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# Long-term Effects of Seeding in an Alpine Environment

and a comparison of the effect of native Festuca ovina and non-native Festuca rubra on the establishment of native Betula nana

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Submission date: September 2011
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# Abstract

As human induced disturbance in alpine ecosystems have increased, more knowledge is needed about the long-term effects of restoration efforts in such environments. There are benefits with using native species in restoration in alpine ecosystems, but the establishment success of native species compared to non-native species, and their effect on the establishment of native species has not been evaluated in detail. We examined ten disturbed alpine sites 21 years after seeding with a commercial seed mix, with regard to vegetation cover, species richness and soil conditions, and compared them with reference sites in close vicinity. After 21 years seeded sites had more vegetation cover, but native vegetation cover and species richness was larger in reference sites. Soil material did have a significant effect on vegetation cover, with less vegetation establishing as dominating soil particle size increased. However, native vegetation cover remained the same with increasing soil material. The effects of a native species, *Festuca ovina*, was compared with the effects of the main ingredient from the commercial seed mix used in 1989, *Festuca rubra,* on the establishment of the native *Betula nana*. *Festuca rubra* established slightly better than *F. ovina* on all soil types in the greenhouse experiment, but had larger plant size. *B. nana* experienced competition from both *Festuca* species, but less from *F. ovina*. The species *F. ovina* facilitated for *B. nana* on coarse soil. Even though these findings indicate that the native *F. ovina* is the best alternative with regard to establishment of a native species in the greenhouse, these patterns may not always be expected in nature due to other environmental factors, like wind. However the findings in this study indicate that using native species is the best alternative in alpine ecosystem restoration.

# Introduction

Disturbance in alpine ecosystems can occur naturally, through procesess such as glacial retreat, wind, erosion and landslides, or be induced by human activity such as tourism (Crawley 1997). Human induced disturbances has increased in alpine ecosystems, which traditionally has been perceived as pristine wilderness (Conservation of Arctic Flora and Fauna 2001). The rate of recovery or succession following disturbance depends largely on its severity and the prevailing environment (Crawley 1997). Natural recovery after disturbance in alpine areas is a very slow process, and with some vegetation types there will be practically no establishment of new vegetation cover if the original cover is removed (Harper and Kershaw 1996). Following disturbance, plants establish from lateral clonal growth in adjacent vegetation, from vegetative fragments rooting (Urbanska and Chambers 2002), or from seeds that either exist on the site or that disperse onto the site. The recruitment may be limited by the number of seeds or by the availability of suitable microsites for establishment, or potentially by both (Fenner and Thompson 2005).

Alpine ecosystems are exposed to abiotic factors which places constraints on the plants. The growing season is shorter than in lowlands, because of a colder climate and snow cover obstructing light to the ground. In addition to the short growing seasons, unpredictable weather conditions may have a huge impact on plant growth. Even though precipitation generally increases with elevation water availability is often limited. Geographical differences with regard to precipitation and the fact that water can be present physically, but not physiologically, partly caused by low soil temperature (Urbanska and Chambers 2002). Soil development at higher altitudes is affected by the low temperatures, and soil depths down to fractured rock or bedrock vary from a few centimeters to one meter. Also soil nutrients such as nitrogen ($NH_4$ and $NO_3$) and phosphorus ($PO_4$) available to plants are generally limiting growth (Urbanska and Chambers 2002). Nutrient levels and the rate of decomposition vary during the growing season, and are influenced by soil moisture, temperature, microbial activity and physiological responses of plants (Olear and Seastedt 1994). Alpine ecosystems are also windy, which increase the chilling factor, reinforce air dryness and may damage the plants mechanically (Urbanska and Chambers 2002). Even though the abiotic factors are most evident, biotic factors also play a role in alpine ecosystems. Competition is defined as interaction between plants which reduces fitness for either one or both of them (Crawley 1997). Belowground competition between plants for water and nutrients has been found in most ecosystems (Wilson 1988, Casper and Jackson 1997, Coomes and Grubb 2000). The main causes of mortality for seedlings in natural seedling populations are drought, herbivory and pathogen attack. Competition from other seedlings account for a relatively small proportion of seedling deaths (Moles and Westoby 2004). But not all interactions are limiting for plants. Facilitation is defined as when at least one neighboring species benefits from interactions between nearby species, either through increased survival, growth or fitness (Padilla and Pugnaire 2006). Accumulation of nutrients, provision of shade, amelioration of disturbance and providing protection from herbivores are some of the benefits that a species can provide for neighboring species (Callaway et al. 2002). Positive interactions are particularly likely in arctic/alpine habitats, since they contain a variety of stresses and disturbances, and the abiotic environment is the primary limitation on plant growth (Brooker and Callaghan 1998).

It can be useful to use active revegetation methods to obtain new vegetation cover (Hagen 2003). The use of seeds, either from native or non-native species, fertilization and different types of treatments of the soil can increase the development of a vegetation cover in alpine areas (Hagen 2003). But the long-term effects of these efforts are disputed (Densmore 1992, Helm 1995, Forbes and Jefferies 1999). Revegetation by seeding, and especially grasses, is considered in cases where a faster and more predictable establishment of vegetation cover is desired, and especially in cases where the seed bank is considered to be small and natural seed dispersal slow. Introduced grass species have through decades been the traditional way to establish a new plant cover following disturbance in alpine areas (Younkin and Martens 1987, Jorgenson and Joyce 1994). There is limited documentation of the long-term effects of revegetation efforts, and especially in alpine areas. In a study in alpine/arctic and boreal zone on Iceland on long-term effects (20-45 years) of seeding, areas seeded with grass had significantly higher total plant cover than untreated control plots and the seeded species had declined or disappeared (Gretarsdottir et al. 2004). Introduced seeded grass has been shown to inhibit or delay establishment and growth of native plants on tundra in Alaska, USA (Densmore 1992), and to obtain lower plant densities than seeded native species in alpine roadsides (Petersen et al. 2004). Seeded alpine spoil heaps in western Norway has been estimated to establish a more or less similar species composition to the surrounding environment after 35-48 years (Rydgren et al. 2011). The use of native species is preferable because these are adapted to the local climatic, geological and ecological conditions. Using native species in revegetation efforts is also preferable because it does not add new genotypes to the locality, genotypes which may not be adapted to the local conditions or which may outcompete (or replace or cross-breed with) the native genotypes (Parker and Reichard 1998).  Native species also improves visual continuity with the surrounding local vegetation, interacts better with natural communities and often result in lower maintenance costs or no aftercare (Urbanska and Chambers 2002). There is not much knowledge about the use of native species and their performance in revegetation, but seeded native species have been found to have higher plant densities and cover than seeded commercial species in different ecosystems (Cotts et al. 1991, Paschke et al. 2000, Petersen et al. 2004, Tinsley et al. 2006).

Fertilization has been, and still is, a common method to increase plant establishment and cover (Petersen et al. 2004). Its primary benefit in alpine environments may be to accelerate plant establishment on soils with low nutrient levels (Urbanska and Chambers 2002). An increase of nitrogen and phosphorus in soil has been showed to increase cover and production of seeded grasses compared to unfertilized soils (Redente et al. 1984, McLendon and Redente 1991). But the use of fertilizers is widely debated, and some proclaim that the benefits from fertilizing are outweighed by the effect it has on plant populations and communities (Petersen et al. 2004). Fertilizers may favor the competitive seeded, non-native species and inhibit the establishment of native, desirable species (Inouye et al. 1987), and decrease species diversity (Redente et al. 1984, Carpenter et al. 1990).

Hjerkinn firing range in the Norwegian Dovre Mountains was established as a military firing range in 1923, and has been used for military purposes until 2006 (Norwegian Defence Estate Agency 2010). In 1999 the Norwegian Parliament decided to terminate the military activity, remove all military installations, and made the ambitious decision that the area is to be restored back to an "original state". This implies that the area should be facilitated for long-term ecological processes. As part of the restoration plan it has been decided that only native species from the area should be used in the revegetation efforts (Martinsen and Hagen 2010). Native *Festuca ovina* seeds have been produced by traditional seed multiplication and will be used in the upcoming restoration efforts (Martinsen and Oskarsen 2010)

The objective of this study is to evaluate the long-term effects of seed sowing on the establishment of the natural vegetation. In this study we will look at revegetation efforts with commercial seed mix done in Hjerkinn firing range in 1989. More specifically we want to test: (1) whether seeding has facilitated for a vegetation cover, (2) whether soil material has an impact on restoration of a vegetation cover and (3) whether native species are better to use in restoration efforts compared to non-native species. Using sites from these revegetation efforts and a comparative greenhouse study of non-native *Festuca rubra* and native *F.* ovina effects on the establishment of native *Betula nana* may help to improve the current knowledge about native versus non-native species and develop improved methods for restoration of alpine vegetation.

# Methods

## Study site

The sites in this study all lie within the borders of the military Hjerkinn firing range (63°N, 10°E), situated in the Dovre Mountains in Oppland County, Norway. The firing range is 165 $km^2$ and situated 1000-1400 m a.s.l. (Hagen 2003), in the low alpine vegetation zone, with a growing season of about 115 days (Moen et al. 1999). The mean air temperature at Fokstugu meteorological station (972 m a.s.l.) close to Hjerkinn firing range for the period 1961-1990 was -8,8 °C in January and 9,8 °C in July, with a mean annual air temperature of 0,1 °C and a mean annual precipitation of 435 mm (The Norwegian Institute for Soil and Forest Mapping 1999, Norwegian Meterological Institute 2011). Coarse, calcium-poor glacial sediments dominate the area. Vegetation is dominated by lichen and dwarf shrub heaths, *Salix* spp., meadows, and scattered bogs and fens (The Norwegian Institute for Soil and Forest Mapping 1999). All sites in this study are roadsides at 1060-1240 m a.s.l., with undisturbed natural vegetation in close vicinity (0-100 m).

## Field study

The roadsides in this study were in 1989 seeded with a commercial seed mix (7 kg/1000 $m^2$) consisting of *Agrostis* “Leikvin”, *Festuca rubra* “Leik”, *Festuca rubra* “Encylva” and *Festuca rubra* “Koket”, and fertilized with a commercial granulate fertilizer (50 kg/1000 $m^2$). The sites may have been grazed by sheep, musk ox and reindeer after seeding.

The field study was carried out during July and August of 2010. In total 10 areas in the firing range were selected, each area having a treated and a reference site. Within each site five 0.5 x 0.5 m plots were placed along a line, 1 m apart. Bryophytes and lichens were determined to at least family and vascular plant species were determined, and their cover (%) visually estimated in each plot (16 subplot within each plot). The soil was visually classified by its dominating particle size following Halvorsen et al. (2008). The moisture of the soil was visually classified on a scale from 1-5 (1= very dry,.., 5 = very wet). Site slope was measured using a bubble lever and a plank. Five soil samples were taken from the upper 5 cm of the soil at each site in a dry period on the same day (8. August 2010), and kept in a freezer at -20° C until analysis. Moisture determination was performed by drying the soil samples (115 °C) for 24 hours and reweighing them. Loss-on-ignition were performed by sieving the dried soil samples, taking a representative sample of the sieved material into crucibles, and placing them in an oven (550 °C) for 8 hours and reweighing the soil samples. pH analysis were performed by taking a representative portion of the soil sample, adding the same amount of distilled water and measuring the pH with a PHM82 Standard pH meter (Radiometer Copenhagen).

### Greenhouse experiment

Coarse and fine soil (categories 3 and 6 respectively according to Halvorsen et al. (2008) was collected from the field sites and brought to the greenhouse. The soils were autoclaved at 120°C with a Tomy Autoclave SS-325. *Betula nana* seeds were collected at Hjerkinn, Dovre, on the 24.09.2010 and placed in moist filter paper in a refrigerator (+ 2° C) for 4 weeks prior to this, to simulate winter and snow cover. In order to test the performance of the two grass species on the different soil types 30 pots were prepared, 10 with each soil type, and 100 seeds of either *F. rubra* or *F. ovina* was added to each of the pots. After 24 days weeding was done in all of the pots so that each of the grass seeded pots contained 20 grass seedlings evenly distributed over the surface of the pot. To test the effect of *F. rubra* and *F. ovina* on the recruitment of *Betula nana,* 25 *B. nana* seeds were sown after weeding (5 pots with each of the two *Festuca* species with each soil type). Fifteen control pots of *B. nana* seed without grasses were sown. The pots used had a diameter of 8 cm, depth of 8 cm and a volume of 1609 $cm^3$. Light:darkness cycle of 18:6 were applied with 2 x 400 W lightbulbs and a Synopta computer system (van Vliet). Room temperature ranged from 2.8 – 26.6 °C, with a mean temperature of 11.5 °C. The pots were watered every 3-4 day. The experiment started on the 28. October 2010, and the number of seedlings in each pot were recorded every second day during the first 30 days of the experiment. For the remainder of the experiment the seedlings were counted every third day. The greenhouse experiment was terminated on the 26. February 2011, lasting for a total of 122 days. The plants were harvested for the above soil parts and the plant material per pot was dried in oven for 24 hours (115 °C) and weighed to find the above ground dry weight of the biomass.

### Statistical analysis

R version 2.10.1 (The R Foundation for Statistical Computing, Vienna, Austria) was used for statistical analyses. SigmaPlot 12 (Systat Software, San Jose, CA, USA) was used to make figures.

The variables were examined statistically using paired t-test looking for differences between seeded and reference sites. In order to do this, measured data from each of the 10 areas had to be averaged.

A Principal Component Analysis (PCA) was conducted to examine the effects of environmental and soil factors. The goal of the PCA was to extract maximum variance from environmental and soil variables, and summarize this variance into components (Tabachnick and Fidell 2007). An analysis of covariance (ANCOVA) was then run for each of the two first principal components (PC1 and PC2) together with seeding, to look for potential effects of seeding, the principal components and interactions between seeding and the principal components on vegetation cover, both total and native vegetation cover. To fulfill the assumptions of normality, the variable total vegetation cover had to be arcsine square root transformed.

The effects of soil material on vegetation cover was investigated by running an ANCOVA for both total vegetation cover and native vegetation cover together with seeding and soil material.

To fulfill the assumptions of normality, the variable total vegetation cover had to be arcsine square root transformed. Correlations were calculated using the rcorr function in the hmisc package for R.

The effects of soil material and species on seedling establishment and dry weight biomass for *Festuca rubra* and *F. ovina* were tested using two-way ANOVA. Post hoc Tukey HSD (Honestly Significant Difference) test were performed to determine significant differences in group means.

None of the variables regarding seedling establishment for *Betula nana* fulfilled the assumptions of normality, therefore a generalized linear model (GLM) was arranged to examine the effects of soil material and seeded species on the seedling establishment of *Betula nana.*

# Results

### Field study

The seeded sites were dominated by graminoids and mainly the seeded *Festuca rubra*. The reference sites were not dominated by any specific functional group (Figure 1, Table 1). In total 76 species where found and nearly all of the species were found in both reference and seeded sites. The species that were found only in either seeded or reference sites, were recorded only once or twice (Appendix 1).

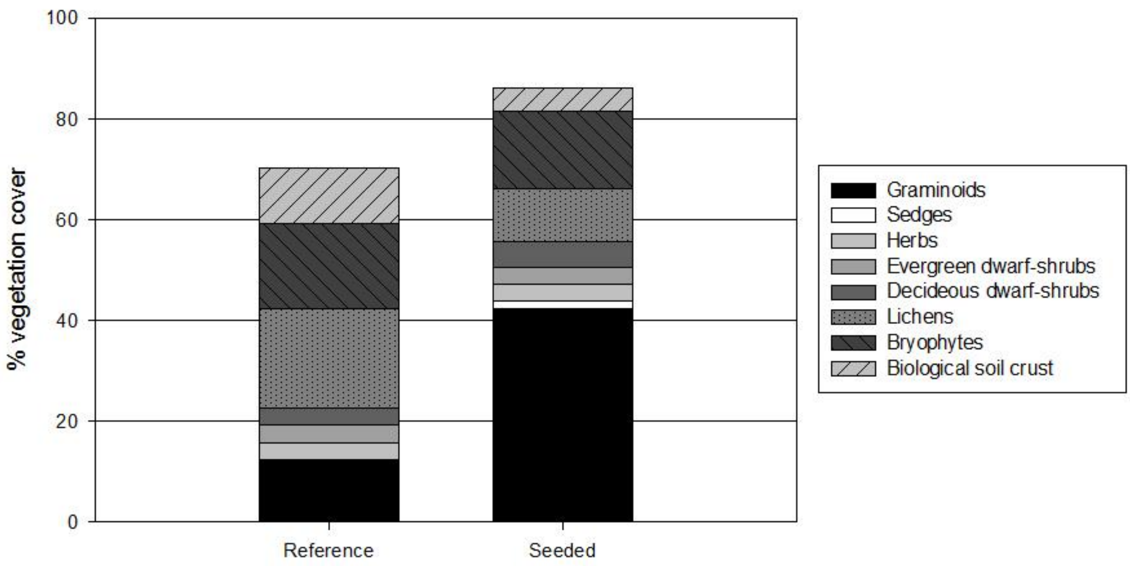


**Figure 1**. Average vegetation cover and average cover of the different functional groups in reference and seeded sites (n=50 in both).

The reference sites had a significantly lower average vegetation cover (71 %) than the seeded site (86%) (Table 1). All functional groups were present in the two treatments, except from sedges being absent in the reference sites (Figure 1, Table 1). In all of the seeded sites *Festuca rubra* had more than 10 % cover. After removing the seeded species from the analysis of total vegetation cover and only considering the native species in the area, reference sites had significantly higher native vegetation cover than the seeded sites (Table 1, Figure 2). The seeded *Festuca rubra* was found in both seeded and reference sites (Table 1, Figure 2).

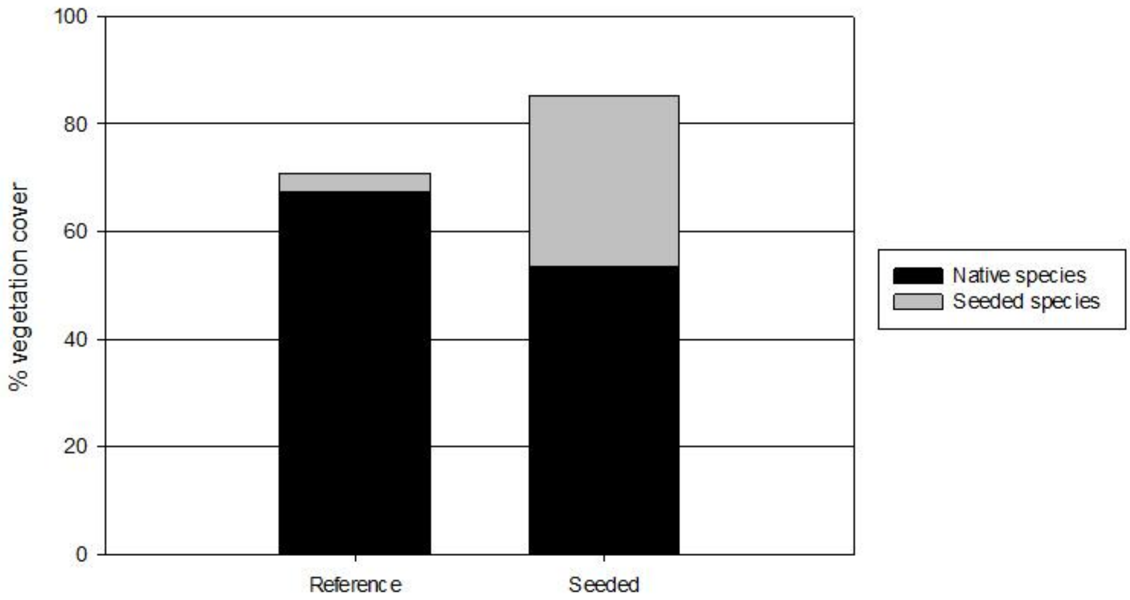


**Figure 2**. Average vegetation cover of native and seeded species in reference and seeded sites (n=50 in both).

The seeded sites had a significantly higher cover of graminoids, while lichens and biological soil crust had a significantly higher cover in the reference sites. Species richness was significantly higher in reference sites (19 species/plot) compared with seeded sites (16 species/plot) (Table 1).

The seeded sites appeared moister when observed in the field, but measured water content was only marginally different between seeded and reference sites. Soil structure and pH did not differ significantly between seeded and reference sites. Organic content was significantly higher in soil samples collected from seeded sites than from reference sites (Table 1).

**Table 1.** Analysis of variance for the effects of seeding on the mean of several vegetation and environmental factors. Statistical significant difference $p < 0.05$.Since elevation was exactly the same in seeded and reference sites, it was not possible to calculate t and p value. Therefore they have the values NaN and NA respectively.

| | Mean % cover (± SD.) | | | |
|---|---|---|---|---|
| **Vegetation factors** | **Reference** | **Seeded** | **t** | **Pr(>F)** |
| **Vegetation cover** | 70.82 (± 16.04) | 86,06 (± 12.56) | **3.734** | **0.004** |
| **Native vegetation cover** | 67,42 (± 14.18) | 53,62 (± 14.20) | **-3.740** | **0.005** |
| **Graminoids** | 12.46 (± 8.77) | 42.44 (± 16.76) | **8.436** | **<0.001** |
| **Native graminoids** | 9.06 (± 6.36) | 10.70 (± 11.30) | 0.703 | 0.500 |
| **Sedges** | None | 1.48 (± 8.57) | 1.015 | 0.337 |
| **Herbs** | 3.10 (± 3.89) | 3.30 (±4.99) | 0.434 | 0.675 |
| **Evergreen dwarf-shrubs** | 3.82 (± 6.06) | 3.30 (± 4.59) | -0.314 | 0.761 |
| **Deciduous dwarf-shrubs** | 3.20 (± 3.46) | 5.08 (± 6.46) | 1.569 | 0.151 |
| **Lichens** | 19.64 (± 11.25) | 10.40 (± 7.71) | **-3.622** | **0.006** |
| **Bryophytes** | 17.12 (± 9.64) | 15.40 (± 9.66) | -0.542 | 0.601 |
| **Biological soil crust** | 11.00 (± 8.73) | 4.68 (± 6.74) | **-2.747** | **0.036** |
| **Species richness (mean)** | 18.80 (± 4.41) | 16.28 (± 4.43) | **-2.368** | **0.042** |
| **Environmental factors** | | | | |
| **Elevation (m a.s.l.)** | 1132 (± 54.17) | 1132 (± 54.17) | NaN | NA |
| **Slope (°)** | 11.34 (± 6.40) | 11.68 (± 7.15) | 0.625 | 0.548 |
| **Soil structure** | 4.6 (± 1.03) | 4.50 (± 1.10) | -0.429 | 0.678 |
| **Soil factors** | | | | |
| **Water content (%)** | 8.16 (± 3.68) | 9.96 (± 2.98) | 1.884 | 0.092 |
| **Organic content (%)** | 4.68 (± 3.07) | 8.06 (± 5.62) | **3.010** | **0.015** |
| **pH** | 5.93 (± 0.48) | 5.95 (± 0.74) | 0 | 1.000 |
| **Moisture (1-5)** | 1.54 (± 0.54) | 2.38 (± 0.67) | **5.547** | **<0.001** |

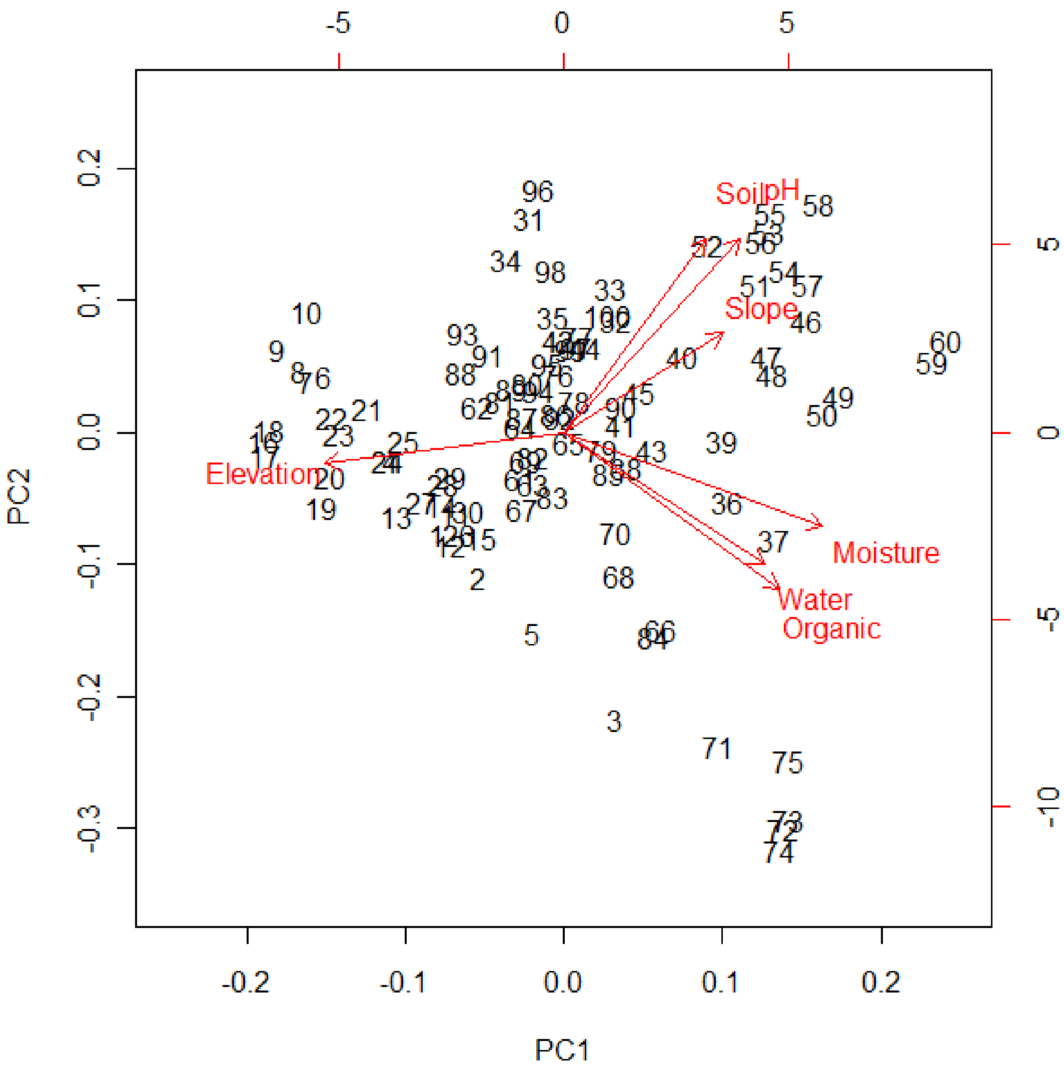


**Figure 3**. Principal component analysis (PCA) of environmental and soil factors. Numbers indicate plot numbers from the field study. Explanation of some variable names; Soil = soil class following Halvorsen et al. (2008), Moisture = visually observed moisture, Water = water content in soil samples, and Organic = organic content in soil samples.

The first principal component (PC1) accounts for 31.7 % of the total variance of the environmental and soil factors. The first principal component indicates a negative relationship between elevation and the rest of the environmental and soil factors, and especially observed moisture and organic content in soil samples (Table 2).

The second component (PC2) accounts for 21.7 % of the variance. This component's main features are the negative relationship between organic content in soil samples and the factors soil material and pH (Table 2). Combined, the two components account for 53.4 % of the total variance for the environmental and soil factors among the 100 measurements (Table 2).

**Table 2**. Principal components for the variance of environmental and soil factors, and their respective proportion of variance for all sites. Values in bold are considered to be practically significant (>0.40) (Manly 1994).

| | **PC1** | **PC2** | **PC3** | **PC4** | **PC5** | **PC6** | **PC7** |
|---|---|---|---|---|---|---|---|
| **Elevation** | **-0.45** | -0.08 | 0.31 | -0.25 | **0.68** | **-0.40** | 0.06 |
| **Slope** | 0.30 | 0.27 | **0.73** | 0.25 | -0.24 | -0.34 | 0.29 |
| **Soil class** | 0.27 | **0.52** | 0.13 | **-0.57** | 0.24 | **0.48** | 0.17 |
| **Moisture** | **0.48** | -0.25 | **-0.40** | -0.20 | 0.12 | -0.38 | **0.58** |
| **Water content soil samples** | 0.37 | -0.36 | 0.19 | **0.47** | **0.54** | **0.43** | 0.00 |
| **Organic content soil samples** | **0.40** | **-0.43** | 0.27 | **-0.48** | -0.12 | -0.14 | **-0.56** |
| **pH** | 0.33 | **0.52** | -0.29 | 0.24 | 0.32 | -0.38 | **-0.48** |
| **Proportion of Variance** | 0.317 | 0.217 | 0.142 | 0.106 | 0.096 | 0.077 | 0.045 |
| **Cumulative Proportion** | 0.317 | 0.534 | 0.677 | 0.783 | 0.879 | 0.955 | 1.000 |

The ANCOVA performed for seeding and the first principal component (PC1) and their effect on vegetation cover, showed that seeding had a significant effect on the percentage vegetation cover (t = 2.199,P = 0.0429). Neither the first principal component (t = -0.597, P = 0.5589) nor the interaction between seeding and the first principal component was significant (t = 1.031, P = 0.3179). There was no significant interaction between seeding and the second principal component (PC2) (t = 0.659, P = 0.5191). There was a significant effect of seeding (t = 2.455, P = 0.0259), but not of the second principal component (t = -0.789, p = 0.4414).

The results were the same for native vegetation cover. Seeding had an effect (PC1: t = -3.305, P = 0.005. PC2: t = -2.469, P = 0.0252). Neither the first principal component (PC1) (t = -0.002, P = 0.999), the second principal component (PC2) (t = 0.738, P = 0.471) nor the interaction between seeding and the principal components (PC1: t = 0.579, P = 0.570. PC2: t = -0.897, P = 0.383) showed to have any significant effect.

In the ANCOVA investigating the effect of seeding and soil material on vegetation cover, seeding (F = 31.68, P < 0.001), soil material (F = 8.21, P = 0.005) and interaction between seeding and soil class (F = 6.80, P = 0.011) had a significant effect on vegetation cover.

In the ANCOVA looking into possible effects of seeding and soil material on native vegetation cover, there were significant effects of seeding (F = 24.43, P < 0.001) and interaction between seeding and soil material (F = 4.72, P = 0.032). There was no significant effect of soil material on native vegetation cover (F = 0.54, P = 0.463).

### Greenhouse experiment

#### Seedling establishment Festuca rubra and F. ovina

*Festuca rubra* and *F. ovina* sown on commercial soil had the highest germination success with 71.6 (± 5.72) % and 60.2 (± 9.31) % seedling establishment respectively. *Festuca ovina* sown on coarse and fine soil had the lowest germination success, with 50.4 (± 6.22) % and 50.4 (± 8.41) % respectively (Table 3).

**Table 3.** Seedling establishment (% of sown) and dry weight biomass (g; total dry weight biomass of 20 individuals in the pots on the final day of the experiment) for *Festuca rubra* and *F. ovina* on the different soil material.

| Species | Soil material | Seedling establishment (%) (± SD) | Dry weight biomass (g) (± SD) |
|---|---|---|---|
| ***Festuca rubra*** | Coarse | 55.2 (± 7.33) | 1.47 (± 0.44) |
| | Fine | 53.4 (± 13.76) | 2.50 (± 0.25) |
| | Commercial | 71.6 (± 5.73) | 3.09 (± 0.68) |
| ***Festuca ovina*** | Coarse | 50.4 (± 6.23) | 1.14 (± 0.52) |
| | Fine | 50.4 (± 8.41) | 1.94 (± 0.75) |
| | Commercial | 60.2 (± 9.31) | 1.80 (± 0.42) |

*Festuca rubra* grown on commercial soil had the highest average dry weight biomass on the final day of the experiment with 3.09 (± 0.680) g. *Festuca ovina* grown on coarse soil had the lowest dry weight biomass with 1.14 (± 0.520) g (Table 3).

Soil material was important for the establishment of both species (F=7.803, p=0.003), with seedling establishment higher for both species on commercial soil (post hoc Tukey HSD). The non-native species had only marginally significantly higher establishment rate than the native species (F=3.904, P=0.06) and this relationship did not change across the soil materials (Interaction seeded species x soil material F=0.622, P=0.546).

There was a significant difference with regard to dry weight biomass between the two species ($F=13.743$, $p=0.001$), with *Festuca rubra* having significantly higher biomass than *F. ovina* (post hoc Tukey HSD). Soil material had also a significant effect on dry weight biomass ($F=12.533$, $P=<0.001$), with seedlings on coarse soil having significantly lower dry weight biomass than both fine and commercial soil (post hoc Tukey HSD). There was no significant interaction between seeded species and soil material ($P=2.1404$, $p=0.14$).

### Seedling establishment Betula nana

Pots filled with fine soil seeded with *Betula nana* had the highest percentage of seedlings (20.0 ± 10.20 %) establishing during the experiment. However, on the final day of the experiment pots filled with commercial soil seeded with *Festuca ovina* and *Betula nana* had the highest percentage (15.2 ± 7.69 %) of *Betula nana* seedlings. In pots filled with coarse soil and seeded with *Festuca rubra* and *Betula nana* and seeded only with *Betula nana* there were no seedlings on the final day of the experiment. The highest average dry weight of the *Betula nana* seedlings (2.13 ± 1.20 mg) was obtained in pots filled with commercial soil and seeded only with *Betula nana* (Table 4).

**Table 4.** Establishment of *Betula nana* and average dry-weight biomass for the different treatments.

| Soil material | Species | Emerged seedlings (%) (± SD) | Seedlings final day (%) (± SD) | Average biomass (mg) |
|---|---|---|---|---|
| Coarse | *B. nana* | 2.4 (± 3.58) | None | None |
| | *F. rubra* + *B. nana* | 4.8 (± 5.22) | None | None |
| | *F. ovina* + *B. nana* | 9.6 (± 7.27) | 6.4 (± 4.56) | 0.64 (± 0.11) |
| Fine | *B. nana* | 20.0 (± 10.20) | 8.8 (± 8.20) | 1.40 (± 0.44) |
| | *F. rubra* + *B. nana* | 6.4 (± 7.80) | 3.2 (± 5.22) | 0.76 (± 0.05) |
| | *F. ovina* + *B. nana* | 8.8 (± 5.22) | 6.4 (± 6.07) | 1.14(± 0.88) |
| Commercial | *B. nana* | 15.2 (± 6.57) | 12.8 (± 5.93) | 2.13 (± 1.20) |
| | *F. rubra* + *B. nana* | 4.8 (± 4.38) | 0.8 (± 1.79) | 0.60 (± 0.00) |
| | *F. ovina* + *B. nana* | 17.6 (± 6.07) | 15.2 (± 7.69) | 0.68 (± 0.19) |

The percentage of sown *Betula nana* seeds germinating during the experiment differed significantly depending on co-occurring species ($F = 5.66$, $p = 0.007$) and soil material ($F = 3.30$, $p = 0.013$). In general less *B. nana* seedlings emerged when seeded together with *F. rubra,* and less emerged on coarse soil (Table 4). There was also significant interaction between co-occurring species and soil material ($F = 2.95$, $p = 0.033$). More seedlings emerged when seeded alone on fine and commercial soil, and when seeded with *F. ovina* on commercial soil. Seedling emergence was quite constant on all soil types when seeded with *F. rubra,* and lower than when seeded with *F. ovina* (Table 4).

Seedling mortality during the establishment phase of the *Betula nana* caused the percentage of seedlings to be lower on the final day of the experiment (Table 4). The percentage of the sown *Betula nana* seeds established on the final day of the experiment differed significantly depending on co-occurring species ($F = 13.30$, $p < 0.001$) and soil type ($F = 9.53$, $p < 0.001$). More seedlings had established There was significant interaction between seeded species and soil material ($F = 3.8284$, $p = 0.011$). This may be explained by the fact that on coarse soil *B. nana* seedlings only survived through the experiment when seeded with *F. ovina*.

There was a significant difference in the dry weight of *Betula nana* when sown with different *Festuca* species ($F = 26.50$, $p < 0.001$), and when seeded alone yielding the highest biomass. Soil material was also significant ($F = 37.25$, $p < 0.001$), with less biomass on coarse soil. This was mainly due to the experienced seedling mortality. There were interaction effects between seeded species and soil material ($F = 18.63$, $p = 0.005$), with *B. nana* seeded alone and with *F. ovina* having more biomass.

# Discussion

This study has showed that sites seeded with commercial non-native species have over a period of 21 years established more vegetation cover than unseeded reference sites. However the non-native species *Festuca rubra* has persisted and dominate the seeded sites, and native vegetation cover and species richness is lower in seeded sites. There was an effect of soil material, with sites dominated by larger soil particle sizes having lower total vegetation cover. The greenhouse experiment indicated that the non-native species *Festuca rubra* limits the recruitment and growth of seedlings of the native *Betula nana*, particularly on more nutrient rich soils. The native *Festuca ovina* is shown to facilitate the establishment of native *B. nana* on coarse soil.

### Vegetation cover created by seeding

Seeded sites had more vegetation cover than reference sites, but the seeded non-native species *F. rubra* had persisted and inhibited the establishment of native species. Native vegetation cover and species richness was significantly lower in seeded sites compared to reference sites. The establishment of seedlings may be inhibited by limited seed numbers, competition for resources from established vegetation, a lack of suitable microsites or a mix of the three (Fenner and Thompson 2005, Turnbull et al. 2005). Since native vegetation cover and species richness is larger in reference sites compared to seeded sites, there are viable seeds and propagules present and there exists suitable microsites for the seeds to germinate in the area. It has been shown that grasses in general (Ewel and Putz 2004)  and the species *F. rubra* (Delarze 1994, Bayfield 1996, Argenti et al. 2000)may produce excessively dense cover and much litter, which can reduce colonization of native species. *F. rubra* is also shown to inhibit the establishment of native species (Appendix 2 for examples). This is in contrast with the findings of Gretarsdottir et al. (2004) from Iceland, where seeded species had facilitated for native species and not persisted over a period of 20-45 years.

The findings from the field study are supported by the results from the greenhouse experiment which indicate that the non-native *F. rubra* competes with the native *B.*

*nana* for resources. When seeded together with *F. rubra*, fewer and smaller *B. nana* seedlings established and survived untill the end of the experiment compared to when seeded alone. The native *F. ovina* does also compete with *B. nana* for resources, but to a smaller degree than *F. rubra. Betula. nana* seeded with *F. ovina* have about the same seedling survival as when seeded alone, but had smaller seedlings.

In addition to compete less for resources compared to *F. rubra, F. ovina* may actually facilitate for the establishment of *B. nana* when seeded on coarse soil. This may be caused by the fact that *F. ovina* establishes a safe-site for the seeds. A safe site is a physical site that is more favourable for germination and establishment compared to the surrounding environment since more moisture is available, nutrients are collected, temperature is moderated, wind is reduced, seeds are trapped and the site may aslo otherwise satisfy regeneration requirements for secies arriving at the safe-site (Walker and Del Moral 2003). This is a promissing result with regard to the upcoming restoration effortsusing native *F. ovina*, and may indicate that the vegetation cover in the future might be more similar to the native vegetation and more species rich.

However the patterns from the greenhouse experiment may not be the the same as one may encounter in nature, especially since the temperature regimes in the greenhouse and in Hjerkinn is not the same and since wind is not taken into account in the greenhouse. As wind is not a factor in the greenhouse, it is difficult to say whether a vegetation cover consisting of *F. ovina* might trap seeds compared to a vegetation cover consisting of *F. rubra*. However it is likely that less seeds are trapped because of *F. ovina* having less biomass and visually determined to be smaller than *F. rubra* in the greenhouse experiment.

### The effect of soil material on restoration of vegetation cover

Soil material had a significant effect on vegetation cover, with soils consisting of larger particle sizes having less total vegetation cover than soils consisting of smaller particle sizes. However native vegetation did not show any difference when it came to establishment on different soil material. For seeds and propagules to establish, safe-sites are needed (Fenner and Thompson 2005). Concave surfaces, coarse surface substrate and vicinity of large rocks are more likely to trap seeds and protect seedlings from desiccation (Jumpponen et al. 1999). If the soil particle sizes are too big, the soil may not provide the necessary root/soil contact and/or does not have sufficient holding capacity for water and nutrients to meet biological requirements for seedling establishment of a species (Chambers 1995). Limited decomposition rates as a result of less moisture in the soil, may lead to less nutrients available (Walker and Del Moral 2003). Even though alpine coarse soil has been demonstrated to better trap seeds than fine soil (Chambers et al. 1991), successful recruitment seems rather limited on coarse soils because of the limited seedling survival.

The fact that native vegetation cover did not follow the trend of total vegetation cover, may be because of more lichens on the larger particles of soil or more biological soil crust.

The seeded sites had more organic content, appeared moister and had marginally more water content than reference sites, which indicate more resources in seeded sites (Walker and Del Moral 2003). Moisture is one of the factors influencing litter decomposition rates, which again determine the recycling of nutrients and thereby soil organic matter, soil development and  the rate of succession (Walker and Del Moral 2003).  Despite having soil richer in organic material and indications of having more nutrients, there were less native vegetation cover and  fewer species in seeded sites. This would indicate that the seeded species *F. rubra* inhibits and outcompetes native species. Succesful invasive species have higher growth rates, and morphological or physiological traits which increase resource capture and/or utilization effieciency (Pattison et al. 1998). These findings are in line with the findings of Densmore (1992) from the Alaskan tundra, where seeded species persisted, dominated and inhibited the establishment of native species.

The results from the greenhouse also indicate that the *Festuca* species has the same establishment success on coarse and fine soil, but have less biomass when seeded on coarse soil. *B. nana* seedlings also emerged significantly less on coarse soil. Because of seedling mortality during the establishment phase of *B. nana*, seedlings only established when seeded with *F. ovina*. The reason for seedlings to establish when seeded with *F.*

*ovina* may be related to *F. ovina*'s ability to create safe-sites for *B.nana* and preventing the seedlings from desiccating.

*B. nana* and the *Festuca* species had more biomass when seeded on commercial soil, which may be explained by commercial soils being highly organic and have better water and nutrient holding capacities than mineral soils (Ball 1997).

### Indications of native species being a better alternative than non-native species in restoration efforts

This study shows that using non-native commercial species in restoration has created a vegetation cover, but has not facilitated for native species over time. The fact that the seeded species *F. rubra* has persisted and spread is not in accordance with the long term goals of restoration ecology (Forbes and Jefferies 1999). If non-native species used in restoration efforts does not manage to create a significant vegetation cover, and/or if the seeded species persist and dominate, the use of non-native species should be avoided or minimized to areas where there exist no suitable alternative (Scherrer and Pickering 2006). When introduced species have established, they may be difficult to remove because they often are subject to less competition and/or predation than native species (Palmer et al. 1997). In addition to ecological aspects, it is important to take for instance economy, local cultural preferences and time limitations into consideration before deciding on species (Hagen 2002). At the time of the seeding at Hjerkinn there were no suitable alternatives, and seeding with commercial non-native species was a common method (Younkin and Martens 1987, Jorgenson and Joyce 1994). With an increasing interest in the long-term effects of restoration by seeding and a desire to restore areas facilitated for long-term ecological processes, the choice between using native and non-native species is currently in focus. Non-native species might outcompete or hybridize with locally-adapted species/subspecies (Parker and Reichard 1998), and it is often difficult to predict the effect non-native species will have on native vegetation development and the surrounding environment (Densmore 1992, Forbes and Jefferies 1999). Using native species in restoration efforts reduces the potential for deleterious hybridization between alien and native species, and thereby enhancing biodiversity through maintaining native genetic characteristics (Mortlock 2000). The rate of restoration increases with greater plant species diversity (Gibson et al. 1985, Schuster and Hutnik 1987, McKell 1989, Robinson and Handel 1993, Urbanska 1995). The results from the field study show that using the non-native *F.* rubra has not created a native vegetation cover. The results from the greenhouse indicate that native species *F. ovina* use fewer resources and therefore compete less with other native species. This study indicates that using a native species is better than using a non-native in restoration efforts in an alpine enviroment.

# Acknowledgements

I would like to thank my supervisors Bente J. Graae (NTNU) and Dagmar Hagen (NINA) for collaboration, advice and a push in the right direction when needed. I would also like to thank Christophe Pelabon (NTNU) for advice and help with the statistical analyses, my girlfriend Siv Aagaard for help in the field and in the greenhouse, and Ellen Torsæter Hoff for help in the greenhouse.I would also like to thank Felleskjøpet for providing me with *Festuca rubra* “Leik” seeds and showing an interest in this study. On a personal basis I would like to thank my girlfriend and my father for always being there for me and supporting me, and my fellow students and friends for all discussions and laughs.

# Literature cited


Argenti, G., M. Merati, N. Staglianò, and P. Talamucci. 2000. Establishment and evolution of technical ski slope covers in an alpine environment. Rivista di Agronomia **34**:186.

Ball, J. 1997. Soil and water relationships. The Samuel Roberts Noble Foundation, Inc. http://www.noble.org/ag/soils/soilwaterrelationships/index.htm 01.09.2011

Bergenståhl, B. and L. Söderström. 1995. Fältbiologernas mossflora. Fältbiologerna, Stockholm.

Bayfield, N. G. 1996. Long-term changes in colonization of bulldozed ski pistes at Cairn Gorm, Scotland. Journal of Applied Ecology **33**:1359.

Brooker, R. W. and T. V. Callaghan. 1998. The balance between positive and negative plant interactions and its relationship to environmental gradients: a model. Oikos **81**:196-207.

Callaway, R. M., R. W. Brooker, P. Choler, Z. Kikvidze, C. J. Lortie, R. Michalet, L. Paolini, F. I. Pugnaire, B. Newingham, E. T. Aschehoug, C. Armas, D. Kikodze, and B. J. Cook. 2002. Positive interactions among alpine plants increase with stress. Nature **417**:844-848.

Carpenter, A. T., J. C. Moore, E. F. Redente, and J. C. Stark. 1990. Plant community dynamics in a semiarid ecosystem in relation to nutrient addition following a major disturbance. Plant and Soil **126**:91-99.

Casper, B. B. and R. B. Jackson. 1997. Plant competition underground. Annual Review of Ecology and Systematics **28**:545-570.

Chambers, J. C. 1995. Relationships between seed fates and seedling establishment in an alpine ecosystem. Ecology **76**:2124-2133.

Chambers, J. C., J. A. Macmahon, and J. H. Haefner. 1991. Seed entrapment in alpine ecosystems - effects of soil particle-size and diaspore morphology Ecology **72**:1668-1677.

Conservation of Arctic Flora and Fauna. 2001. Arctic flora and fauna: status and conservation. Edita, Helsinki.

Coomes, D. A. and P. J. Grubb. 2000. Impacts of root competition in forests and woodlands: A theoretical framework and review of experiments. Ecological Monographs **70**:171-207.

Cotts, N. R., E. F. Redente, and R. Schiller. 1991a. Restoration methods for abandoned roads at lower elevations in Grand-Teton national park, Wyoming. Arid Soil Research and Rehabilitation **5**:235-249.

Crawley, M. J. 1997. Plant ecology. Blackwell, Oxford.

Delarze, R. 1994. Vegetation dynamics on the artificially sown ski runs of Crans-Montana (Valais, Suisse). Botanica Helvetica **104**:3.

Densmore, R. V. 1992. Succession on an Alaskan tundra disturbance with and without assisted revegetation with grass. Arctic and Alpine Research **24**:238-243.

Ewel, J. J. and F. E. Putz. 2004. A place for alien species in ecosystem restoration. Frontiers in Ecology and the Environment **2**:354-360.

Fenner, M. and K. Thompson. 2005. The ecology of seeds. Cambridge University Press, Cambridge.

Forbes, B. C. and R. L. Jefferies. 1999. Revegetation of disturbed arctic sites: constraints and applications. Biological Conservation **88**:15-24.

Gibson, D. J., F. L. Johnson, and P. G. Risser. 1985. Revegetation of unreclaimed coal strip mines in Oklahoma.2. Plant-communities. Reclamation & Revegetation Research **4**:31-47.

Gretarsdottir, J., A. L. Aradottir, V. Vandvik, E. Heegaard, and H. J. B. Birks. 2004. Long-term effects of reclamation treatments on plant succession in Iceland. Restoration Ecology **12**:268-278.

Hagen, D. 2002. Propagation of native Arctic and alpine species with a restoration potential. Polar Research **21**:37-47.

Hagen, D. 2003. Assisted recovery of disturbed arctic and alpine vegetation: an integrated approach. Dr. scient. Department of Biology, Faculty of Natural Sciences and Technology, Norwegian University of Science and Technology, Trondheim.

Halvorsen, R., T. Andersen, H. H. Blom, A. Elvebakk, R. Elven, L. Erikstad, G. Gaarder, A. Moen, P. B. Mortensen, A. Norderhaug, K. Nygaard, T. Thorsnes, and F. Ødegaard. 2009. Naturtyper i Norge (NiN) versjon 1.0.0.

Harper, K. A. and G. P. Kershaw. 1996. Natural revegetation on borrow pits and vehicle tracks in Shrub Tundra, 48 years following construction of the CANOL No 1 pipeline, NWT, Canada. Arctic and Alpine Research **28**:163-171.

Helm, D. J. 1995. Native grass cultivars for multiple revegetation goals on a proposed mine site in south-central Alaska. Restoration Ecology **3**:111-122.

Holien, H. and T. Tønsberg. 2006. Norsk lavflora. Tapir akademisk forl., Trondheim.

Inouye, R. S., N. J. Huntly, D. Tilman, J. R. Tester, M. Stillwell, and K. C. Zinnel. 1987. Old-field succession on a Minnesota sand plain. Ecology **68**:12-26.

Jorgenson, M. T. and M. R. Joyce. 1994. 6 strategies for rehabilitating land disturbed by oil development in arctic Alaska. Arctic **47**:374-390.

Jumpponen, A., H. Väre, K. G. Mattson, R. Ohtonen, and J. M. Trappe. 1999. Characterization of 'safe sites' for pioneers in primary succession on recently deglaciated terrain. Journal of Ecology **87**:98-105.

Lid, J., D. T. Lid, and T. Alm. 2005. Norsk flora. Samlaget, Oslo.

Manly, B. F. J. 1994. Factor analysis. Pages 93-106 *in* B. F. J. Manly, editor. Multivariate statistical methods. A primer. Chapman & Hall, London.

Martinsen, O. E. and D. Hagen. 2010. Restoration of Hjerkinn firing range into nature conservation areas (Hjerkinn PRO). Pages 35-37 *in* D. Hagen and A. Skrindo, editors. Restoration of nature in Norway - a glimpse into the tematic field, professional institutions and ongoing activity. Norwegian Institute for Nature Research, Trondheim.

Martinsen, O. E. and H. Oskarsen. 2010. Multiplication of Sheep fescue (*Festuca ovina*) - Restoration in Hjerkinn firing range into nature conservation area. Pages 65-66 *in* D. Hagen and A. Skrindo, editors. Restoration of nature in Norway – a glimpse into the tematic field, professional institutions and ongoing activity. Norwegian Institute for Nature Research, Trondheim.

McKell, C. p.-S. D. A. P. 1989. The role of shrubs in plant community diversity. Pages 307-320 *in* C. McKell, editor. The Biology and Utilization of Shrubs. Academic Press, San Diego McLendon, T. and E. F. Redente. 1991. Nitrogen and phosphorus effects on econdary succession dynamics on a semiarid sagebrush site. Ecology **72**:2016-2024.

Moen, A., A. Lillethun, and A. Odland. 1999. Vegetation. Norges geografiske oppmåling, [Hønefoss].

Moles, A. T. and M. Westoby. 2004. What do seedlings die from and what are the implications for evolution of seed size? Oikos **106**:193-199.

Mortlock, B. W. 2000. Local seed for revegetation. Ecological Management & Restoration **1**:93-101.

Norwegian Defence Estate Agency. 2010. Hjerkinn PRO. http://www.forsvarsbygg.no/Prosjekter/Hjerkinn-PRO/ 03.03.2011

The Norwegian Institute for Soil and Forest Mapping. 1999. Vegetation map Hjerkinn firing range. Norwegian Institute of Land Inventory, Ås

Norwegian Meterological Institute. 2011. Monthly average temperatures Fokstugu meteorological station 1961-1990. Page eklima.met.no. Norwegian Meterological Institute.

Olear, H. A. and T. R. Seastedt. 1994. Landscape patterns of a litter decomposition in alpine tundra. Oecologia **99**:95-101.

Padilla, F. M. and F. I. Pugnaire. 2006. The role of nurse plants in the restoration of degraded environments. Frontiers in Ecology and the Environment **4**:196-202.

Palmer, M. A., R. F. Ambrose, and N. L. Poff. 1997. Ecological Theory and Community Restoration Ecology. Restoration Ecology **5**:291-300.

Parker, I. M. and S. H. Reichard. 1998. Critical issues in invasion biology for conservation science. In: Conservation biology: for the coming decade. Chapman & Hall, New York.

Paschke, M. W., C. DeLeo, and E. F. Redente. 2000. Revegetation of roadcut slopes in Mesa Verde National Park, USA. Restoration Ecology **8**:276-282.

Pattison, R. R., G. Goldstein, and A. Ares. 1998. Growth, biomass allocation and photosynthesis of invasive and native Hawaiian rainforest species. Oecologia **117**:449-459.

Petersen, S. L., B. A. Roundy, and R. M. Bryant. 2004. Revegetation methods for high-elevation roadsides at Bryce Canyon National Park, Utah. Restoration Ecology **12**:248-257.

Redente, E. F., T. B. Doerr, C. E. Grygiel, and M. E. Biondini. 1984. Vegetation establishment and succession on disturbed soils in northwest Colorado. Reclamation & Revegetation Research **3**:153-165.

Robinson, G. R. and S. N. Handel. 1993. FOREST RESTORATION ON A CLOSED LANDFILL - RAPID ADDITION OF NEW SPECIES BY BIRD DISPERSAL. Conservation Biology **7**:271-278.

Rydgren, K., R. Halvorsen, A. Odland, and G. Skjerdal. 2011. Restoration of alpine spoil heaps: Successional rates predict vegetation recovery in 50 years. Ecological Engineering **37**:294-301.

Scherrer, P. and C. M. Pickering. 2006. Recovery of alpine herbfield on a closed walking track in the Kosciuszko alpine zone, Australia. Arctic Antarctic and Alpine Research **38**:239-248.

Schuster, W. and R. Hutnik. 1987. Community development on 35-year-old planted minespoil banks in Pennsylvania. Reclamation and Revegetation Research [RECLAM. REVEG. RES.] **6**:109-120.

Tabachnick, B. G. and L. S. Fidell. 2007. Using multivariate statistics. Pearson/Allyn and Bacon, Boston.

The Norwegian Institute for Soil and Forest Mapping. 1999. Vegetation map Hjerkinn firing range. Norwegian Institute of Land Inventory, Ås.

Tinsley, M. J., M. T. Simmons, and S. Windhager. 2006. The establishment success of native versus non-native herbaceous seed mixes on a revegetated roadside in Central Texas. Ecological Engineering **26**:231-240.

Turnbull, L. A., L. Manley, and M. Rees. 2005. Niches, Rather than Neutrality, Structure a Grassland Pioneer Guild. Proceedings: Biological Sciences **272**:1357-1364.

Urbanska, K. M. 1995. Biodiversity assessment in ecological restoration above the timberline. Biodiversity and Conservation **4**:679-695.

Urbanska, K. M. and J. C. Chambers. 2002. Restoration in practice. Cambridge University Press, Cambridge.

Walker, L. R. and R. Del Moral. 2003. Primary succession and ecosystem rehabilitation. Cambridge University Press, Cambridge.

Wilson, J. B. 1988. Shoot competition and root competition. Journal of Applied Ecology **25**:279-296.

Younkin, W. E. and H. E. Martens. 1987. Long-term success of seeded species and their influence on native species invasion at abandoned rig site A-01 Caribou Hills, NWT, Canada. Arctic and Alpine Research **19**:566-571.

# Appendix 1 (continuing on next page

**List of species found in reference and seeded sites, following Lid et al 2005, Holien and Tønsberg 2006,and Bergenståhl and Söderström.1995.**

| | Site | | | Site | |
|---|---|---|---|---|---|
| **Species** | **Reference** | **Seeded** | **Species** | **Reference** | **Seeded** |
| *Andromeda polifolia* | | x | *Luzula sudetica* | | x |
| *Antennaria alpina* | x | x | *Lychnis alpina* | x | x |
| *Arctostaphylos uva-ursi* | x | | *Nardus stricta* | x | |
| *Betula nana* | x | x | *Nephroma articum* | x | x |
| *Betula pubescens* | | x | *Omalotheca supina* | x | x |
| *Biological soil crust* | x | x | *Oxyria digyna* | x | x |
| *Bistorta vivipara* | x | x | *Oxytropis lapponica* | | x |
| *Brodoa intestiniformis* | x | x | *Parnassia palustris* | x | x |
| *Bryocaulon divergens* | x | x | *Pedicularis lapponica* | x | x |
| *Calluna vulgaris* | x | x | *Phyllodoce caerulea* | x | x |
| *Caloplaca chlorina* | x | x | *Pinguicula vulgaris* | x | x |
| *Campanula rotundifolia* | x | x | *Poa alpina* | x | x |
| *Carex bigelowi* | | x | *Polytrichum sp.* | x | x |
| *Cerastium alpinum* | x | | *Ptilium sp.* | x | x |
| *Cetraria islandica* | | x | *Racomitrium lanuginosum* | x | x |
| *Cladonia arbuscula* | x | x | *Rhizocarpon geographicum* | x | x |
| *Cladonia cornuta* | x | x | *Rhizocarpon umbilicatum* | x | x |
| *Cladonia fimbriata* | x | x | *Rumex acetosella* | x | x |
| *Cladonia rangiferina* | x | x | *Salix glauca* | x | x |
| *Cladonia sp.* | x | x | *Salix herbacea* | x | x |
| *Cladonia stellaris* | | x | *Salix lanata* | | x |
| *Collema tenax* | x | x | *Salix lapponum* | x | x |
| *Deschampsia cespitosa* | x | x | *Salix myrsinifolia* | | x |
| *Empetrum nigrum* | x | x | *Salix phylicifolia* | x | x |

| | Site | | | Site | |
|---|---|---|---|---|---|
| **Species** | **Reference** | **Seeded** | **Species** | **Reference** | **Seeded** |
| *Euphrasia frigida* | x | x | *Salix reticulata* | x | x |
| *Festuca ovina* | x | x | *Sanionia uncinatus* | x | x |
| *Festuca rubra* | x | x | *Saxifraga aizoides* | | x |
| *Flavocetraria cucullata* | x | x | *Solorina crocea* | x | |
| *Flavocetraria nivalis* | x | x | *Spaghnum sp.* | | |
| *Frutidella caesioatra* | x | x | *Stereocaulon sp.* | x | x |
| *Gentiana nivalis* | x | x | *Taraxacum croceum* | | x |
| *Hieracium alpina* | x | x | *Thamnolia vermicularis* | x | x |
| *Huperzia selago* | x | x | *Tofieldia pusilla* | x | x |
| *Juncus trifidus* | x | x | *Vaccinium myrtillus* | x | x |
| *Juniperus communis* | x | | *Vaccinium uliginosum* | x | x |
| *Leontodon autumnalis* | | x | *Vaccinium vitis-idaea* | x | x |
| *Loiseleuria procumbens* | x | x | *Viola biflora* | x | |
| *Luzula arcuata* | x | | *Xanthoria elegans* | x | x |
| *Luzula spicata* | x | x | | | |

# Appendix 2

Examples of the visual differences between seeded sites, reference sites and the surrounding vegetation. Upper left:: Unseeded reference site in the bottom half, seeded site in the middle of the picture (bright green) and native vegetation in the surroundings. Upper right: Seeded site in the middle of the picture, native vegetation cover to the left.

Bottom left: Seeded site following the road, native vegetation in the surroundings. Bottom right: Unseeded reference site, native vegetation in the upper right corner.