/).

We used linear mixed effects models (LMM) to analyse the total vegetation cover data and the dissimilarity data, and we used generalized linear mixed effects models (GLMM) with a Poisson error distribution to analyse the species richness data. To select the random component structure for all models, we started with a model that contained all explanatory variables in the fixed component (beyond optimal model), following the method of Zuur et al. (2009). With the beyond optimal model we tested different random component structures (turf nested in road nested in year, turf nested in road and turf alone). The resulting nested models were run with restricted maximum likelihood estimation (REML) (Zuur et al. 2009) and compared by using the corrected Akaike information criterion (AICc) (Appendix S2). The best fitting model for the random structure for total vegetation cover and species richness was turf nested in road, whereas the model fitting the community dissimilarity best was turf nested in road, nested in year (Appendix S2). As we were interested in the effect of year and to better compare the models, we included year in the fixed effects, so that the random structure for the community dissimilarity models was the same as for the other models. Sampling sites Pilot I and II were combined in the analysis, since these were short roads and we were not able to select as many turfs on each road as on the other roads.

To identify the fixed component of the models, we used a forward selection procedure for model selection. Total vegetation cover was analysed as a function of time since restoration (year), and the explanatory value of additional predictor variables (distance to next turf, distance to intact vegetation, organic matter in the soil, soil grain size, cover of turf, turf size) was tested with AICc and validated by inspecting coefficients and p-values. Only predictors significantly improving the model were included in a more complex model, which was compared with the simpler alternative models with AICc (Appendix S3). Species richness was analysed as a function of time since restoration (year), and the explanatory value of additional predictor variables (distance to next turf, distance to intact vegetation, organic matter in the soil, soil grain size, species richness of turf, turf size) was tested with AICc and validated by inspecting coefficients and p-values. Complex models were constructed using the same procedure as for the total vegetation cover analyses (Appendix S3).

Plant community dissimilarity was analysed as a function of time since restoration (year), and the explanatory value of additional predictor variables (distance to next turf, distance to intact vegetation, organic matter in the soil, soil grain size, turf size) was tested with AICc and validated by inspecting coefficients and p-values (Appendix S3). Model validation for linear mixed effect models and generalized linear mixed effect models was performed to check for over-dispersion and confirm that the assumptions for normal distribution of residuals and homoscedasticity were met. The response in the dissimilarity models was log-transformed to account for heteroscedasticity. AICc-selection tables and model estimates are shown with log-transformed values, while descriptive figures show raw data. All analyses were conducted using the R-package "lme4" (Bates et al. 2015) and only the most parsimonious models are shown.

Results

Species richness

In total 116 vascular plant species were found, of these 102 were identified to species, 13 to genus and one to family (Appendix S4).

Thirteen species were solely found in the turf surroundings, among these *Sagina nivalis* and *Epilobium davuricum*, whereas 24 species were solely found in the turfs, including *Vaccinium myrtillus*, *Andromeda polyfolia* and *Calluna vulgaris* (Appendix S4). Furthermore, one red-list species (*Comastoma tenellum*) was recorded in the turfs, and none in the turf surroundings. The most abundant species in the turf surroundings were *Deschampsia cespitosa* (187 plots), *Festuca ovina* (149 plots) and *Luzula multiflora* (108 plots) while the most abundant species in the turfs were *Festuca ovina* (93 turfs), followed by *Betula nana* (90 turfs) and *Salix glauca* (83 turfs). Woody plants, especially ericaceous shrubs, were absent or sparsely occurring in the turf surroundings, while short-lived dicots such as *Cerastium* spp. and *Epilobium* spp., as well as *Equisetum* spp., occurred much more frequently in turf surroundings than in turfs.

Mean species richness in turf surroundings increased with years since restoration, but species richness in turfs was more or less constant over years since restoration (Table 2).

Species richness in turf surroundings was best explained by presence of organic matter in the soil and years since restoration (R^2m = 0.319, R^2c = 0.418, Fig. 3b, Appendix S3). Species richness was higher when there was organic matter in the soil and increased with restoration age (Fig. 5). At restoration ages seven/ fourteen, species richness was twice as high as compared to restoration ages three/ six (Appendix S6). There were no apparent effects of turf characteristics (species richness turfs, total vegetation cover turfs, turf size) or distance to intact vegetation on species richness of the plots adjacent to turfs (Appendix S3). The mean distance from a study turf to the closest turf was 252 cm (standard deviation 99 cm, range 90–640 cm), whereas the mean distance from a study turf to intact vegetation was 414 cm (standard deviation 172 cm, range 90–1330 cm).

The model fitting the plant community dissimilarity data best included years since restoration and turf size as explanatory variables ($R^2 = 0.975$, $\Omega_0{}^2 = 0.975$, Fig. 3c, Appendix S3). There was a tendency for a higher similarity in species composition between turf surroundings and turfs with smaller turf size (Fig. 6a). The species composition was significantly more similar at restoration age six, seven and fourteen (Bray-Curtis dissimilarity ~ 0,1) than at restoration age three (Bray-Curtis dissimilarity ~ 0,3) (Fig. 6b, Appendix S7).

Table 2: Recorded species richness and total vegetation cover of plots and turfs over the different years of restoration, mean with standard deviation. Plots are highlighted in grey.

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

Cover

Mean total vegetation cover of the plots adjacent to turfs increased with years since restoration, and turf vegetation cover was generally higher than 90% (Table 2).

The model fitting the total vegetation cover data best included presence of organic matter in the soil, soil grain size and years since restoration as explanatory variables ($R^2 = 0.744$, $\Omega_0{}^2 = 0.740$, Fig. 3a, Appendix S3). Total vegetation cover on silt-dominated soils and with organic matter present was approximately twice than that on coarser soil types and without organic matter (Fig. 4a, b), and vegetation cover increased with restoration age (Fig. 4c). Vegetation cover in the plots was significantly higher at restoration ages seven/ fourteen compared to restoration ages three/ six (Appendix S5).

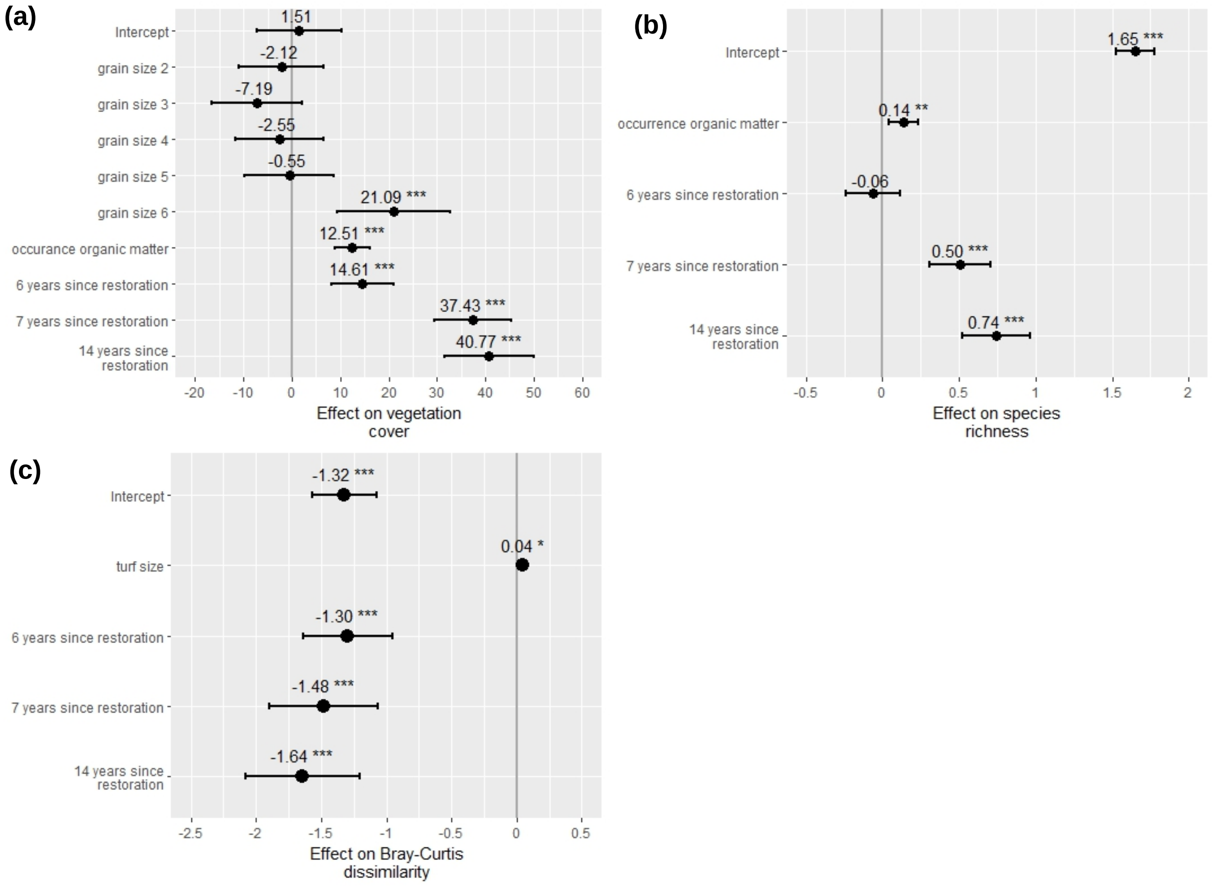

Fig. 3: Beta values of fixed effects of the best fitting model for (a) total vegetation cover, (b) species richness and (c) plant community dissimilarity (log-transformed). Model estimates are printed against model parameters. Note that x-axes have different scales.

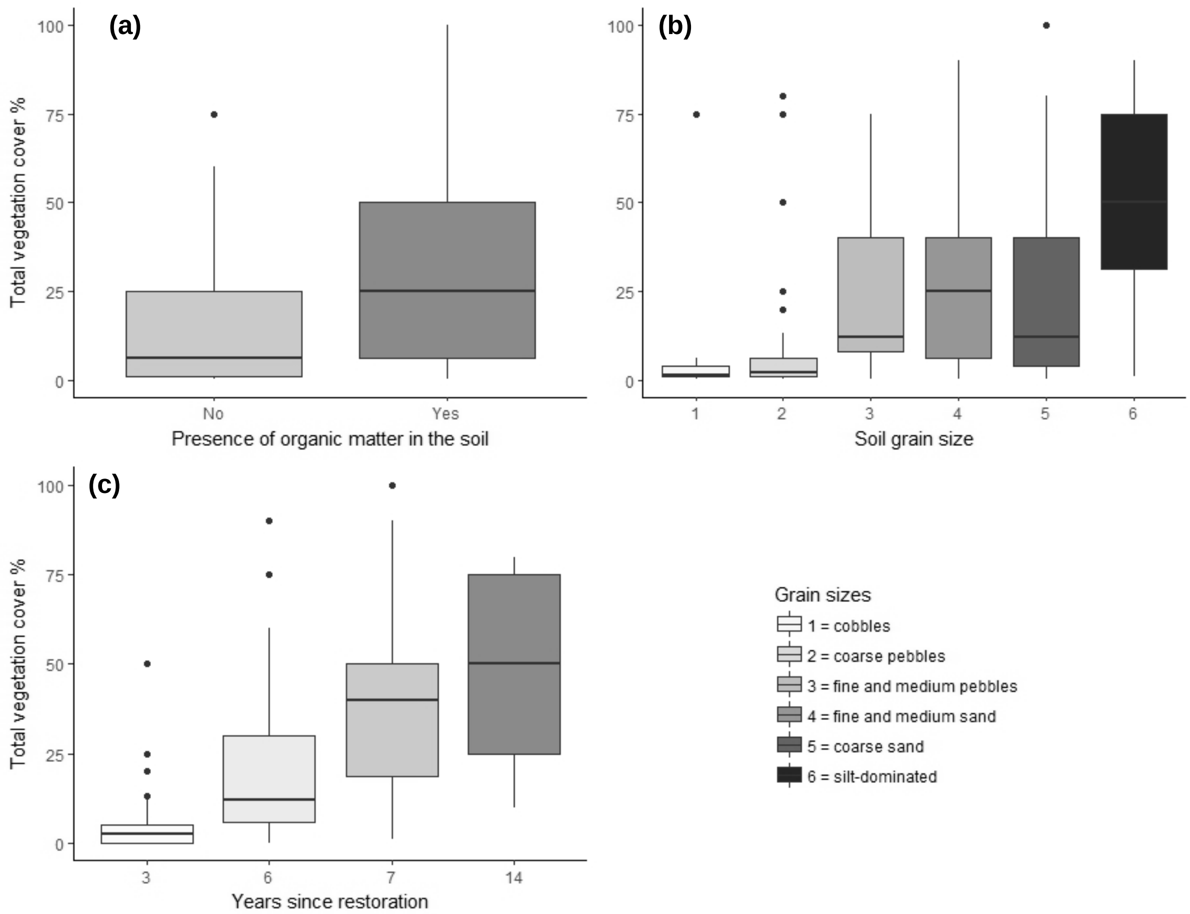

Fig. 4: Total vegetation cover (untransformed, %) as a function of (a) organic matter in the soil, (b) soil grain size, and (c) years since restoration.

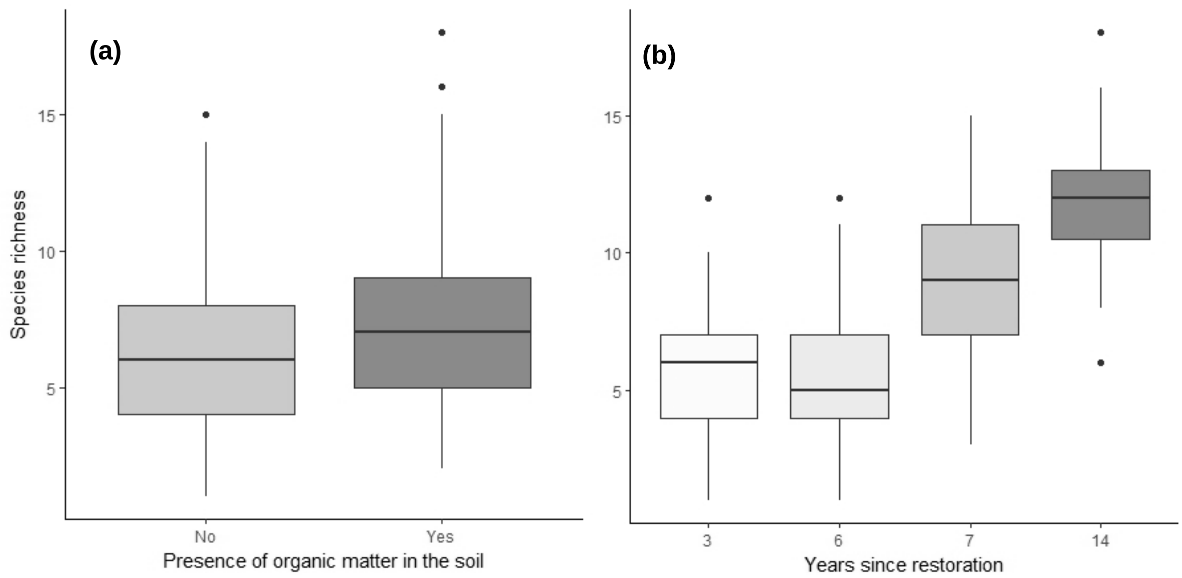

Fig. 5: Species richness of the plots (untransformed) as a function of (a) organic matter in the soil, and (b) years since restoration.

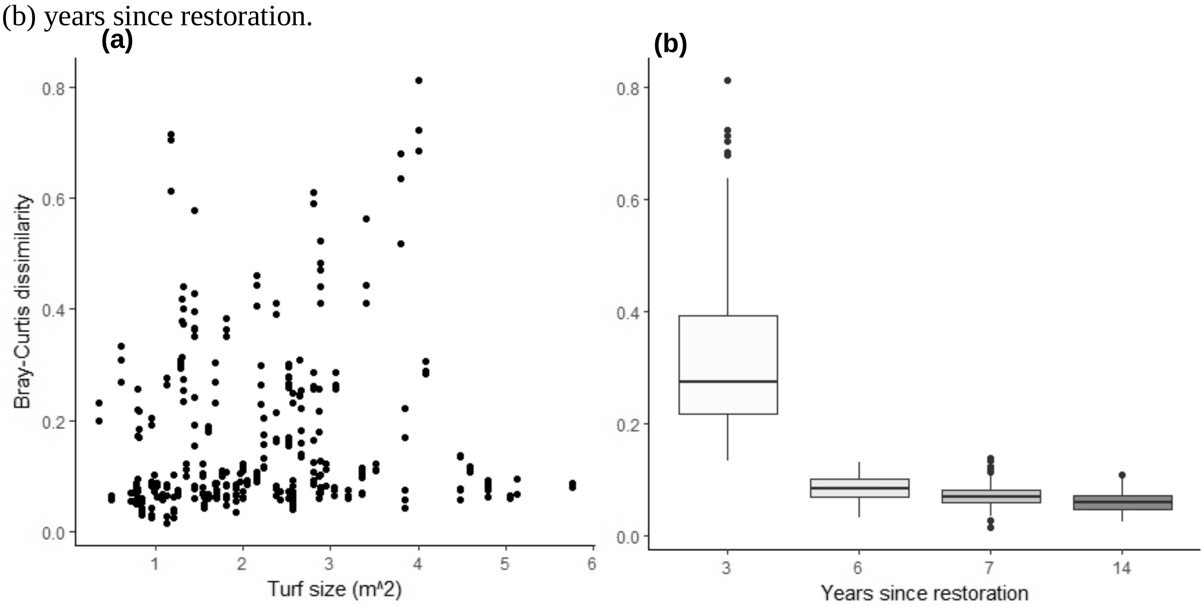

Fig. 6: Plant community dissimilarity (Bray-Curtis dissimilarity, untransformed) as a function of (a) turf size, and (b) years since restoration.

Discussion

Vegetation recovery relates to conditions in turf surroundings, but time is essential

This study demonstrates the importance of preparing restoration sites before transplanting turfs to increase vegetation recovery in the turf surroundings. The recovery at sites adjacent to turfs following turf transplantation (both vegetation cover and species richness) depends largely on soil conditions of the turf surroundings. Particularly important is the presence of organic matter in the soil, and a fine soil grain size (silt-dominated) improves the recovery next to the turfs. Our results show that vegetation cover on silt soil and with organic matter present was about twice that of coarser soil types. Both factors provide ecological advantages for plant establishment. Soil with organic matter contains more nutrients than soil without organic matter, and a fine grain size improves water holding capacity of the soil (Baldock & Skjemstad 1999). Furthermore, fine grain size increases the possibilities for plants to establish small roots. Thus, a successful turf transplantation and also vegetation recovery of the surroundings, requires that the preparation of the restoration site is performed thoroughly, which agrees with studies from Kiehl et al. (2010) and Aradottir (2012). Thorough preparations include removing of all crushed stones, gravel and other materials, that may have been added onto the original surface, all the way down to the original terrain surface. Furthermore, if the surface is very compressed, the soil top layer should be loosened to make it easier for the plants to establish (Hagen & Evju 2013).

However, the most important factor for successful recovery, in terms of increasing species richness and vegetation cover, is time. At restoration age fourteen, the mean species richness of turf surroundings is almost the same as the species richness of the turfs. Our results of the plant community dissimilarity analysis, which shows that plots and turfs are dissimilar at restoration age three, support this. With increasing restoration age, plots and turfs are generally similar in terms of species composition (Fig. 6b). Although we did not perform vegetation analyses in intact vegetation and thus lack information of species richness and composition in a "target" community, turfs were excavated from the intact vegetation in the immediate vicinity of the roads (Appendix S1). Thus, if we consider the turfs as representatives of intact vegetation (and of the donor site vegetation), our results indicate that species richness is restored after 14 years, but that longer time is needed to restore vegetation cover.

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). In our study, dissimilarity between plots and turfs is below 0.1 at six years after restoration, indicating that largely the same species are present in turfs and in turf surroundings. However, about 20% of the species recorded were only found in turfs, including several ericaceous shrubs. In contrast, approximately 10% of the species, mainly short-lived forbs, were only found in turf surroundings. The turf surroundings, particularly in the newly restored sites, are still in a relatively early successional phase, and thus a higher occurrence of ruderal species (cf. Grime 2001) is to be expected. Woody species have inherently low growth rates and low recovery rates (MacGillivray et al. 1995), and the sparse occurrence of these species in turf surroundings even 14 years after turf transplantation emphasizes the need for a long-term perspective on restoration in alpine areas.

The increase of total vegetation cover and species richness over the years since restoration was also observed by Hagen and Evju (2013) in a short-term pilot study in the same area. This development is comprehensible, as in low-alpine ecosystems the environmental conditions are harsher than in lower-altitude ecosystems. Short growing seasons, low temperatures, strong winds and often less resource availability slow down germination and establishment processes, and hence the vegetation needs longer to recover (Urbanska & Chambers 2002; Bay & Ebersole 2006; Krautzer et al. 2012; Hagen & Evju 2013).

In the same pilot study Hagen and Evju (2013) found higher species richness with decreasing distance to turfs. However, in their study, plots were placed randomly on restored roads, with different distances to the turfs. In our study, with all plots placed in the same distance from a centre turf, neither distance to the second closest turf or distance to intact vegetation affected species richness of the plots adjacent to turfs. Hence our study was not designed to evaluate the spatial scale of turf effects on vegetation recovery in turf surroundings and thus to determine an optimal turf density. Furthermore, no restored roads without turf transplants were included in our study, simply because no such roads exist in the study area. The dispersal distance and colonization of plants in alpine ecosystems can vary to a great degree both temporally and spatially, and depending on the species' functional traits. However, most seeds are spread over short distances only (Howe & Smallwood 1982). For example, Stöcklin and Bäumler (1996) found in a study of dispersal distances of six alpine herbs that > 80% of the seeds dispersed shorter than 39 cm from the mother plant, although the maximum dispersal distance varied from < 1 to 50 m. Furthermore, also the clonal mobility is limited for most species (e.g. Tamm et al. 2001; Moora et al. 2009). This supports our hypothesis that the turfs act as main sources for recolonization of turf surroundings. However, the density of turf blocks may be of less importance in narrow linear landscape elements than factors such as turf density and time, at least within the range of densities included in this study. For restoration in large disturbed areas, where the distance to intact vegetation is considerably larger, turfs – and the density of turf blocks – will be of even greater importance, and more detailed studies of optimal turf density for vegetation recovery are needed.

Turf density in restoration projects is, however, a trade-off between recovery rates and availability of turfs. When extracting turfs, it is essential not to destroy nearby plant communities (Kiehl et al. 2010; Aradottir 2012; Aradottir & Oskarsdottir 2013; Hagen & Evju 2013). In cases where work is in progress, e.g. with turfs available from the construction site, this could be feasible (Bay & Ebersole 2006; Kiehl et al. 2010; Aradottir & Oskarsdottir 2013; Mudrák et al. 2017), but it may be challenging in sites where turfs are not easily accessible (Krautzer et al. 2012; Aradottir & Oskarsdottir 2013).

Turf characteristics of less importance for recovery

Turf characteristics, including vegetation cover and species richness did not affect vegetation recovery in the surroundings of the turfs, in contrast to our expectation. The turf size was not a significant predictor of species richness or vegetation cover around the transplants in our study, although our results showed a tendency for plots around smaller turfs to be more similar to turf species composition than plots around larger turfs. Aradottir (2012) states that the turf size is important for survival of transplantation, at least for some functional groups of plants. Compared to Aradottir (2012), who used small turfs (up to 30 cm diameter), the turfs in our study were mostly larger (between 0.35 and 5.76 m^2), and only turfs that already had survived the transplantation were included. We found that turf vegetation cover was always high, and there were no clear differences in turf species richness among different years since restoration, suggesting that turf establishment after transplantation and survival over time was high.

We predicted that recovery of turf surroundings would be positively affected by turf vegetation cover and species richness, based on the assumption of turfs functioning as islands for species dispersal. Thus, the higher the species richness and total vegetation cover of the turfs, the more species would be able to disperse and establish. Our findings do not support this prediction, although the results indicate that the main source for recolonization of plots adjacent to turfs still is the closest turf ("centre turf"), as explained in the previous section.

The turfs might also just have functioned as safe sites where seeds can establish in the immediate vicinity of turfs, independent of the turf species richness and vegetation cover. Such safe sites are highly important for vegetation regeneration from seeds in arctic ecosystems (Cooper et al. 2004), and other transplant studies have demonstrated this effect (Klimeš et al. 2010; Hagen & Evju 2013). To clarify the actual impact of species cover and species richness of the turfs, it would be necessary to investigate the seed dispersal distance of the species in the turf transplants.

Other studies, that have highlighted the importance of the turfs for promoting a quicker vegetation establishment in their surroundings (Bay & Ebersole 2006; Klimeš et al. 2010; Aradottir & Oskarsdottir 2013; Hagen & Evju 2013; Mudrák et al. 2017), were often limited to studying the survival of species in the turf transplants and if species spread from the turfs, but not the underlying factors responsible for the recovery around the turfs. Soil contains not only nutrients and water, but also microorganisms and nematodes that have a great influence on soil decomposition, nutrient cycles and water holding capacity (Baldock & Skjemstad 1999; Conlin & Ebersole 2001; Klimeš et al. 2010) and could, when transferred with the turfs, have a major influence on plant establishment around the turfs. Furthermore, the soil seed bank, transferred with the transplants or from the soil at the receptor site, might also contribute to recovery (Urbanska & Chambers 2002; Klimeš et al. 2010; Krautzer et al. 2012). Further studies are needed to disentangle the importance of the plants in the turfs and seed banks transferred with the turfs.

Conclusion

Our study demonstrates that time, presence of soil organic matter, and fine soils increase recovery rates around turf transplants. Our results further indicate that in narrow linear restoration sites such as roads, the size and density of turfs is not too crucial. Preparations towards a better condition of the restoration site, includes removing of all foreign materials that might have been added onto the original surface all the way down to the original surface, and if necessary, loosening of the soil top layer. This is highly valuable information for the planning and implementation of restoration measures, and for informing the public about expected recovery times.

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References

Aradottir, A.L. 2012. Turf transplants for restoration of alpine vegetation: does size matter? *Journal of Applied Ecology* 49: 439-446.

Aradottir, A.L. & Oskarsdottir, G. 2013. The use of native turf transplants for roadside revegetation in a subarctic area. *Icelandic Agricultural Sciences* 26: 59-67.

Baldock, J. & Skjemstad, J. 1999. Soil organic carbon /Soil organic matter. In: Peverill, K., Sparrow, L. & Reuter, D. (eds.) *Soil analysis: an interpretation manual*. CSIRO publishing.

Bates, D., Maechler, M., Bolker, B. & Walker, S. 2015. Fitting Linear Mixed-Effects Models Using {lme4}. *Journal of Statistical Software* 67: 1-48.

Bay, R.F. & Ebersole, J.J. 2006. Success of turf transplants in restoring alpine trails, Colorado, USA. *Arctic Antarctic and Alpine Research* 38: 173-178.

Bochet, E., Tormo, J. & García-Fayos, P. 2010. Native Species for Roadslope Revegetation: Selection, Validation, and Cost Effectiveness. *Restoration Ecology* 18: 656-663.

Bruelheide, H. & Flintrop, T. 2000. Evaluating the transplantation of a meadow in the Harz Mountains, Germany. *Biological Conservation* 92: 109-120.

Bullock, J.M. 1998. Community translocation in Britain: Setting objectives and measuring consequences. *Biological Conservation* 84: 199-214.

Conlin, D.B. & Ebersole, J.J. 2001. Restoration of an Alpine Disturbance: Differential Success of Species in Turf Transplants, Colorado, U.S.A. *Arctic, Antarctic, and Alpine Research* 33: 340-347.

Cooper, E.J., Alsos, I.G., Hagen, D., Smith, F.M., Coulson, S.J. & Hodkinson, I.D. 2004. Plant recruitment in the High Arctic: Seed bank and seedling emergence on Svalbard. *Journal of Vegetation Science* 15: 115-124.

Falk, D.A., Palmer, M.A. & Zedler, J.B. 2006. *Foundations of Restoration Ecology*. Island Press.

Good, J.E.G., Wallace, H.L., Stevens, P.A. & Radford, G.L. 1999. Translocation of herb-rich grassland from a site in Wales prior to opencast coal extraction. *Restoration Ecology* 7: 336-347.

Grime, J.P. 2001. *Plant Strategies, Vegetation Processes, and Ecosystem Properties*. 2nd Edition ed. John Wiley & Sons, Chichester.

Hagen, D. & Evju, M. 2013. Using Short-Term Monitoring Data to Achieve Goals in a Large-Scale Restoration. *Ecology and Society* 18.

Hagen, D., Hansen, T.-I., Graae, B.J. & Rydgren, K. 2014. To seed or not to seed in alpine restoration: introduced grass species outcompete rather than facilitate native species. *Ecological Engineering* 64: 255-261.

Hobbs, R.J. & Norton, D.A. 1996. Towards a conceptual framework for restoration ecology. *Restoration Ecology* 4: 93-110.

Howe, H.F. & Smallwood, J. 1982. Ecology of Seed Dispersal. *Annual Review of Ecology and Systematics* 13: 201-228.

Kiehl, K., Kirmer, A., Donath, T.W., Rasran, L. & Hoelzel, N. 2010. Species introduction in restoration projects - Evaluation of different techniques for the establishment of semi-natural grasslands in Central and Northwestern Europe. *Basic and Applied Ecology* 11: 285-299.

Klimeš, L., Jongepierová, I., Doležal, J. & Klimešová, J. 2010. Restoration of a species-rich meadow on arable land by transferring meadow blocks. *Applied Vegetation Science* 13: 403-411.

Krautzer, B., Uhlig, C. & Wittmann, H. 2012. Restoration of Arctic–Alpine Ecosystems. In: *Restoration Ecology*, pp. 189-202. John Wiley & Sons, Ltd.

MacGillivray, C., Grime, J. & The Integrated Screening Programme Team 1995. Testing predictions of the resistance and resilience of vegetation subjected to extreme events. *Functional Ecology*: 640-649.

Ministry of Defence 1998. Regionalt skyte- og øvingsfelt for Forsvarets avdelinger på Østlandet - Regionfelt Østlandet. St. meld. nr. 11 (1998-99). In: White paper (ed.). Ministry of Defence, Oslo, Norway.

Moora, M., Öpik, M., Zobel, K. & Zobel, M. 2009. Understory plant diversity is related to higher variability of vegetative mobility of coexisting species. *Oecologia* 159: 355-361.

Mossberg, B. & Stenberg, L. 2014. *Gyldendals store nordiske Flora*. Gyldendal Norsk Forlag AS, Oslo.

Mudrák, O., Fajmon, K., Jongepierová, I. & Doležal, J. 2017. Restoring species-rich meadow by means of turf transplantation: long-term colonization of ex-arable land. *Applied Vegetation Science* 20: 62-73.

Norwegian Defence Estates Agency 2017. Hjerkinn PRO publications. In. Forsvarsbygg, https://www.forsvarsbygg.no/no/miljo/rive-og-ryddeprosjekt/hjerkinn/hjerkinn-pro/.

Norwegian Environment Agency 2013. Dovrefjell-Sunndalsfjella National Park. In: Norwegian Environment Agency (ed.). Norwegian Environment Agency, http://www.miljodirektoratet.no/no/Publikasjoner/2013/Desember-2013/Dovrefjell-Sunndalsfjella-national-park/.

Norwegian Geological Institute 2017. Geological Survey of Norway - Bedrock and debris maps. In. Norwegian Geological Institute, http://geo.ngu.no/kart/berggrunn, http://geo.ngu.no/kart/losmasse.

Norwegian Institute of Bioeconomy Research (NIBIO) 2017. Type of vegetation Norway. In. Kartverket, Geovekst og kommunene, NIBIO, https://kilden.nibio.no.

Norwegian Meteorological Institute 2017. Klimanormaler for Norge 1961-1999. In. Norwegian Meteorological Institute, www.met.no.

Norwegian Meteorological Institute & Norwegian Broadcasting Corporation 2017. Climate statistics for Fokstugu obervation site, Dovre (Oppland). In. Norwegian Meteorological Institute, Norwegian Broadcasting Corporation, www.yr.no.

Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P., Henry, M., Stevens, H., Szoecs, E. & Wagner, H. 2017. vegan: Community Ecology Package. R package version 2.4-2. In, https://CRAN.R-project.org/package=vegan.

Perring, M.P., Standish, R.J., Price, J.N., Craig, M.D., Erickson, T.E., Ruthrof, K.X., Whiteley, A.S., Valentine, L.E. & Hobbs, R.J. 2015. Advances in restoration ecology: rising to the challenges of the coming decades. *Ecosphere* 6: 1-25.

Society for Ecological Restoration Science & Policy Working Group 2002. The SER Primer on Ecological Restoration. *www.ser.org/*.

Stöcklin, J. & Bäumler, E. 1996. Seed Rain, Seedling Establishment and Clonal Growth Strategies on a Glacier Foreland. *Journal of Vegetation Science* 7: 45-56.

Suding, K.N. 2011. Toward an era of restoration in ecology: successes, failures, and opportunities ahead. *Annual Review of Ecology, Evolution, and Systematics* 42.

Tamm, A., Kull, K. & Sammul, M. 2001. Classifying clonal growth forms based on vegetative mobility and ramet longevity: a whole community analysis. *Evolutionary Ecology* 15: 383-401.

Urbanska, K.M. & Chambers, J.C. 2002. High-elevation ecosystems. In: *Handbook of Ecological Restoration - Volume 2 - Restoration in Practice*, pp. 376-400. Cambridge University Press.

Young, T.P., Petersen, D.A. & Clary, J.J. 2005. The ecology of restoration: historical links, emerging issues and unexplored realms. *Ecology Letters* 8: 662-673.

Zuur, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A. & Smith, G.M. 2009. Mixed effects modelling for nested data. In: *Mixed effects models and extensions in ecology with R*, pp. 101-142. Springer New York.

List of Appendices

Appendix S1. Pictures of the restoration measure.

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Appendix S5. Effect plots for total vegetation cover.

Appendix S6. Effect plots for species richness.

Appendix S7. Effect plots for Bray-Curtis dissimilarity.