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Master thesis

Effects of increased intensity of soil scarification on natural regeneration of Scots pine *Pinus sylvestris* and birch *Betula* spp.

Master in Applied Ecology

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Abstract

In this study I tested the effect of high intensity of soil scarification on density and growth of young pine and birch seedlings in natural pine regenerations in Hedmark County, South-eastern Norway. The reason for testing high intensity of soil scarification is to establish dense stands, as several studies have shown that proportion of damaged trees from moose decreases with stem density. During the autumn after the growing season of 2015, we collected data on establishment, growth and age of young tree seedlings in 67 pine stands on low and medium productivity sites. We also measured scarification intensity estimated as proportion of exposed mineral soil and humus. The stands were distributed over control and experiment areas, which were treated with normal intensity and high intensity of soil scarification respectively. Results from statistical analyses showed a positive correlation between density of pine seedlings and soil scarification intensity. For the oldest stands included in this study (scarified in 2011), the model predicted a pine density of 6065 to 24 319 (lower and upper 95 % confidence limits) trees per hectare when scarification intensity was normal (15-20 % exposed mineral soil), and 11 497 to 54 056 trees per hectare when scarification intensity was high (40 % exposed mineral soil). There was a substantial variation between stands, which could be explained by differences in soil conditions between stands. The results for birch were less clear, which imply that other, unmeasured factors are more important for establishment of birch. Concerning growth, the correlation between soil scarification intensity was negative for both pine and birch. However looking at the effect of intensity of soil scarification measured as proportion exposed humus, the correlation was positive for downy birch seedlings when age was 3 or higher. For silver birch I found no correlation between scarification intensity and growth. This study shows that higher density of pine seedlings can be achieved by exposing a larger proportion og the ground during soil scarification, but the effect on early growth of pine and birch might be detrimental. Future research should focus on investigating long term effects of high intensity of soil scarification on density, growth and survival of trees. Particularly early growth should be studied more closely for trees older than 4-5 years.

Sammendrag (Abstract in Norwegian)

I dette studiet ser jeg på effekten av økt markberedningsintensitet på tetthet og vekst av unge planter av furu og bjørk i naturlige furuforyngelser i Trysil, Våler og Åsnes kommune i Hedmark. Formålet med å intensivere markberedningen er å etablere tette bestand, da flere studier har vist at andel trær som er beiteskadd av elg går ned når tettheten av trær øker. Høsten etter vekstsesongen 2015 samlet vi data på etablering, vekst og alder på unge trær, samt intensitet av markberedning i 67 furubestand på lave til middels høye furuboniteter. Prøveflatene var fordelt over kontroll- og eksperimentområder, med henholdsvis normal intensitet av markberedning og høy intensitet av markberedning. Resultatene fra statistiske modelleringer viste en positiv sammenheng mellom tetthet av furuplanter og intensitet av markberedning målt som andel mineraljord blottlagt. For de eldste bestandene i studiet (markberedt i 2011), spådde modellen en tetthet av furutrær på mellom 607 og 2432 (nedre og øvre 95 % konfidensintervall) per dekar når intensiteten av markberedning var 15-20 %, og mellom 1150 og 5406 per dekar når intensiteten av markberedning var 40 %. Variasjonen i tetthet på forskjellige intensiteter av markberedning skyldtes trolig variasjon mellom prøveflatene i forhold til næring og fuktighet. Resultatene for bjørk var mindre entydige og tydet på liten sammenheng mellom intensitet av markberedning og tetthet. Når det gjaldt vekst, var sammenhengen med intensitet av markberedning negativ for furu og dunbjørk. Effekten var derimot positiv på de eldste dunbjørkene (alder 3-4 år) når andel eksponert humus ble brukt som forklaringsvariabel. For hengebjørk fant jeg ingen sammenheng mellom intensitet av markberedning og vekst. Dette studiet viser at det er mulig å oppnå tettere furuforyngelser ved å eksponere en større andel av bestandet, men effekten på tidlig vekst av furu og bjørk kan slå ut negativt. Det er viktig at man videre får undersøkt langtidseffektene av høy intensitet av markberedning både på etablering, vekst og overlevelse av trær. Spesielt tidlig vekst for trær som er eldre enn de eldste trærne fra dette studiet er viktig å undersøke i den sammenheng.

Table of content

1. Introduction

Browsing damage by moose (*Alces alces*) on Scots pine (*Pinus sylvestris*) has been a cause of conflict between foresters and moose hunters for decades in Scandinavia, as it causes great economical losses in forestry every year. In addition, timber harvesting and establishment of young stands largely control the forage availability for moose (Lavsund, Nygrén & Solberg 2003). In wintertime when feeding options for moose are limited, moose mainly forage on Scots pine (Bergström & Hjeljord 1987; Månsson *et al.* 2010), and damages to pine stands caused by moose browsing may be severe (Heikkilä & Härkönen 1996; Bergqvist, Bergström & Edenius 2003).

Many measures have been taken in order to reduce cervid browsing in young forest stands. Examples of such measures include fencing, use of chemical repellants (Solbraa 2008) and use of aluminum tags fastened to the top of the tree seedling in order to block moose from browsing (Sæther *et al.* 1992). Some studies rather focus on providing alternative food sources for cervids in order to reduce browsing damages, such as introducing feeding stations with silage (Gundersen, Andreassen & Storaas 2004), piling up residues of branches and tree tops after commercial thinning (Heikkila & Harkonen 2000; Månsson *et al.* 2010), or preserving trees of preferred browsing species within browsing height (Haug 2014).

A potential conflict reducing method I want to look closer into in this thesis is intensification of soil scarification as a means of stimulating dense seedling establishments of pine and birch. Soil scarification is a mechanical procedure that involves turning over the top layer of vegetation and humus in order to expose the mineral soil beneath. In this way seed – soil water contact improves (Oleskog & Sahlén 2000a; Oleskog & Sahlén 2000b), soil temperature increases (Kubin & Kemppainen 1994; Bedford & Sutton 2000), and nutrients become more accessible to young trees as competing vegetation is removed in the process (Nilsson & Örlander 1999; Øyen 2002). This improves both germination (Karlsson *et al.* 1998; Karlsson & Örlander 2000; Oleskog & Sahlén 2000a; González-Martínez & Bravo 2001; Chantal *et al.* 2003; Hille & Den Ouden 2004) and early growth of trees (Mäkitalo 1999; Bedford & Sutton 2000; Karlsson & Örlander 2000; Hille & Den Ouden 2004). Soil scarification has also been shown to reduce mortality of both pine (Löf *et al.* 2012; Johansson, Ring & Hogbom 2013) and birch seedlings (Karlsson 1996).

Soil scarification is commonly used when foresters need to ensure a successful regeneration of trees, either by planting, sowing, or by natural regeneration (Nygaard 2001). Natural regeneration simply means that the new generation of tree seedlings sprouts from seeds that spread naturally from remaining seed trees or the forest edge. Soil scarification is often used in pine stands, and mainly in locations where natural regeneration is unsuccessful or slow unless measures of soil preparation are taken (Øyen 2002). High tree density may be achieved by using more intensive scarification methods as these are reported to produce a higher yield of established seedlings (Aleksandrowicz-Trzcinska *et al.* 2014). Dense stands naturally produces more moose forage, and studies have shown that dense stands have a larger proportion of undamaged stems from moose browsing compared to less dense stands (Lyly & Saksa 1992; Andren & Angelstam 1993; Heikkilä & Härkönen 1996; Wallgren *et al.* 2013). This is connected to the phenomenon that moose tend to rebrowse on certain trees, both as a consequence of some trees originally being more palatable than others, and as browsing induce lusher growth with larger and more nutritious shoots which enhances palatability and promotes rebrowsing on the same trees (Löyttyniemi 1985). Such rebrowsing is shown to occur both on pine and birch (Bergstrom 1984; Heikkilä 1991; Bergqvist, Bergström & Edenius 2003), and reduces the probability for other trees being browsed. Consequently, in a dense stand a proportionally small number of trees take on most of the browsing pressure until the stand has reached sufficient mean height of about 4 - 5 m in order to avoid the heaviest moose browsing pressure (Siipilehto & Heikkilä 2005). Damaged trees may then be removed during the process of thinning, thus leaving a successful regeneration of trees to form the future stand.

Soil scarification is shown to have a positive effect on growth of pine, which is mainly related to increased soil moisture conditions (Oleskog & Sahlén 2000a) and elevated soil temperature during growth season in scarified patches (Bedford & Sutton 2000; Oleskog & Sahlén 2000b). Enhanced growth following soil scarification is also found for birch (Perala & Alm 1989). As mentioned earlier, the scarification procedure removes other vegetation in the process, and thus reduces competition for light and nutrients with other plants. Another aspect of competition with other vegetation includes the release of phyotoxins. Phytotoxins can be released by dwarf shrubs such as crowberry (*Emperum nigrum*) and bog bilberry (*Vaccinium uliginosum*), and are shown to inhibit germination and growth of pine and birch (Hytönen 1992; Nilsson 1994). Growth rate of plants may further affect cervid browsing in different ways, as fast growing plants are generally more nutrient rich and thus more attractive for browsers (Bryant, Chapin III & Klein 1983). Yet, fast growing trees may reach inaccessible heights at an earlier stage and thus reduce the time frame in which browsing may occur.

In commercial forestry in Norway, the common soil scarification practice is to expose mineral soil in 15 - 20 % of the total accessible area (Øyen 2002). In order to establish even denser stands foresters have suggested that we could intensify commercial soil scarification, which means we expose a higher proportion of the ground compared to what is normal: up to 40 %. In order to evaluate this hypothesis I have compared areas with low and high intensity of soil scarification in order to investigate effects of increased scarification intensity on density and growth of established tree seedlings of Scots pine and birch (*Betula pubescens, Betula pendula*). I hypothesize that density of pine and birch seedlings will show a positive correlation with scarification intensity as soil scarification is shown to enhance seed germination. Time since the scarification treatment is expected to have a positive correlation with density of seedlings, as more seeds have time to spread naturally over time. Site productivity is expected to have a negative correlation with seedling density as more competition from other vegetation is expected at higher site productivities. However this effect might be negligible as site productivity was generally low in the pine stands included in this study. Further, I hypothesize that growth, as represented by length of last year’s top shoot, will have a positive correlation with soil scarification intensity, as exposed mineral soil and humus provide good growth conditions in terms of soil water retention, soil temperature and reduced competition for light and nutrients. I also expect growth to increase with plant age, and growth of pine to be higher in areas with higher site productivity, as site productivity indexes are related to pine growth.

2. Material and methods

2.1 Study area

The study area consists of three separate sites of roughly 50-60 km^2 each in Hedmark County in south-eastern Norway, (60-61° N, 12° E), at an altitude of 300-500 meters above sea level. Two of these sites, Plassen and Ljørdalen, are located in Trysil municipality, and the third which is called Gravberget, is located in Våler and Åsnes municipality. All these are managed areas for forestry. Ljørdalen and Gravberget consist of state-owned forests managed by the State-owned Land and Forest Company (Statskog). Plassen study area is managed by private land owners and Trysil Municipality Forests. Most of the stands included in this study were located in Gravberget, see table 1.

The study areas are located in the middle boreal vegetation zone, on podzolic soils, where boreal conifer forest and mixed conifer and deciduous forest constitute most of the natural landscape (Moen 1998). Dominating tree species include Scots pine *Pinus sylvestris,* silver birch *Betula pendula* and downy birch *Betula pubescens,* and to a lesser extent, Norwegian spruce *Picea abies*, grey alder *Alnus incana*, rowan *Sorbus aucuparia*, goat willow *Salix caprea* and aspen *Populus tremula* (Moen 1998). The field layer mainly consists of bilberry (*Vaccinium myrtillus*) and other dwarf shrubs, with bilberry as dominating species. In the wettest parts of the area there are bogs dominated by *Sphagnum spp*. mosses with scattered drier spots of *Calluna vulgaris* and other dwarf shrubs. Average yearly precipitation recorded from Trysil weather station is ~800 mm, and average temperature during the growth season (May - September) is +11 °C (eKlima 2016). Growth season is here defined as the period of an average daily temperature above 5 °C, which according to Moen (1998), is 150-160 days for the area surrounding Trysil, Våler and Åsnes municipalities.

2.2 Soil scarification treatment

The study areas were divided into treatment and control areas in order to create a basis for comparison between high and “normal” soil scarification intensity. There were 29 stands within the control areas and 38 stands within the treatment areas, (see table 1). In pine stands in the control areas 15-20 % of the ground was exposed during mechanical soil scarification. This represents “business as usual” as normal practice is to expose 15-20 % in order to achieve a successful natural regeneration of pine. “Normal” intensity will further out in the text be referred to as “low” intensity, as it is low in comparison to the experiment treatment. In the treatment areas ~40 % of the ground was scarified in order to achieve *high* intensity of soil scarification for comparison. This involves that the scarification patches or stripes were more densely distributed than what is normally the case.

The scarification treatment was done using a forwarder with an attached scarification device that would scrape under the lower part of the humus layer and lift it up and turn it over in order to expose the top of the mineral soil layer beneath. The soil scarification was done 1-2 years after clear cut logging, as the stand have had time to dry up after felling so that remains do not block the machine. Recommendations are to scarify the summer or autumn before a good seed fall. If more time passes between soil scarification and a decent seed fall, more vegetation will have had time to establish in the scarification patches which could reduce germination (Nygaard 2001). Scarification treatments for this project have been carried out in Plassen since 2011, in Gravberget since 2012 and in Ljørdalen since 2013, (see table 1).

Table 1: Distribution of number of stands per year of scarification treatment according to study area site and experiment (A) vs control (B) area.

	Gravberget		Plassen		Ljørdalen	
	A	B	A	B	A	B
2011	-	-	9	-	-	-
2012	6	23	1	-	-	-
2013	10	5	1	-	3	1
2014	6	-	-	-	2	-
Total	**22**	**28**	**11**	**0**	**5**	**1**

2.3 Field procedures

For each of the 67 stands included in this study, ten sampling points with fixed distance between each point were positioned on a straight line following the longest axis of the stand. The fixed distance between the sampling points were, depending on the size and the shape of the stand, 100 m, 50 m or 25 m in order to cover the area of each stand. If the shape of the stand did not allow for ten points to fit on the same line, a perpendicular line were positioned at the longest perpendicular axis of the stand. Alternatively, a parallel transect was added. A compass was used for direction, and the distance between sampling points was measured using a GPS. At each sampling point, seedling density and height was measured in 8 plots of 1m^2. The plots were grouped in pairs with 2 in each direction (north, east, south, and west), 5m from the plot center. All measures of seedlings were carried out after the growing season, from August to the start of October.

A field personnel consisting of up to 10 students including me, carried out the survey of tree seedlings. For each plot we estimated percentage exposed mineral soil and percentage turned over humus from soil scarification. This was done as a visual estimate as % of the plot area. Obstacles such as large rocks, seed trees or water bodies covering the whole or parts of the plots were recorded as a percentage “other cover”. This was done as a means to estimate the proportion of each plot that was unsuitable for seedling establishment. The remaining parts of the plots, which were not defined as mineral soil, humus or “other cover”, were mainly intact vegetation cover consisting of graminoids, moss, lichens and dwarf-shrubs. We counted and measured all tree seedlings inside the sampling plots and classified them to species. The species present were Scots pine, Norway spruce, downy birch, silver birch, rowan, aspen, sallow/willows (*Salix* spp.) and juniper (*Juniperus communis*), (see appendix A). For birch seedlings less than a few centimeters long, species identification was often difficult as species specific traits were underdeveloped. Thus, these observations were recorded as undefined birch species, or “*Betula* spp.”. The age of the trees were registered by counting annual growth nodes. For pine and spruce age determination was done by counting the number of shoot-whorls on the stem. Side branches normally start to develop during the third year (Skogsstyrelsen *et al.* 2009). Each shoot-whorl corresponds to one year of growth, for trees ≥ 3 years. Conifer tree seedlings of two years were distinguished from those which were ≤ 1year by the presence of a fresher and greener shoot on the top of the seedling, and also by the presence of the longer double-joint needles for pine seedlings (Skogsstyrelsen *et al.* 2009). For deciduous tree seedlings age was determined from color and/or growth form. Each node on the stem with a visible shift in coloration, or a ring-like scar was counted as one year.

Height of the seedlings was measured as total vertical height from the ground to the highest shoot-tip. As a measure of growth during the last summer’s growth season, length of the last year’s top shoot was measured from the last shoot-whorl, for conifer trees or node for deciduous trees, on the stem to the base of the bud at the tip of the terminal shoot. Each tree observation sampled within a plot was assigned to one out of three substrate categories:

exposed mineral soil, exposed humus or intact vegetation depending on the quality of the substrate of which the seedlings were growing in.

For each stand, data on general stand information was entered into a registration form. This data included date of sampling, study area site (Gravberget/Ljørdalen/Plassen), stand number, control/experiment area, year of scarification treatment, scarification intensity and forest productivity index. This index was based on the H40-system (Statistics Norway 2016) and was retrieved from forestry management plans. Most of the stands included in this study had site productivity index F11 or F14, (see table 2).

Table 2: Distribution of number of stands per class of site productivity index present in the study area according to study area site and experiment (A) vs control (B) group.

	Gravberget		Plassen		Ljørdalen	
	A	B	A	B	A	B
F8	-	-	1	-	2	-
F11	11	12	9	-	3	1
F14	12	15	1	-	-	-
F17	-	1	-	-	-	-
Total	**22**	**28**	**11**	**0**	**5**	**1**

2.4 Statistical analyses

2.4.1 Measure of soil scarification intensity

I ended up using proportion exposed mineral soil and proportion exposed humus per area unit as continuous explanatory variables, instead of comparing high vs low intensity of treatment, as these classes corresponded poorly to the actual measured proportions of mineral soil and humus. The low correlation might be a result of misunderstandings somewhere down the line of communication between researchers, land owners/foresters and forestry workers that operated the scarification forwarder. It might also be due to reduced mobility of the forwarder in rugged landscape with many natural obstacles. Proportion mineral soil and proportion humus were expected to be correlated variables as these covers are caused by the same mechanical process. On sampling point and plot level however, the scale is quite small and proportions of exposed mineral soil and exposed humus were less correlated: on sampling point level: $r = 0.25$, $p < 1.0\text{e-}10$, on plot-level: $r = 0.03$, $p = 0.019$. Hence I could include both proportion exposed mineral soil and proportion exposed humus as explanatory variables in the statistical modelling process and avoid complications with confounding effects.

2.4.2 Site productivity index

As all observation with a site productivity index of F17 originated from only one stand, I grouped this level with index F14. Thus I ended up with 3 levels of site productivity index: F8, F11, F14/F17. An overview of sample size in each productivity class is shown in table 2.

2.4.3 Model selection

I fitted linear models in order to investigate the relationship between my measures of soil scarification intensity and the response variables according to my hypotheses. I used mixed effects models in order to deal with spatial dependency induced by the spatially nested sampling design. Model selection was done separately for the random model structure and the fixed model structure following the model selection protocol explained by Zuur *et al.* (2009). The most optimal model for each response variable was obtained via model selection using AIC as a selection criteria. First I used AIC to find the most optimal random model structure by including all meaningful explanatory variables and interactions while only making changes in the random structure of the model candidates. I chose to proceed with the random structure that had the lowest AIC. After initial data exploration I created a set of biologically meaningful candidate models in which all included the random structure found in the former step. I then used AIC selection to identify the most optimal fixed model structure. The same selection criteria were used as with the random structure; the model with the lowest AIC was chosen as final model. If several models had equally low AIC, meaning Δ AIC ≤ 2, the simplest model with the lowest number of explanatory variables was chosen as the final model. All analyses were made in RStudio, R 3.2.4 (R Core Team 2015).

2.4.4 Density hypothesis

As modelling with observations on sampling plot level failed to pass model validation steps because of a high number of plots with zero trees, I decided to carry out the analysis at sampling point level, combining all plots at each sampling point. I did the reduction by adding together all counts from plots within the same sampling point while averaging the other variable values to point level. My dataset now consisted of 626 observations (see table 3), and my proportion of zero values was reduced from 69 % to 15 % which should be more appropriate for fitting a model to my data. In order to explain the relationship between density of trees and scarification intensity, I used number of trees per sampling point as response variable. The model selection procedure was done separately for Scots pine and birch spp. Explanatory variables were percentage exposed mineral soil and percentage exposed humus, which were used as measures of soil scarification intensity. I included site productivity index, year of scarification treatment and percentage "other cover" as covariates. The covariate "other cover" was included in order to account for the expected negative effect of proportion of unsuitable habitat for tree seedling germination. In addition, meaningful interactions between the explanatory variables and the categorical covariates were included into the full model. Sampling point nested with stand number was included as random intercept. I fitted a generalized linear mixed model specified with a negative binomial distribution with log link, using the glmer.nb() function from the R package "lme4" (Bates *et al.* 2015). The final model was obtained via model selection with AIC as described under the "Model selection" paragraph. Final model from AIC selection was then validated by checking for overdispersion and by inspecting the normalized residuals in a "residuals vs. fitted" plot.

2.4.5 Growth hypothesis

In order to explain the relationship between growth and scarification intensity I used length of the last year's top shoot as a measure of growth during the current growing season. Explanatory variables were percentage exposed mineral soil and percentage exposed humus cover. I included site productivity index, age of the tree seedlings, year of scarification treatment and percentage "other cover" as covariates and also interactions between the explanatory variables and the categorical covariates. The model selection procedure was done separately for Scots pine, downy birch and silver birch. Observations of very small birches that did not show any species-specific traits were not included in the analyses as it was necessary to separate between the two species of birch as they showed different growth responses to the explanatory variables and covariates. Plot nested with sampling point nested with stand number was included as random intercept. I fitted the model as a linear mixed effect model using the lme() function in the R package "nlme" (Pinheiro *et al.* 2015). I log-transformed the response variable by using the natural logarithm in order to achieve normality of the model residuals. Since I was mainly interested in the effects of soil scarification on growth, I only included observations of trees that established *after* the soil scarification treatment took place in the respective stand. This dataset consisted of 10 344 observations of pine and birch spp. As scarification treatments were done in 2011, 2012, 2013 and 2014, the age classes of trees represented in my data range from 1-5 years, (see table 14). For downy birch there was only 1 observation with age = 5, and for silver birch there were only 2 observations with age = 5, hence these observations were removed from further analyses due to too little data to carry out the analysis. For silver birch there was only one observation in treatment year 2014, so this observation was also removed from further analyses. Sample sizes used in the statistical analyses for pine, downy birch and silver birch are shown in table 3. Final model from AIC selection was fitted with restricted maximum likelihood and then validated by inspecting normality of the residuals in quantile-quantile plots and residual histograms, and also by confirming homoscedasticity in "residuals vs. fitted" plots.

Table 3: Sample sizes used in the statistical modelling according to the different hypotheses and to tree species. Statistical unit used for density was sampling point, and total number of sampling points was 626, regardless of tree species. Total number of trees counted according to species can be found in appendix A. For growth, observations were on tree-level, and thus sample sizes vary between the tree species in focus. Only observations of trees established after the soil scarification treatment were included into the growth analyses.

Hypothesis		Sample size
Density		626
	Tree species:	
Growth	Scots pine	2803
	downy birch	6964
	silver birch	572

3. Results

3.1 Seedling density

For pine seedling density there were 3 candidate models with equally low AIC (ΔAIC ≤ 2), and thus the most parsimonious model was chosen as final model (see table 4). The final model included the variables: mineral soil, other cover and year of scarification treatment. Stand ID was included as random intercept in the final model.

Table 4: Results from pine seedling density model selection using GLMMs with negative binomial error distribution. Stand ID as random intercept was chosen as the optimal random structure, and was included in the candidate models. Table shows the five models with lowest AIC from 26 candidate models. Model parameters are presented with corresponding degrees of freedom, AIC value, delta-AIC and AIC weights. Models are ranked from lowest to highest AIC, and the models that have ΔAIC ≤ 2 are considered to be equally adequate. Final model is highlighted in bold.

Pine seedling density	Df	AIC	ΔAIC	Weight
mineral + other + year + year×mineral	11	3036.55	0.00	0.26
mineral + other + year	**8**	**3036.75**	**0.20**	**0.24**
mineral + humus + other + year + year×mineral + year×humus	15	3038.54	1.98	0.10
mineral + humus + other + year	9	3038.64	2.09	0.10
mineral + other + site.prod + year + year×mineral.soil	13	3039.23	2.68	0.07

Increasing proportion of mineral soil exposed by scarification had an exponential positive effect on pine seedling density, (table 5 and figure 1). In figure 1 only predicted lines for scarification year 2011 and 2014 are included in order to maintain readability. Predicted lines for scarifications years 2012 and 2013 plus confidence intervals would position themselves between predicted lines for 2011 and 2014. When using the oldest treatment year, 2011 (time since scarification treatment = 5) as baseline, and keeping proportion of "other cover" constant at the mean of 8.7 % other cover, expected density of pine seedlings at 15 % mineral soil is estimated as 10 991 per hectare (95 % Cl, 6065 – 17 235 per hectare). At 20 % mineral soil expected density of pine seedlings increases to 12 947 per hectare (95 % Cl, 6893 – 24 319 per hectare), and for 40 % of mineral soil expected density of pine seedlings furtherly increases to 24 930 per hectare (95 % Cl, 11 497 – 54 056 per hectare). Proportion of other cover had a negative exponential effect on pine density, (table 5). As expected, pine seedling density increased with years since scarification treatment, as can be seen by increasingly higher negative estimates for the youngest treatment years 2014 and 2013 compared to that of 2012 and the intercept (table 5). The variance of the random intercept of 0.26 implies that there was considerate variation between stands (table 5).

Table 5: Shows final model parameters with corresponding estimates, standard errors, *Z*-statistics and *p*-values for pine seedling density fitted as a GLMM with negative binomial error distribution. Stand ID was included as random intercept. An R^2 that takes into account the random intercept is presented as an indication of explained deviance.

Parameter	Estimate	SE	Z	*p*-value
intercept	1.8271	0.2002	9.13	< 2e-16
mineral soil	0.0328	0.0037	8.95	< 2e-16
other cover	-0.0166	0.0056	-3.00	0.003
2012	-0.5627	0.2133	-2.64	0.008
2013	-1.0981	0.2227	-4.93	8.18e-07
2014	-1.2122	0.2730	-4.44	8.97e-06
Variance of random intercept:	Stand ID 0.26			R^2: 0.64

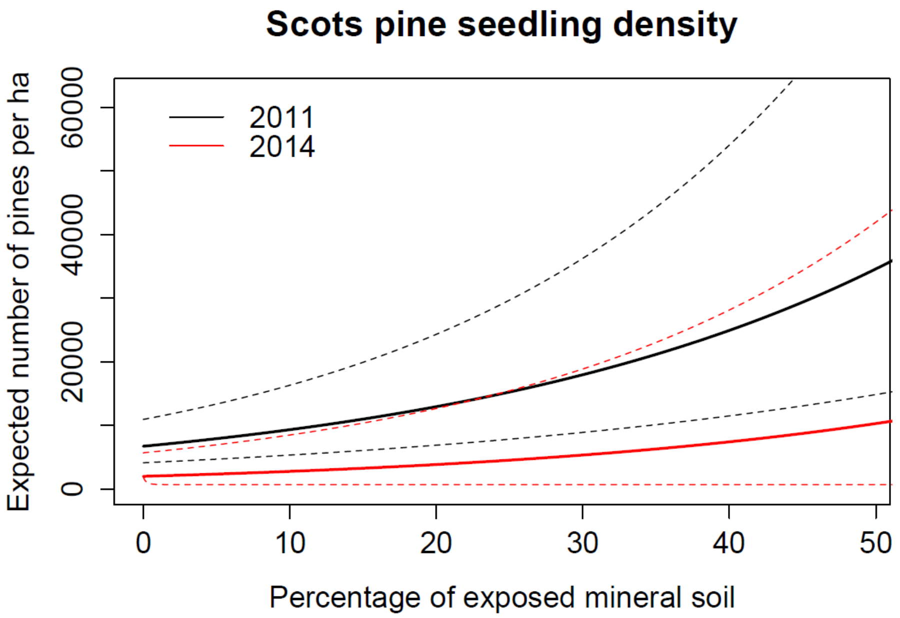

Figure 1: Prediction lines for expected density of pine seedlings with increasing proportions of mineral soil for stands scarified in 2011 (black solid line) and stands scarified in 2014 (red solid line). 95 % confidence intervals are illustrated by dotted lines. Prediction lines for stands scarified in 2012/2013 are not included in the figure in order to maintain readability. The predicted lines are based on a constant negative contribution of the effect of “other cover” at the mean level of 8.7 % other cover.

For birch seedling density, the results from model selection differed when using all birch spp. in total and when separating between birch species. The candidate models that met the model assumptions and had the best fit, included all birch spp. seedling counts as response variable. Comparing models using observations from birch spp. in total resulted in 4 candidate models with equally low AIC. Hence, the principle of parsimony was used to choose the simplest model (see table 6).

Table 6: Results from birch spp. seedling density model selection using GLMMs with negative binomial error distribution. Stand ID nested within site as random intercept was chosen as the optimal random structure, and was included in the candidate models. Table shows the five models with lowest AIC from 26 candidate models. Model parameters are presented with corresponding degrees of freedom, AIC value, delta-AIC and AIC weights. Models are ranked from lowest to highest AIC, and the models that have ΔAIC ≤ 2 are considered to be equally adequate. Final model is highlighted in bold.

Birch spp. Seedling density	Df	AIC	ΔAIC	Weight
mineral + other	**6**	**4404.72**	**0.00**	**0.29**
mineral + humus + other	7	4405.69	0.97	0.18
mineral + other + year	9	4406.03	1.31	0.15
mineral + humus + other + year	10	4406.36	1.64	0.13
mineral + other + year + year×mineral.soil	12	4407.80	3.08	0.06

The final model for birch seedling density included the variables mineral soil and other cover. Stand ID nested within site was included as random intercept in the final model. Both proportion of mineral soil and proportion of “other cover” had an exponential positive effect on birch seedling density, (see table 7). Expected density of birch seedlings at 15 % mineral soil was estimated as 5943 per hectare (95 % Cl, 1114 – 31 706 per hectare), keeping the effect of “other cover” constant at the average level of 8.7 % other cover. Expected density of birch seedlings at 20 % mineral soil was estimated as 6762 per hectare (95 % Cl, 1164 – 39 275 per hectare), and expected density of birch seedling at 40 % mineral soil was estimated as 11 337 per hectare (95 % Cl, 1390 – 92 479 per hectare), (see figure 2). It should be noted that there was a huge variation in birch density between stand and sites, which was reflected by the large standard errors, and by the contribution to the variance of the random intercept (stand ID nested with site) = 1.16, (table 7).

Table 7: Shows final model parameters with corresponding estimates, standard errors, z-statistics and p-values for birch spp. seedling density fitted as a GLMM with negative Binomial error distribution. Stand ID nested within site was included as random intercept. An R^2 that takes into account the random intercept is presented as an indication of explained deviance.

Parameter	Estimate		SE	Z	*p*-value
intercept	0.9833		0.6491	1.52	0.130
mineral soil	0.0258		0.0070	3.69	< 0.001
other cover	0.0217		0.0087	2.50	0.012
Variance of random intercept:	Site	1.08			R^2: 0.48
	Stand ID	1.16			

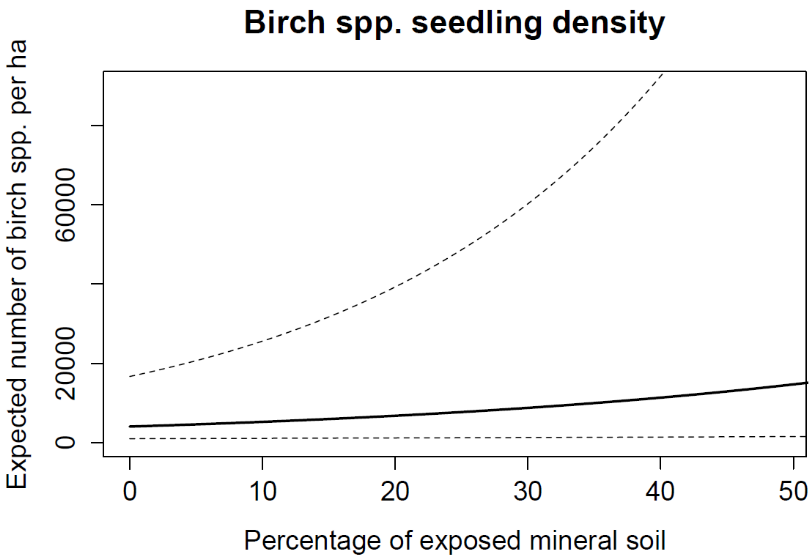

Figure 2: Prediction lines for expected density of birch spp. seedlings with increasing proportions of mineral soil (black solid line) with 95 % confidence intervals (dotted lines). The prediction line is based on a constant negative contribution of the effect of "other cover" at the mean level of 8.7 % other cover.

3.2 Growth

For growth of pine there were 3 candidate models with equally low AIC ($\Delta AIC \leq 2$), and thus the most parsimonious model was chosen as final model for pine seedling density (see table 8). The final model included the variables: mineral soil, humus, age of tree seedling and an interaction variable between age of tree seedling and proportion mineral soil. Plot nested within sampling point nested within stand ID was included as random intercept in the final model, see table 9.

Table 8: Results from model selection on growth of pine seedlings measured as a log (ln) transformed version of the response variable length of top shoot. Candidate models were fitted as LMMs with normal error distribution. Plot nested within sampling point nested within stand ID as random intercept was chosen as optimal random structure, and was included in the candidate models. Table shows the five models with lowest AIC from 49 candidate models. Model parameters are presented with corresponding degrees of freedom, AIC value, delta-AIC and AIC weights. Models are ranked from lowest to highest AIC, and the models that have ΔAIC ≤ 2 are considered to be equally good. Final model is highlighted in bold.

Length of pine top shoot	Df	AIC	ΔAIC	Weight
mineral + humus + year + year×humus + age + age×mineral	21	5749.55	0.00	0.42
mineral + humus + year + age + age×mineral	16	5751.40	1.85	0.17
mineral + humus + age + age×mineral	**15**	**5751.42**	**1.87**	**0.17**
mineral + humus + age + age×mineral + year + year×mineral	24	5754.61	5.06	0.03
mineral + age + year + age×mineral	15	5754.81	5.26	<0.01

This model predicts a negative exponential relationship between both proportion exposed mineral soil and proportion exposed humus with length of top shoot. In addition it predicts an interaction effect between the age of the tree seedling and proportion exposed mineral soil, where the youngest age classes contribute to an even stronger negative effect, and the oldest age classes (age 4-5) contribute to a weaker negative effect of proportion exposed mineral soil, (see table 9 and figure 3). However, it should be noted that the standard errors of these interaction effects were larger than the estimates for seedling ages 3, 4 and 5. Proportion of exposed humus had a negative correlation with length of pine top shoot, (figure 4). The model predicts no interaction effect between age of pine seedling and proportion of exposed humus.

Table 9: Shows final model parameters with corresponding estimates, standard errors, t-statistics and p-values for pine seedling growth fitted as a LMM with normal error distribution. The response variable, length of top shoot, was log transformed using ln transformation. Plot nested within sampling point nested within stand ID was included as random intercept. An R^2 that takes into account the random intercept is presented as an indication of explained deviance.

Parameter	Estimate	SE	t	*p*-value
intercept	0.6305	0.0507	12.43	0.000
mineral soil	-0.0040	0.0012	-3.46	0.006
humus	-0.0023	0.0010	-2.42	0.016
age 2	0.0454	0.0517	0.88	0.380
age 3	0.9295	0.0547	16.99	0.000
age 4	1.4407	0.0659	21.88	0.000
age 5	1.7565	0.1505	11.67	0.000
age 2 × mineral soil	-0.0041	0.0014	-2.94	0.003
age 3 × mineral soil	-0.0006	0.0015	-0.42	0.674
age 4 × mineral soil	0.0006	0.0019	0.30	0.762
age 5 × mineral soil	0.0013	0.0043	0.31	0.755
Variance of random intercept:	Stand ID	0.0225		R^2: 0.56
	Point	0.0394		
	Plot	0.0699		

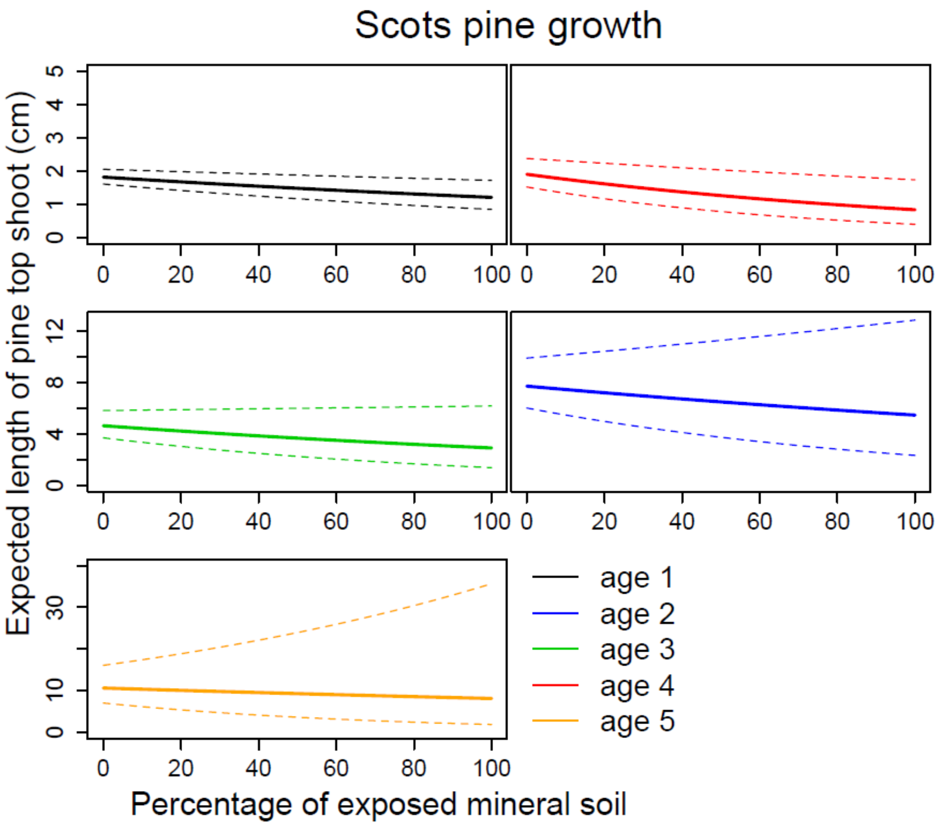

Figure 3: Predicted lines for length of top shoot of pine at different age classes with increasing proportion of exposed mineral soil. The dotted lines indicate the 95 % confidence interval. The predicted lines are based on a constant negative contribution of the effect of “other cover” at the mean level of 8.7 % other cover. The effect of proportion of exposed humus was also included in the predicted lines and was held constant at the mean value of 11 % humus cover. Note the different scale on the Y-axis between age classes 1-2, 3-4 and 5

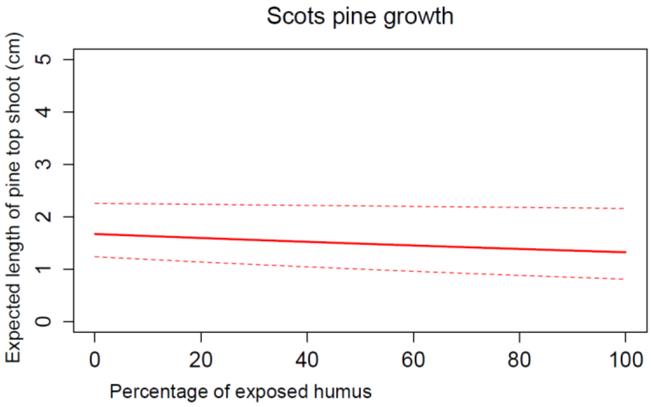

Figure 4: Predicted line for length of top shoot of pine at age = 2 with increasing proportions of exposed humus. The dotted lines indicate the 95 % confidence interval. The predicted line is based on a constant negative contribution of the effect of “other cover” at the mean level of 8.7 % other cover. The effect of proportion of exposed mineral soil was also included in the predicted line and was kept constant at the mean value of 20 % mineral soil.

For length of the top shoot of downy birch there were two models with equally low AIC. These models only differed by the presence or absence of the variable “other cover”. I chose the model with the fewest parameters. This model included the explanatory variables mineral soil, humus, year of scarification, age of tree seedling, the interaction between age of tree seedling and exposed mineral soil and the interaction between age of tree seedling and exposed humus, (see table 10). Plot nested within sampling point nested within stand ID was included as random intercept in the final model, (see table 11).

Table 10: Results from model selection on growth of downy birch seedlings measured as a log (ln) transformed version of the response variable length of top shoot. Candidate models were fitted as LMMs with normal error distribution. Plot nested within sampling point nested within stand ID as random intercept was chosen as optimal random structure, and was included in the candidate models. Table shows the five models with lowest AIC from 39 candidate models. Model parameters are presented with corresponding degrees of freedom, AIC value, delta-AIC and AIC weights. Models are ranked from lowest to highest AIC, and the models that have ΔAIC ≤ 2 are considered to be equally good. Final model is highlighted in bold.

Length of downy birch top shoot	Df	AIC	ΔAIC	Weight
mineral + humus + year + age + age×mineral + age×humus	**19**	**11183.78**	**0.00**	**0.58**
mineral + humus + other + year + age + age×mineral + age×humus	20	11185.00	1.22	0.31
mineral + humus + other + year + prod + age + age×mineral + age×humus	22	11188.55	4.77	0.05
mineral + humus + other + year + site.prod + age + age×mineral + age×humus + year×mineral + year×humus + site.prod×mineral	24	11190.31	6.53	0.02
mineral + humus + year + age + age×mineral + age×humus + year×mineral + year×humus	25	11191.59	7.81	0.01

As for pine, proportion exposed mineral soil and proportion exposed humus had a negative exponential correlation with length of downy birch top shoot. The negative correlation seemed more apparent for seedlings of age 1-2 for both mineral soil and humus. For older tree seedlings there were more variation as predicted lines indicated both possibilities for a positive or a negative correlation between growth and scarification intensity, (see figure 5 and 6). For both the interaction effect between age and exposed mineral soil and between age and humus estimates are positive when seedling age is > 2. For proportion of exposed humus, these estimates are large enough to predict a positive correlation with length of downy birch top shoot, (see table 11 and figure 6). Time since scarification affected growth of downy birch positively, as can be seen from increasingly more negative estimates of the most recently treated stands.

Table 11: Shows final model parameters with corresponding estimates, standard errors, t-statistics and p-values for downy birch seedling growth fitted as a LMM with normal error distribution. The response variable, length of top shoot, was log transformed using ln transformation. Plot nested within sampling point nested within stand ID was included as random intercept. An R^2 that takes into account the random intercept is presented as an indication of explained deviance.

Parameter	Estimate	SE	Df	t	*p*-value
intercept	0.4037	0.1512	5858	2.67	0.008
mineral soil	-0.0037	0.0015	732	-2.53	0.012
humus	-0.0015	0.0016	732	-0.97	0.334
year 2012	-0.0496	0.1525	60	-0.33	0.746
year 2013	-0.3999	0.1635	299	-2.45	0.015
year 2014	-0.3641	0.2006	299	-1.81	0.071
age 2	1.2256	0.0463	5858	26.50	0.000
age 3	1.8519	0.0482	5858	38.43	0.000
age 4	2.3295	0.0578	5858	40.32	0.000
mineral soil × age 2	-0.0050	0.0017	5858	-3.01	0.003
mineral soil × age 3	0.0009	0.0018	5858	0.49	0.623
mineral soil × age 4	0.0019	0.0022	5858	0.90	0.369
humus × age2	-0.0025	0.0016	5858	-1.58	0.115
humus × age3	0.0066	0.0020	5858	3.34	0.001
humus × age4	0.0073	0.0028	5858	2.63	0.009
Variance of random intercept:	Stand ID	0.05			R^2: 0.84
	Point	0.08			
	Plot	0.20			

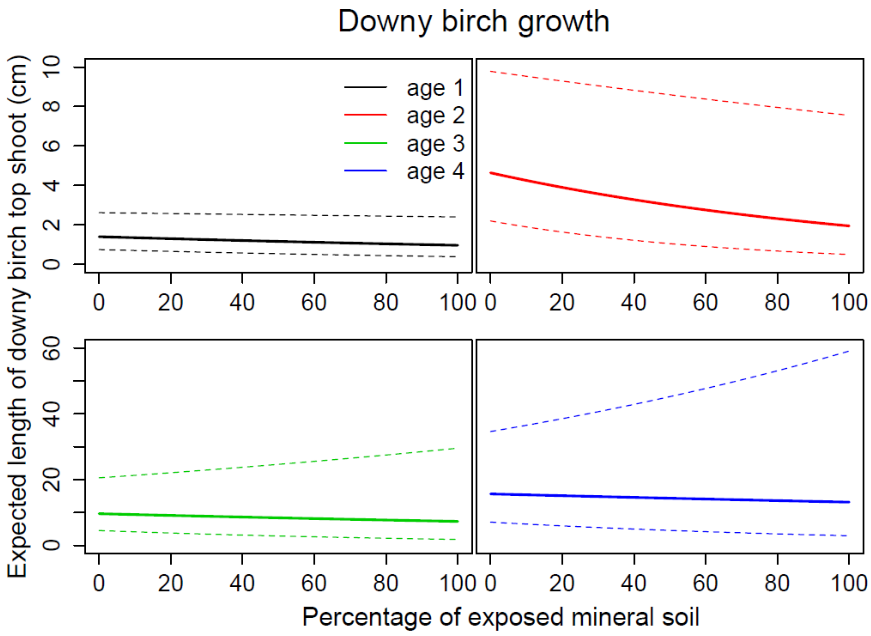

Figure 5: Predicted lines for length of top shoot at different age classes with increasing proportions of mineral soil. The dotted lines indicate the 95 % confidence interval. The predicted lines are based on a constant negative contribution of the effect of "other cover" at the mean level of 8.7 % other cover. The effect of humus cover was also included in the predicted lines and was held constant at the mean value of 11 % humus cover. Note the different scale on the Y-axix between age classes 1-2 and 3-4.

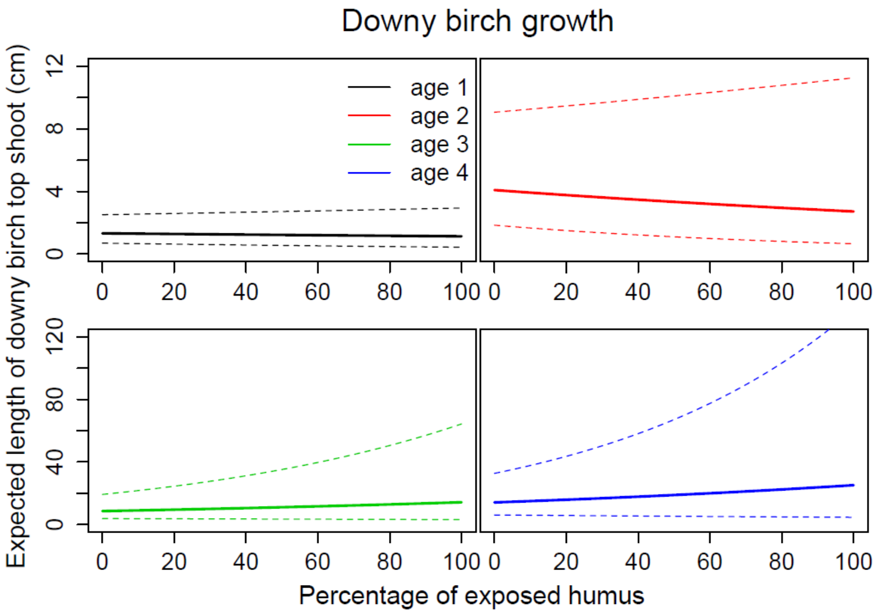

Figure 6: Predicted lines for length of top shoot at different age classes with increasing proportions of humus cover. The dotted lines indicate the 95 % confidence interval. The predicted lines are based on a constant negative contribution of the effect of "other cover" at the mean level of 8.7 % other cover. The effect of mineral soil was also included in the predicted lines and was held constant at the mean value of 20 % humus cover. Note the different scale on the Y-axix between age classes 1-2 and 3-4.

For silver birch there were two candidate models with equally low AIC, (see table 12). Model selection using AIC provided little support for intensity of soil scarification having any effect on growth of silver birch, as a model containing only year of scarification and age of tree seedling had equally low AIC with the second best candidate model that also included proportion of exposed humus as explanatory variable, and lower AIC than candidate models that included proportion of exposed mineral soil. In the final model selected for growth of silver birch, both explanatory variables time since scarification and age of seedling had positive correlations with length of silver birch top shoot, (see table 13).

Table 12: Results from model selection on growth of silver birch seedlings measured as a log (ln) transformed version of the response variable length of top shoot. Candidate models were fitted as LMMs with normal error distribution. Plot nested within sampling point nested within stand ID as random intercept was chosen as optimal random structure, and was included in the candidate models. Table shows the five models with lowest AIC from 39 candidate models. Model parameters are presented with corresponding degrees of freedom, AIC value, delta-AIC and AIC weights. Models are ranked from lowest to highest AIC, and the models that have ΔAIC ≤ 2 are considered to be equally good. Final model is highlighted in bold.

Length of silver birch top shoot	Df	AIC	ΔAIC	Weight
year + age	**10**	**1236.54**	**0.00**	**0.32**
humus + other + year + site.prod + age + age×humus	17	1238.45	1.91	0.12
mineral + humus + other + year + site.prod + age	15	1238.79	2.24	0.10
mineral + humus + year + age + age×humus	15	1239.56	3.01	0.07
mineral + humus + other + year + age + age×mineral	16	1239.61	3.06	0.07

Table 13: Shows final model parameters with corresponding estimates, standard errors, t-statistics and p-values for silver birch seedling growth fitted as a LMM with normal error distribution. The response variable, length of top shoot, was log transformed using ln transformation. Plot nested within sampling point nested within stand ID was included as random intercept. An R^2 that takes into account the random intercept is presented as an indication of explained deviance.

Parameter	Estimate	SE	Df	t	*p*-value
Intercept	0.3958	0.2478	340	1.60	0.111
year 2012	0.5454	0.1843	33	2.96	0.006
year 2013	0.1231	0.2486	33	0.50	0.624
age 2	1.1182	0.1879	340	5.95	0.000
age 3	1.8789	0.1865	340	10.07	0.000
age 4	2.1175	0.1945	340	10.89	0.000
Variance of random intercept:	Stand ID	0.03			R^2: 0.52
	Point	0.14			
	Plot	0.08			

3.3 Secondary results

Among the measured tree observations 98 % was either Scots pine or birch spp., see appendix A for a list over distribution of all counted tree seedlings according to species. The age distribution of tree seedlings, (see table 14) reveals a decreasing proportion of 1-year-olds in the stand with increasing time since scarification. Most of the pine seedlings established in mineral soil, and most birch seedlings established in either mineral soil or intact vegetation, (see figure 7). Average stand height for pine in the oldest treatments (scarified in 2011) was 10.4 cm (SD = 9.0). For birch there were very few observations in the 2011 treatments, but in stands scarified in 2012 average stand height was 15.4 cm (SD = 12.9) for downy birch and 29.3 cm (SD = 19.7) for silver birch. Browsing from cervids only occurred on 3 % of all tree observations. The browsed trees were mainly deciduous, only 0.5 % of the total number of browsed trees was Scots pine.

Table 14: Number of observations according to age for Scots pine, downy birch and silver birch, and year of the scarification treatment. Only observations with age younger than time since soil scarification treatment are presented in this table, as these observations constituted the dataset included in the statistical analyses. The observations in italics were removed prior to analyses due to too few data points in the particular categorical level to carry out analyses. Note that the stands, and by consequence also the age of the observations, were unevenly distributed across treatment years, with most stands being scarified in 2012.

	Age 1	**Age 2**	**Age 3**	**Age 4**	**Age 5**
Scots pine					
2011	64	344	362	255	41
2012	254	416	299	131	
2013	182	211	109		
2014	85	50			
Total	**585**	**1022**	**770**	**386**	**41**
Downy birch.					
2011	0	42	15	7	*2*
2012	512	1425	1840	465	
2013	1874	421	200		
2014	105	58			
Total	**2491**	**1946**	**2055**	**472**	**2**
Silver birch					
2011	1	42	23	8	*1*
2012	13	110	215	106	
2013	2	26	25		
2014	*1*	*0*			
Total	**17**	**179**	**263**	**114**	**1**

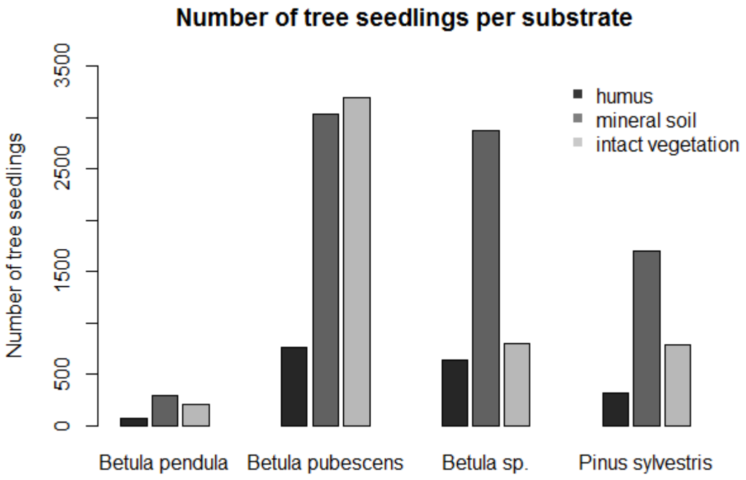

Figure 7: Frequencies of observations of birch and pine in each measured substrate.

4. Discussion

4.1 Seedling density

The positive correlation between soil scarification intensity and pine seedling density found in this study was consistent with another study using other methods of soil scarification intensity (Aleksandrowicz-Trzcinska *et al.* 2014). I also found a positive correlation between seedling density and time since soil scarification treatment, as can be expected as more seeds have had time to spread naturally from seed trees and nearby forest. At the same time recruitment of 1-year-olds are decreasing with time since scarification as can be seen from a proportionally small number of 1-year-olds for the older classes of scarification treatment, see table 4. The decreasing recruitment with time since scarification could be explained by patches of mineral soil being more compact and overgrown with vegetation with over time (Karlsson & Örlander 2000). Proportion of trees with ages 4-5 were also comparatively small, which likely reflect the low sample size in year of scarification class 2011 both early and late in the growing season of 2011.

Considering birch spp. seedling density, the relationship with soil scarification intensity was less clear. The final model predicted a positive correlation, but with much variation between stands and study area sites, implying there might as well be no correlation between birch density and scarification intensity. Compared to the model for pine seedling density, little of the residual deviance was explained, which indicates a poor fit of the model to the data. This might be due to somewhat different responses in establishment of the different birch species to scarification intensity, (figure 7). Still, modelling downy birch, silver birch and young unspecified birch spp. separately resulted in no valid models, probably due to other factors such as humidity or nutrient availability, that we did not measure playing a larger role for birch seedling establishment.

There was a considerable variation between stands in density of both pine and birch spp. seedlings. This variation might be mostly related to moisture conditions such as soil retention, evaporation and climatic factors, as several studies point on moisture condition as an essential factor explaining seedling germination (Oleskog & Sahlén 2000a; Oleskog & Sahlén 2000b; Chantal *et al.* 2003). Other factors causing variation in tree seedling establishment could be occurrences of good seed years (Karlsson & Örlander 2000), timing of scarification treatment (Hörnfeldt, Hu & Chiriacò 2012), yearly variation in climatic factors (Sarvas 1962), spatial variation in climatic factors (Tegelmark 1998), or density of seed trees or distance to forest edge. However the relevance of distance to seed trees have been found to be negligible for the establishment of pine seedlings (Kuuluvainen & Pukkala 1989; Karlsson & Örlander 2000), and studies show that pine seeds from nearby stands also contribute to the natural regeneration in clear-felled stands (Yazdani & Lindgren 1992; Ackzell 1994). Based on my data, I can not pinpoint any seed year, but if a good seed fall occurred in 2014, this could have failed to produce a high yield of seedlings due to an unusually warm and dry summer.

The average proportion of “other” cover in stands in the study area was 8.7 %. Other cover, being my measure of unsuited habitat for tree seedling germination, was as expected negatively correlated with pine seedling density. The final model for birch spp. seedling density however, predicted a positive correlation with other cover, which might seem odd at first glance considering that this variable was included to account for unsuitable germination habitat. However, as other cover often referred to water bodies or bogs, the positive correlation was likely due to a positive response to the soil moisture in areas related to bogs and water. Downy birch, which accounted for the majority of the birch counts, typically grow in very moist soil (Kinnaird 1974; Paavilainen & Päivänen 1995), as implied by my data.

Considering my measures of soil scarification intensity, only proportion of exposed mineral soil and not humus, was an important factor describing pine and birch seedling density. Seedling of birch spp. and pine were also more often established in exposed mineral soil than in exposed humus, see figure 7. This was consistent with other studies that have found mineral soil to be the most optimal seed bed for germination (Béland *et al.* 2000; Oleskog & Sahlén 2000a; Oleskog & Sahlén 2000b).

4.2 Growth

Early growth of pine seedlings showed a negative correlation with intensity of soil scarification, although variation in growth response was larger for pine seedling with age 3-5, as indicated by larger confidence intervals. The larger variation in length of top shoot for pine seedlings with an age of > 2 was consistent with observation from the field. For downy birch there was an even larger variation in length of top shoot, which might reflect real differences in variation in the length of top shoot between birch and pine, but also it might be a result of misjudgement of age based on counting growth nodes, which proved to be more challenging for birch compared to pine. This is related to the different growth forms of pine and birch (Kozlowski & Clausen 1966). While pine has a predetermined growth with an apical leader (Kozlowski 1964) and distinguishable shoot-whorls, individual birches may display more variation in growth form. Annual growth nodes in deciduous trees may be hard to distinguish from other shifts in growth or colour that do not represent annual growth.

Growth of downy birch seedlings was also negatively correlated with soil scarification intensity measured. The exception was when scarification intensity was measured as proportion of exposed humus, and age of seedlings was > 2 years. The negative correlation between growth of pine and downy birch and higher proportions of exposed mineral soil and exposed humus might be due to the time it takes to develop roots that are long enough to ensure stable contact with nutrients and stable moisture conditions in the soil. Poor moisture conditions may limit growth of roots (Morris *et al.* 2006). Young seedling may experience stress due to poor root connection with water, similar to stress that are reported for newly planted seedlings (Grossnickle 2005). Such stress of newly planted seedlings is shown to limit early growth (Kozlowski & Davies 1975). Downy birch, which grows faster than pine may develop roots that are long enough to access nutrients and stable moisture conditions at an earlier age than pine. It is also possible that exposed humus provided better growth conditions for birch compared to exposed mineral soil. This relationship is described well by Karlsson (1996), who addressed that birch grows best when there is a thin layer of humus on top of the mineral soil. This correlation was explained by the enhanced access of organic matter to the roots. In the study by Karlsson, growth was modest for birch seedlings with age 1. The growth response to soil tillage was better when age was 2-3, and this was explained by longer roots that could reach more nutrient rich soil layers. The relevance of organic matter for growth of birch is supported by Perala & Alm (1989), while another study states that while mineral soil is the best seedbed for birch germination, organic soils are more important for growth of birch (Marquis 1969).

A commonly known risk of soil scarification is erosion, and hence scarification is typically avoided in steep and rugged landscape (Nygaard 2001). Nutrient leaching caused by soil erosion may affect growth. Downy birch typically grows on nutrient rich soils, while pine tolerates to grow in rather nutrient poor conditions (Paavilainen & Päivänen 1995). However availability of nitrogen can be a limiting factor for boreal trees (Odland 1994; Bergh *et al.* 1999). The importance of nutrient availability is indicated by studies that report higher growth of seedlings established in scarified patches with burnt litter and humus on top (Bjorkbom 1972; Hille & Den Ouden 2004; MacKenzie, Schmidt & Bedford 2005).

Changes in nutrient availability, and reduction of nitrogen and carbon are shown to follow disturbances from clear felling (Olsson *et al.* 1996). Mechanical soil preparation is also shown to increase nutrient leaching (Örlander, Egnell & Albrektson 1996; Kubin 1998; Piirainen *et al.* 2007). Still, most studies report a positive long term effect on growth (Örlander, Egnell & Albrektson 1996; Nilsson & Allen 2003) and similarly no reduction in site fertility (MacKenzie, Schmidt & Bedford 2005). In our study area the mineral soil consisted of much stone and gravel which might promote more nutrient leaching.

For silver birch other factors than soil scarification intensity seemed to play a bigger role, as neither proportion exposed mineral soil or proportion exposed humus were shown to explain growth. Possibly nutrient availability is a more important factor, as silver birch is known to establish in soils rich on lime (Odland 1994).

Even though there is a vast support in literature for mechanical site preparation having a positive effect on early growth of Scots pine (Karlsson & Örlander 2000; Hille & Den Ouden 2004; Johansson, Ring & Hogbom 2013), and this correlation is also described for other types of pine (Bedford & Sutton 2000), a high intensity of soil scarification may have undesired effects on growth, as implied by my results. However, it might be that this negative effect only applies for very young tree seedlings, as growth response of birch differ for the oldest seedlings in this study. As growth continues and roots reach further into the soil, the effect of high intensity of soil scarification growth might show a different trend.

Site productivity index was not an important factor for neither seedling density or growth when included as all 3 represented levels: F8, F11, F14/F17, nor was it important when these indexes were grouped into 2 levels representing high and low site productivity index. It might be possible that the site productivity variable included in this study was somewhat crude as indexes were retrieved from forestry plans and might not be up to date. Also, the site productivity classes used in this study reflect growth of pine rather than growth of birch.

4.3 Management implications

In this study I have evaluated effects of intensity of soil scarification on both seedling density and growth of Scots pine and two species of birch. I found evidence for an exponential positive correlation between proportion of exposed mineral soil and density of young pine seedlings. The predicted densities of pine from this study had substantial variation between stands, but were estimated as 10 991 per hectare and 24 930 per hectare on low and high scarification intensity respectively.

This study did not focus on effects of intensity of soil scarification on tree species diversity or browsing. This was due to the pine stands being very young and there were not a sufficient amount of data to evaluate either of these aspects. Among the measured tree observations 98 % was either Scots pine or birch spp., and only 3 % of all tree observations were browsed by cervids. The browsed trees were mainly deciduous. Browsing from cervids in these pine stands will likely increase when the mean height of the stands increases further with time. There is currently little focus in literature on the effect of site preparation on tree species diversity, and the effect of tree species diversity on moose browsing is reported to be ambiguous. Both positive (Lavsund 2003) and negative effects (Härkönen, Miina & Saksa 2008) of tree species diversity on browsing damage levels have been reported, and the effect might be a matter of scale.

Possible negative aspects of soil scarification are important to keep in mind when talking about using higher intensity methods, as negative effects might be amplified by the increased intensity. Such negative effects might be related to soil erosion as pointed out earlier in the text, but also the aesthetics of the landscape near populated areas or popular hiking routes needs to be considered, as high intensity of scarification might be perceived as a larger intervention in nature compared to low intensity of soil scarification. The effect on other flora and fauna also needs to be taken into consideration. A master thesis from 2014 (Knudsen) has been focusing on the effects of intensity of soil scarification on bilberry cover in clear-cut pine stands. Conclusions from this thesis were that high intensity of soil scarification could work detrimentally as it negatively affects bilberry abundance. Bilberry is another important food source for moose, but it is also an important an important part of the diet for many different animals. It has also been suggested that facilitating bilberry may enhance wildlife diversity (Parlane *et al.* 2006). Another aspect that should be mentioned is the environmental impact. Disturbance of the soil from mechanical site preparation may release CO_2 that have accumulated in the soil into the atmosphere (Conen *et al.* 2004), and in that way contribute to increased emissions of greenhouse gasses.

4.4 Conclusions

In pine stands with high risk of moose browsing during wintertime, it is recommended to establish a higher density of trees in order to ensure a sufficient density of trees undamaged by moose (Øyen 2002). This study shows that high densities of Scots pine seedlings in naturally regenerated pine stands can be achieved by intensifying soil scarification by exposing a larger proportion of the mineral soil per clear cut area (40 %) compared to the standard procedure where 15 – 20 % mineral soil is exposed. Results from this study also indicate a negative effect from soil scarification intensity on growth during the youngest ages for both Scots pine and downy birch seedlings. An evaluation of long term effects on seedling growth is needed in order to see if this trend changes with increasing age. Bilberry vegetation produces much preferred moose forage and may act as a release for browsing damage on pine stems. Hence negative effects of intense soil scarification on bilberry cover should be taken into account. In rugged and steep landscape, erosion of soil minerals is more likely when using soil scarification and hence extra caution should be taken when using high intensity soil scarification.

Future research should focus on long term effects of high soil scarification intensity on seedling density, growth and survival of pine and birch seedlings. Particularly, this study address the need for further knowledge on effect of high intensity of soil scarification on early and long term growth, also on higher site productivities than were used in this study. As stands reach a higher mean height in a few years, it will also be possible to directly assess the effect of intensity of soil scarification on moose browsing distribution. In addition it might be possible in more mature stands to look at the effect of intensity of soil scarification on tree species diversity, as occurrence of other tree species is shown to influence moose browsing distribution.

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References

Ackzell, L. (1994) Natural regeneration on planted clear-cuts in boreal Sweden. *Scandinavian Journal of Forest Research,* **9,** 245-250.

Aleksandrowicz-Trzcinska, M., Drozdowski, S., Brzeziecki, B., Rutkowska, P. & Jablonska, B. (2014) Effects of different methods of site preparation on natural regeneration of Pinus sylvestris in Eastern Poland. *Dendrobiology,* **71**.

Andren, H. & Angelstam, P. (1993) Moose browsing on Scots pine in relation to stand size and distance to forest edge. *Journal of Applied Ecology,* **30,** 133-142.

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

Bedford, L. & Sutton, R. (2000) Site preparation for establishing lodgepole pine in the sub-boreal spruce zone of interior British Columbia: the Bednesti trial, 10-year results. *Forest Ecology and Management,* **126,** 227-238.

Béland, M., Agestam, E., Ekö, P., Gemmel, P. & Nilsson, U. (2000) Scarification and seedfall affects natural regeneration of Scots pine under two shelterwood densities and a clear-cut in southern Sweden. *Scandinavian Journal of Forest Research,* **15,** 247-255.

Bergh, J., Linder, S., Lundmark, T. & Elfving, B. (1999) The effect of water and nutrient availability on the productivity of Norway spruce in northern and southern Sweden. *Forest Ecology and Management,* **119,** 51-62.

Bergqvist, G., Bergström, R. & Edenius, L. (2003) Effects of moose (Alces alces) rebrowsing on damage development in young stands of Scots pine (Pinus sylvestris). *Forest Ecology and Management,* **176,** 397-403.

Bergstrom, R. (1984) Rebrowsing on birch (Betula pendula and B. pubescens) stems by moose. *Alces,* **19,** 3-13.

Bergström, R. & Hjeljord, O. (1987) Moose and vegetation interactions in northwestern Europe and Poland. *Swedish Wildlife Research (Sweden)*.

Bjorkbom, J.C. (1972) Stand changes in the first 10 years after seedbed preparation for paper birch. *U.S.D.A Forest Service Research Paper,* **NE-238,** 10.

Bryant, J.P., Chapin III, F.S. & Klein, D.R. (1983) Carbon/nutrient balance of boreal plants in relation to vertebrate herbivory. *Oikos,* **40,** 357-368.

Chantal, M.d., Leinonen, K., Ilvesniemi, H. & Westman, C.J. (2003) Combined effects of site preparation, soil properties, and sowing date on the establishment of Pinus sylvestris and Picea abies from seeds. *Canadian journal of forest research,* **33,** 931-945.

Conen, F., Zerva, A., Arrouays, D., Jolivet, C., Jarvis, P.G., Grace, J. & Mencuccini, M. (2004) The carbon balance of forest soils: detectability of changes in soil carbon stocks in temperate and boreal forests. *The carbon balance of forest biomes,* **9,** 233-247.

eKlima (2016) Climate data. Norwegian Meteorological Institute, Norwegian Meteorological Institute.

González-Martínez, S.C. & Bravo, F. (2001) Density and population structure of the natural regeneration of Scots pine (Pinus sylvestris L.) in the High Ebro Basin (Northern Spain). *Annals of Forest Science,* **58,** 277-288.

Grossnickle, S.C. (2005) Importance of root growth in overcoming planting stress. *New Forests,* **30,** 273-294.

Gundersen, H., Andreassen, H.P. & Storaas, T. (2004) Supplemental feeding of migratory moose Alces alces: forest damage at two spatial scales. *Wildlife Biology,* **10,** 213-223.

Haug, F., Haget, D., Hekne, A. M., & Hegg, B. R. (2014) Elgbeite på gran: Taksering i Stange og Våler kommuner 2013. Fylkesmannen i Hedmark, landbruksavdelingen.

Heikkila, R. & Harkonen, S. (2000) Thinning residues as a source of browse for moose in managed forests in Finland. *Alces,* **36,** 85-92.

Heikkilä, R. (1991) Moose browsing in a Scots pine plantation mixed with deciduous tree species. *Acta Forestalia Fennica,* **224**.

Heikkilä, R. & Härkönen, S. (1996) Moose browsing in young Scots pine stands in relation to forest management. *Forest Ecology and Management,* **88,** 179-186.

Hille, M. & Den Ouden, J. (2004) Improved recruitment and early growth of Scots pine (Pinus sylvestris L.) seedlings after fire and soil scarification. *European Journal of Forest Research,* **123,** 213-218.

Hytönen, J. (1992) Allelopathic potential of peatland plant species on germination and early seedling growth of Scots pine, silver birch and downy birch. *Silva Fennica,* **26,** 63-73.

Härkönen, S., Miina, J. & Saksa, T. (2008) Effect of cleaning methods in mixed pine–deciduous stands on moose damage to Scots pines in southern Finland. *Scandinavian Journal of Forest Research,* **23,** 491-500.

Hörnfeldt, R., Hu, B. & Chiriacò, M.V. (2012) Optimum timing of soil scarification for the natural regeneration of Pinus sylvestris in Central Sweden. *Scandinavian Journal of Forest Research,* **27,** 424-431.

Johansson, K., Ring, E. & Hogbom, L. (2013) Effects of pre-harvest fertilization and subsequent soil scarification on the growth of planted Pinus Sylvestris seedlings and ground vegetation after clear-felling. *Silva Fennica,* **47,** 18.

Karlsson, A. (1996) *Site preparation of abandoned fields and early establishment of naturally and direct-seeded birch in Sweden no. 199*.

Karlsson, A., Albrektson, A., Forsgren, A. & Svensson, L. (1998) An analysis of successful natural regeneration of downy and silver birch on abandoned farmland in Sweden. *Silva Fennica,* **32,** 229-240.

Karlsson, C. & Örlander, G. (2000) Soil scarification shortly before a rich seed fall improves seedling establishment in seed tree stands of Pinus sylvestris. *Scandinavian Journal of Forest Research,* **15,** 256-266.

Kinnaird, J. (1974) Effect of site conditions on the regeneration of birch (Betula pendula Roth and B. pubescens Ehrh.). *The Journal of Ecology,* **62,** 467-472.

Knudsen, M.F. (2014) Effects of different scarification intensities on bilberry abundance. Master in Applied Ecology, Hedmark University College

Kozlowski, T.T. (1964) Shoot growth in woody plants. *The Botanical review,* **30,** 335-392.

Kozlowski, T.T. & Clausen, J.J. (1966) Shoot growth characteristics of heterophyllous woody plants. *Canandian Journal of Botany,* **44,** 827-843.

Kozlowski, T.T. & Davies, W. (1975) Control of water balance in transplanting trees. *Journal of Arboriculture,* **1,** 1-10.

Kubin, E. (1998) Leaching of nitrate nitrogen into the groundwater after clear felling and site preparation. *Boreal Environment Research,* **3,** 3-8.

Kubin, E. & Kemppainen, L. (1994) Effect of soil preparation of boreal spruce forest on air and soil temperature conditions in forest regeneration areas. *Acta Forestalia Fennica,* **244**.

Kuuluvainen, T. & Pukkala, T. (1989) Effect of Scots pine seed trees on the density of ground vegetation and tree seedlings. *Silva Fennica,* **23,** 159-167.

Lavsund, S. (2003) Skogsskötsel och älgskador i tallungskog. *Skogforsk, resultat no. 6,* pp. 1-4.

Lavsund, S., Nygrén, T. & Solberg, E.J. (2003) Status of moose populations and challenges to moose management in Fennoscandia. *Alces,* **39,** 109-130.

Lyly, O. & Saksa, T. (1992) The effect of stand density on moose damage in young Pinus sylvestris stands. *Scandinavian Journal of Forest Research,* **7,** 393-403.

Löf, M., Dey, D.C., Navarro, R.M. & Jacobs, D.F. (2012) Mechanical site preparation for forest restoration. *New Forests,* **43,** 825-848.

Löyttyniemi, K. (1985) On repeated browsing of Scots pine saplings by moose (Alces alces).

MacKenzie, M., Schmidt, M. & Bedford, L. (2005) Soil microclimate and nitrogen availability 10 years after mechanical site preparation in northern British Columbia. *Canadian journal of forest research,* **35,** 1854-1866.

Marquis, D.A. (1969) Silvical requirements for natural birch regeneration. *Birch Symposium of University of New Hampshire Durham NH 19-21 August 1969* (ed. Larson), pp. 40-49. USDA Forest Service Northeastern Forest Experiment Station.

Moen, A. (1998) *Vegetasjonsatlas for Norge: vegetasjon*. Statens kartvek, Hønefoss.

Morris, L., Ludovici, K., Torreano, S., Carter, E., Lincoln, M. & Will, R. (2006) An approach for using general soil physical condition–root growth relationships to predict seedling growth response to site preparation tillage in loblolly pine plantations. *Forest Ecology and Management,* **227,** 169-177.

Mäkitalo, K. (1999) Effect of site preparation and reforestation method on survival and height growth of Scots pine. *Scandinavian Journal of Forest Research,* **14,** 512-525.

Månsson, J., Bergström, R., Pehrson, Å., Skoglund, M. & Skarpe, C. (2010) Felled Scots pine (Pinus sylvestris) as supplemental forage for moose (Alces alces): Browse availability and utilization. *Scandinavian Journal of Forest Research,* **25,** 21-31.

Nilsson, M.-C. (1994) Separation of allelopathy and resource competition by the boreal dwarf shrub Empetrum hermaphroditum Hagerup. *Oecologia,* **98,** 1-7.

Nilsson, U. & Allen, H.L. (2003) Short-and long-term effects of site preparation, fertilization and vegetation control on growth and stand development of planted loblolly pine. *Forest Ecology and Management,* **175,** 367-377.

Nilsson, U. & Örlander, G. (1999) Vegetation management on grass-dominated clearcuts planted with Norway spruce in southern Sweden. *Canadian journal of forest research,* **29,** 1015-1026.

Nygaard, P. (2001) Rett tid for markberedning. *Aktuelt fra skogforskningen* (ed. S. Woxholtt).

Odland, A. (1994) Bjørkeartenes spredning, etablering og samspill med naturmiljøet. *Nina oppdragsmelding 292*. Norsk institutt for naturforskning

Oleskog, G. & Sahlén, K. (2000a) Effects of seedbed substrate on moisture conditions and germination of Pinus sylvestris seeds in a clearcut. *Scandinavian Journal of Forest Research,* **15,** 225-236.

Oleskog, G. & Sahlén, K. (2000b) Effects of seedbed substrate on moisture conditions and germination of Scots pine (Pinus sylvestris) seeds in a mixed conifer stand. *New Forests,* **20,** 119-133.

Olsson, B.A., Staaf, H., Lundkvist, H., Bengtsson, J. & Kaj, R. (1996) Carbon and nitrogen in coniferous forest soils after clear-felling and harvests of different intensity. *Forest Ecology and Management,* **82,** 19-32.

Paavilainen, E. & Päivänen, J. (1995) *Peatland forestry: ecology and principles*. Springer Science & Business Media.

Parlane, S., Summers, R., Cowie, N. & Van Gardingen, P. (2006) Management proposals for bilberry in Scots pine woodland. *Forest Ecology and Management*, **222,** 272-278.

Perala, D.A. & Alm, A.A. (1989) Regenerating paper birch in the Lake States with the shelterwood method. *Northern Journal of Applied Forestry*, **6,** 151-153.

Piirainen, S., Finér, L., Mannerkoski, H. & Starr, M. (2007) Carbon, nitrogen and phosphorus leaching after site preparation at a boreal forest clear-cut area. *Forest Ecology and Management*, **243,** 10-18.

Pinheiro, J., Bates, D., DebRoy , S., Sarkar, D. & R Core Team (2015) nlme: Linear and Nonlinear Mixed Effects Models. R package version 3.1-121. http://CRAN.R-project.org/package=nlme.

R Core Team (2015) R: A language and environment for statistical computing. (ed. R.C. Team). R Foundation for Statistical Computing, Vienna, Austria.

Sarvas, R. (1962) Investigations on the flowering and seed crop of Pinus silvestris. *Metsatieteellisen tutkimuslaitoksen julkaisuja*, **53,** 198.

Siipilehto, J. & Heikkilä, R. (2005) The effect of moose browsing on the height structure of Scots pine saplings in a mixed stand. *Forest Ecology and Management*, **205,** 117-126.

Skogsstyrelsen, Karlsson, C., Sikström, U., Orlander, G., Hannerz, M. & Hånell, B. (2009) Naturlig föryngring av tall och gran [Natural regeneration of Scots pine and Norway spruce]. *Skogsskötselserien*.

Solbraa, K. (2008) Elg i Atndal og naboområder: forvaltning av elg og skog. *Høgskolen i Hedmark Oppdragsrapport*.

Statistics Norway (2016) Klassifisering av produktivt skogareal etter bonitet (H40) 1977. Statistics Norway (Statistisk sentralbyrå).

Sæther, B.-E., Solbraa, K., Sødal, D.P. & Hjeljord, O. (1992) Sluttrapport elg-skog-samfunn. *NINA forskningsrapport*, pp. 1-153.

Tegelmark, D. (1998) Site factors as multivariate predictors of the success of natural regeneration in Scots pine forests. *Forest Ecology and Management*, **109,** 231-239.

Wallgren, M., Bergström, R., Bergqvist, G. & Olsson, M. (2013) Spatial distribution of browsing and tree damage by moose in young pine forests, with implications for the forest industry. *Forest Ecology and Management*, **305,** 229-238.

Yazdani, R. & Lindgren, D. (1992) Gene Dispersion after Natural Regeneration under a Widely-Spaced Seed-Tree Stand of Pinus sylvestris. *Silvae Genetica*, **41,** 1-5.

Zuur, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A. & Smith, G.M. (2009) *Mixed Effects Models and Extensions in Ecology with R*. Springer, New York, USA.

Örlander, G., Egnell, G. & Albrektson, A. (1996) Long-term effects of site preparation on growth in Scots pine. *Forest Ecology and Management*, **86,** 27-37.

Øyen, B.-H. (2002) Litt om markberedning i furuskog. *Aktuelt fra skogforskningen*, **3,** 47-49.

5. Appendix A: Distribution of observations across study area site and year of scarification treatment

Table A1: Distribution of total number of tree seedling observations from the data sampling according to site, year of scarification and species. Note that the distribution of scarification years differs between sites.

	Gravberget			Ljørdalen		Plassen			
Year Species	*2012*	*2013*	*2014*	*2013*	*2014*	*2011*	*2012*	*2013*	**Total**
Scots pine	1197	437	134	108	42	1041	76	49	**3084**
Downy birch	4484	2544	181	52	10	71	12	4	**7358**
Silver birch	503	77	1	0	2	78	4	1	**666**
Young unspecidied birch	2087	1399	398	74	45	250	12	47	**4312**
Norway spruce	71	50	0	12	27	8	1	1	**170**
Common juniper	1	0	0	0	0	0	0	0	**1**
Salix spp.	29	18	1	0	7	1	0	0	**56**
Aspen	1	15	0	0	0	0	0	0	**16**
Rowan	5	9	1	0	8	0	4	0	**27**
Total	**8378**	**4549**	**716**	**246**	**141**	**1449**	**109**	**102**	**15690**