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Master thesis

Effects of different scarification intensities on bilberry abundance

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Abstract

In the boreal forest bilberry (*Vaccinium myrtillus*) plays an important role for a large variety of insects, birds and mammals, and it is especially important for moose (*Alces alces)* in autumn and spring. Bilberry is commonly found in commercial forests in Norway, often in mature coniferous stands of Norwegian spruce (Picea abies) and Scots pine (Pinus sylvestris). Bilberry is therefore affected by modern forestry operations such as clear-cuts and scarification. Commercial forests in moose wintering-areas may experience severe damage to young Scots pine stands due to heavy moose browsing. As a suggested solution to this problem is high intensity scarification to increase the amount pine seedlings. I studied the effects of different scarification intensities on bilberry abundance. The scarification variables cover of mineral soil, turned humus and driving tracks showed a negative effect on bilberry at plot level. As I found no effect on a stand level, the large variation within stands, are not detected unless using a small scale. There were differences in bilberry cover and average height in stands scarified in different years. The reduction in bilberry cover, will lead to a decrease in available forage for moose, which could cause bigger browsing damages on Scots pine.

Keywords: Scarification; high intensity; bilberry; Vaccinium myrtilus; Moose; Alces alces

Sammendrag (Abstract in Norwegian)

I den boreale barskogen spiller blåbær (*Vaccinium myrtillus*) en viktig rolle for en rekke insekter, fugler og pattedyr, og den er spesielt viktig for elg (*Alces alces*) om høsten og våren. Blåbær finnes ofte i skogområder av kommersiell interesse i Norge, da ofte i eldre barskog dominert av gran (*Picea abies*) og furu (*Pinus sylvestris*). Blåbær blir derfor påvirket av skogbrukets aktiviteter som flatehogst og markberedning. I elgens vinterbeite områder kan furuforyngelse ha betydelige skader som følge av elgbeite. En foreslått løsning på denne problematikken er å utføre høy intensitets markberedning for å sikre høyt nok antall furuplanter. Jeg har sett på effekten av markberedning ved ulike intensiteter på dekningen av blåbær. Jeg fant at markberedningsvariablene blottlagt mineraljord, omvendt humus og kjørespor hadde en negativ effekt på blåbær på plot-nivå. Jeg fant ingen effekt av markberedning på bestandsnivå, som tyder på at det er stor variasjon i hvor mye som er markberedt i bestandene, og at dette oppdages kun ved å bruke en liten skala for måling av effekt. Det var forskjellig dekning- og gjennomsnitts høyde for blåbær for bestandene markberedt i ulike år. Reduksjonen i dekningen av blåbær, førte også til en reduksjon i tilgjengelig elgfór, noe som kan skape mer beiting på furu.

Nøkkelord: Markberedning; høy intensitet; blåbær; Vaccinium myrtilus; Elg; Alces alces;

Table of content

1. Introduction

In the boreal forest bilberry (*Vaccinium myrtillus*) plays an important role for a large variety of insects, birds and mammals, such as moose (*Alces alces)*. Either by sheltering them from predators or, by being a source for forage either directly or indirectly (Cederlund, Ljungqvist & Markgren 1980; Fernandez-Calvo & Obeso 2004; Parlane *et al.* 2006). Bilberry is commonly found in commercial forests in Norway. The forestry operations have an negative effect on bilberry (Atlegrim & Sjöberg 1996; Palviainen *et al.* 2007), bilberry being an important species in the boreal forest, it is therefore important to understand how modern forestry practices will affect their abundance. Two forestry practices that have the largest impact on bilberry are clear-cut and scarification (Atlegrim & Sjöberg 1996; Palviainen *et al.* 2007), and both are commonly practiced in Norwegian forests. Clear-cutting have been found reduce abundance the of bilberries due to direct damage and to stress caused by increased solar radiation, less nutrient transportation in the roots (Nybakken, Selas & Ohlson 2013) and increased competition with new species which will start to colonize the stand, changing the species composition (Bergquist, Örlander & Nilsson 1999). While scarification will increase soil temperatures (Bedford & Sutton 2000), and possible increase evaporation.

Scarification is a common forestry technique used in boreal forests (Palviainen *et al.* 2007) to ensure high numbers of the desired commercial species either through planting, natural regeneration or by sowing (Uusitalo 2010; Hedwall *et al.* 2013; Aleksandrowicz-Trzińska *et al.* 2014). The principle of scarification is to remove or disturb the humus layer and expose the mineral soil. Scarification also removes competitive species from nearby surroundings that could reduce sprouting success or even outcompete new seedlings. Although this is not a new technique, scarification is becoming a more common procedure in the Norwegian forestry. During the period 2001-2013, 4700-8300 hectares have been scarified per year in Norway (Statistics Norway 2014).

Soil scarification can be done in several different ways (Aleksandrowicz-Trzińska *et al.* 2014) factors such as humidity in soil, amount of stones/boulders and bedrock can limit the effect of some scarification methods. Today there are mainly three different methods used to mechanically scarify a stand (Uusitalo 2010). Disc-harrowing is done by pulling two large, rotating metal toothed wheels after a vehicle creating a continuous row (Uusitalo 2010). Another method is scalping or patch scarification, where an apparatus mounted on the back of a machine will lift the humus layer of the mineral soil and then flip the humus over (Uusitalo 2010). This process is done repeatedly, creating a line of patches in the forest floor. The third way of doing scarification is mounding (Uusitalo 2010). When mounding an excavator is digging into the mineral soil, then flipping the humus layer over and burying it under a thin layer of mineral soil.Scarification is usually done a few years after clear-cutting of a mature stand. The time period varies, but scarification is often carried out during seed years especially at higher altitudes to achieve higher seedling establishment. According to Hörnfeldt, Hu and Chiriacò (2012) the optimum time for scarification in central Sweden is between snow-melt and mid-May, as most seeds are dropped in mid-May.

In addition to removing parts of the field layer vegetation, scarifying a stand causes the microclimate to be altered and this can effect plant species composition by increasing establishment of pioneer species, such are wavy hair-grass (*Deschampsia flexuosa*), and fireweed (*Chamerion angustifolium*) which are commonly found to increase their abundance in clear-cuts (Bergstedt & Milberg 2001). After clear-cutting, the field layer vegetation in a stand is exposed to more sunlight, which will lead to reduces air humidity and higher temperature in the mineral soil (Bedford & Sutton 2000). This temperature increase is beneficial from a forestry perspective as it can increase sprouting of seeds, but it can also have a negative effect on the field layer vegetation. Depending on the species in the stand and adaptions to different environments, this alteration in the microclimate will have different effects on plant species and is generally believed to be negative for the amount of bilberry (Palviainen *et al.* 2007) .

Moose is the largest herbivore in Fennoscandia. Being a browser it feeds on shrubs, trees and forbs (Cederlund, Ljungqvist & Markgren 1980), though diet composition varies with seasons. Moose are also semi-migratory, meaning that they might migrate to higher altitudes during the summer and to lower altitudes during the winter. In summer moose forages on forbs and leaves of deciduous trees, while in winter moose primarily feed on twigs from trees and shrubs above snow cover, deciduous and evergreen. The degree of migration varies in different regions of Norway (Lavsund, Nygrén & Solberg 2003) may cause very high moose densities during winter in certain areas. During the late 1960’s and mid 1970’s the moose population in Norway increased rapidly before stabilizing in the 1990’s (Lavsund, Nygrén & Solberg 2003). This increase in the population was caused by several factors such as a change in the harvest quota system and the introduction of modern forestry techniques (Østgård 1987; Lavsund, Nygrén & Solberg 2003). Modern forestry techniques created large continuous areas of moose forage due to clear-cutting. The moose will utilize these clear-cuts both in summer and winter, as available moose forage is very much affected by logging (Wam, Hjeljord & Solberg 2010). Preferring deciduous trees primarily (Markgren 1974; Cederlund, Ljungqvist & Markgren 1980; Pastor *et al.* 1993; Persson *et al.* 2005) such as aspen (*Populus* tremula) and, birch (*Betula* spp.) and Scots pine secondarily (Bergström & Hjeljord 1987; Hörnberg 2001; Persson *et al.* 2005). For the forestry industry and forest owners the Scots pine is a highly economically valuable tree species, as well as one of the most important forage species in terms of biomass for moose in winter in certain areas. Especially in moose wintering-areas commercial forests may experience severe damage to young Scots pine stands due to heavy moose browsing (Bergström & Hjeljord 1987). There have been several suggestions to solve the problem of browsing damage caused by moose on Scots pine. But this is not an simple issue for many Norwegian forest owners as the moose is also an important game species with a high economic value as well (Markgren 1974). The selling of hunting rights can provide landowners with a substantial income.

Another important forage species for moose that is affected by forestry operations is bilberry. Bilberry is a common dwarf-shrub in large parts of Eurasia (Ritchie 1956) and is commonly found in the Norwegian boreal forests. The bilberry plant is between 10-60 cm in height (Ritchie 1956; Parlane *et al.* 2006; Hedwall *et al.* 2013), and can reproduce asexually with several shoots commonly deriving from the same rhizome (Ritchie 1956; Flower-Ellis 1971). Bilberry is most commonly found in mature coniferous stands of Norwegian spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) with high semi-closed canopies and moderately wet soils (Ritchie 1956; Parlane *et al.* 2006; Hedwall *et al.* 2013). The bilberry is important in late autumn (August-October) when most plants have lost their leaves and in spring (April) before the leaves starts to grow (Markgren 1974; Cederlund, Ljungqvist & Markgren 1980). According to Markgren (1974) moose have been found to feed on bilberry during winter if snow cover is low.

One suggestion to reduce the problem of heavy browsing is to increase the density of Scots pines per hectare, as a higher density will leave a sufficient number of undamaged future stems in the stand after pre-commercial thinning (Heikkilä 1991; Andren & Angelstam 1993). According to Wallgren *et al.* (2013) an increased density of Scots pine up to 10.000 trees per hectare will reduce damages caused by moose, but at higher densities the damages will increase again. To achieve a higher density of seedlings it has been suggested to carry out high intensity scarification, exposing more mineral soil for seeds to sprout in. Normally scarification exposes about 15-20 percent of the total stand area, or about 3000 scarified patches of 120 cm by 80 cm (Karlsson *et al.* 2009; Uusitalo 2010). However, although scarification may increase the density of Scots pine, it may have negative effects on bilberry, another important moose food. Dwarf-shrubs such as bilberry and cowberry (*Vaccinium vitis-idaea*) were found to generally decrease in abundance after scarification (Palviainen *et al.* 2007). Thus, removing large amounts of bilberry in a stand could lead to larger damages on pine as bilberry is an important alternative food source for moose in late autumn and early spring. The goal of this study is to investigate the effect of different scarification intensities on bilberry, specifically with the following hypothesis:

Hypothesis 1: With increasing scarification intensity, abundance of bilberry will decrease.

Abundance of bilberry will vary with time since scarification, due the changes in microclimate and competition from pioneer species. After a scarification the abundance of bilberry will be reduced, but with a reduced abundance of competing species the bilberry will have an increase in coverage due to reduced competition for nutrients and that pioneer species need to establish in the stand. However, these pioneer species may reduce the abundance of bilberry until the stand matures, as the change in microclimate and nutrient availability will favour faster growing and more light tolerant pioneer species (Bergstedt & Milberg 2001).

Hypothesis 2: Initially, in the first years after scarification, the abundance of bilberry in scarified stands is reduced, but will increase before decreasing again.

If the abundance of bilberry is reduced by scarification, this will in turn lead to a reduction of biomass available as moose forage. Also, the scarification itself will damage the plants, forcing the bilberry to regrow lost or damages plant parts. This reduced growth is due to the bilberry's response to increased sun exposure, microclimatic changes and increased competition from pioneer species.

Hypothesis 3: In stands with a higher scarification intensity there will be less biomass from bilberry available as forage for moose.

2. Methods

2.1 Study area

The study area was situated in Gravberget in Våler and Åsnes municipalities, Hedmark County, southeast Norway (X: 0352316 Y: 6752789,5 UTM 33V). The forest in this area is owned by Statsskog SF, who manages all state-owned forest in Norway. The area is a part of the boreal coniferous forest, and is classified as middle boreal zone by Moen (1999). The forest consists mainly of Norway spruce, Scots pine, downy birch (*Betula pubescens*), silver birch (*Betula pendula*), rowan (*Sorbus aucuparia*), aspen (*Populus tremula*) and goat willow (*Salix caprea*). In the study area Scots pine is the dominating coniferous species. The area has an annual average temperature of 2-4° Celsius and an annual precipitation of 1000-1500 mm, and the duration of the snow cover is 150-174 days (Moen 1999). According to Moen (1999) the annual growth season in the middle boreal zone is 150-160 days, with an average temperature over 5° Celsius. All sampling for bilberries was done in July 2013. My study is a part of a forestry an moose research project, which investigates options to improve integrated management of moose and forestry (Hedmark university college s.a.).

2.2 Scarification

The scarification method used in the project was patch scarification (also called scalping) which was carried out by using a forwarder with a mounted apparatus to scrape the humus layer off the mineral soil and turn it over. In the Norwegian forestry recommended percentage of a stand area being scarified is 15-20 %. On humid soil the goal should be to expose a large part, approximately 20 % of the mineral soil (Karlsson *et al.* 2009). For this project, the goal was to compare high intensity scarification with low intensity; therefore the low intensity scarification in this area was approximately 15-20 % of the stands area, while the high intensity scarified areas had a proportion of approximately 40 % of the stand area scarified.

The area was divided in two comparable parts, an experimental area (A) with a size of 20.1 km^2 and a control area (B) which was 25.5 km^2. In the experimental area stands were scarified with high intensity and in the control area stands were scarified with low/normal intensity. The stands scarified within the project with high and low intensity were treated in

2012, but the area also contained stands with older scarification at low intensity. The older scarifications from 2008 and 2009 were treated with the same method as the ones from 2012 allowing comparison of the abundance of bilberries in stands scarified with a low intensity at different time since scarification. For high intensity scarified stands there were no stands older than 2012.

Figure 1. A control stand scarified in 2012, this stand had been scarified at a low intensity (15-20%). Photo by author.

2.4 Selection of stands for survey of bilberry

I choose a subsample of stands for surveys of bilberry based on their site index, intensity and age. Within each treatment group, stands were selected using random numbers in Excel, in order to get as equal sample sizes as possible among groups. The Scots pine site index H40 system indicates predicted tree height at the age of 40 years (Steinset 2000). I chose to use stands with a site index of F11 and F14, because the stands that have a lower site index than 11, usually have very low natural abundance of bilberries, and only one stand with a higher site index was available in the study area There were only two stands scarified in F11 in 2008 (Table 1). To prevent bias caused by a seasonal effect I alternated sampling days between control stands and experimental stands. In total 36 stands were surveyed (Table 1).

Table 1: The number of stands surveyed for bilberry with level of scarification intensity, site index and year treated.

Year	**Site index**	**Intensity**	**N**
2012	F11	Low	5
2012	F14	Low	6
2012	F11	High	5
2012	F14	High	5
2009	F11	Low	3
2009	F14	Low	5
2008	F11	Low	2
2008	F14	Low	5
Total number			36

2.4.1 Selection of plots within stands

For survey of bilberry, I laid out transects of 5-10 sample points in each stand, based on the size of the stand. I placed as many points as possible with five as minimum and ten as maximum. The first sample point was placed six meters from the edge of the stand, along the longest axis in the middle of the stand. When this line was not long enough for ten sample points, I placed a new line perpendicular to the first line. To ensure that the lines would be straight in the terrain, I used a compass course to stay on the line from one sample point to the next. I used a fixed distance of 50 meters between each point.

At every sample point I placed four 1 m^2 plots five meters from the centre of the sample point in the cardinal directions, north, east, south, and west and numbered them in that order from one to four using a rope to measure the distance and a compass for directions. In the field I used a wooden frame that was one meter by one meter internally, and to make the estimates in the field easier I marked every ten cm on all sides. One ten cm by ten cm square represented one percent of the plot area. I also had a rope with me in the field that I used to make the plots if there were any tree bases preventing me from using the wooden frame, so that I did not have to move the plot due to obstacles.

Figure 2. An example of how the plot looked like in the field, this plot is from a control stand from 2012. Photo by author

2.5 Variables measured

In the plot data were collected as follows; I estimated the percent vegetation cover of bilberry per plot, including both dead and live plant parts as an estimate of abundance. I estimated the percentage of dead biomass from standing biomass in each plot. I measured the average canopy height of the closest group of plants to each corner of the plot. To measure area scarified I estimated the percentage of bare mineral soil in the plot due to scarification. In addition, I also estimated the percentage of turned humus and percentage of driving tracks in the plot. I measured the maximum depth from the surface of the scarified area in the plot. The dominating species of other field layer vegetation was recorded and percentage vegetation cover of this species was estimated. In cases where there were two species with the same cover, I recorded both of them. I also estimated the percentage of the plot that was neither field vegetation nor scarified area. This was defined as: water, stones, trees and dead wood such as logs, branches and stumps.

2.5.1 **Biomass/necromass of bilberries:**

To be able to estimate biomass of bilberry from cover and height measured in the field, I cut and removed bilberry plants from 16 plots in 8 positions, constructed for that purpose and providing a representative variation in bilberry cover. I used a sub-sample from the 2012 stands, with two from area A and two from area B. I choose to use one F14 and one F11 from experiment and from control area. I placed one sample point in the edge of the stand and one in the middle, each with two plots. For each plot cover, height and percentage dead plants was estimated as described above. The bilberry was cut at ground level, and all plants (dead and live) were removed from the plots. The plants were put in paper bags and marked with stand number, date, and plot number. In the lab the plants were sorted in dead and live plant parts from each plot. After the plants were sorted they were put in a drying cabinet and left to dry at 73° Celsius until their weight was constant. To determine constant weight I measured three bags of different sizes placed at different places in the drying cabinet repeatedly to find out when the weight was constant. This took about 24 hours, and when their weight was constant I took the bags out and weighed all of them, subtracting the weight of the bag, to get estimates of biomass and necromass per plot.

2.5.2 **Estimation of biomass**

I used Microsoft Excel 2010 to calculate the total biomass (both live biomass and necromass) of bilberry in the non-cut plots based on a regression curve between cover and average weight from the plots where bilberry was cut. To do this I started by separating the necromass from live biomass. I calculated the percentage of necromass based on the weight of dead bilberries in the cut plots. I then subtracted the necromass from the total biomass, leaving me with live biomass and necromass dry weights. I did a linear regression with percentage bilberry cover and the total bilberry dry weight from the cut plots. I found a significant linear relationship between percentage bilberry cover and the bilberries dry total weight (slope 1.1034 ± 0.43, R^2 0.84, $F_{1,14} = 72.98$; $p < 0.001$). The formula from this linear regression was used to estimate total biomass based on estimated percent bilberry cover of all plots.

To check the accuracy of the estimates made for the proportion of dead bilberry to the cover of bilberries measured in the field, I did a linear regression with the estimated percentage of dead bilberry and the weight of dead bilberry from the plots where I removed bilberry. I found a significant linear relationship (slope 1.2387 ± 8.79, R^2 0.82, $F_{1,14} = 65.30$; $p < 0.001$) between estimated proportion dead bilberry cover and percentage dead bilberry weight. Since the fit between estimated and dead biomass for the cut plots was quite good ($R^2 = 0.82$), I used the proportion of dead bilberry cover to separate between the total biomass into necromass and live biomass for all the plots surveyed.

2.6 Statistical analysis

All responses were analyzed by using linear models in R 2.15.1 (http://cran.r-project.org/). Since my plots were nested within points and stands, I used linear mixed models in the nlme package in R. I used a manual backwards selection procedure, where I removed the least significant variable step by step. The final models therefore included only variables where $p < 0.05$. For backwards selection, I used comparison of likelihood ratios between nested models fitted with maximum likelihood estimation (ML) dropping one and one explanatory variable, as described in Zuur *et al.* (2009). The final models were fitted with restricted maximum likelihood estimation. To account for multiple observations from the same stand and point, I used stand number and point number as random intercepts in all models.

I tested the effects of scarification on bilberry in two ways: the effect of scarification intensity (high/low at stand scale) separately and the effect of the other scarification variables at plot scale: cover of mineral soil, cover of humus and tracks. This was due to scarification intensity and the other scarification variables being most likely correlated. With a high scarification intensity there was a higher proportion of bare mineral soil, turned humus and more tracks. In my analysis I therefore made two models for each response variable when I used scarification intensity. The variables other field layer vegetation species, cover of other species, cover of stones and water, cover of trees and cover of dead wood were co-variables and I used them in the models to account for the large variation among plots. I grouped some of the co-variables due to a low number of observations. In other field layer vegetation species I grouped the species with lower than five observations and those that were not in the same family as other observations in to the group "other species". The group includes fireweed, common oak fern (*Gymnocarpium dryopteris*), purple moore grass (*Molinia caerulea*) and *Salix* spp. Species that belonged to the same family and that only had a few observations were grouped by genus name. Water had only a few observations in the field; therefore I grouped it together with stones. Water and stones is considered permanent cover that is not going to dissolve unlike wood debris (cover of dead wood). Water can change by drying up, but at the point of sampling it was non-vegetation.

2.6.1 **Test of assumptions**

I tested for correlation between my numerical explanatory variables, and found that the correlation coefficient of cover of mineral soil and depth where just below 0.7. I therefore compared which variable explained the most of the variation in the response variable using linear model, by looking at R^2 and AIC values. In general R^2 was higher and AIC values lower for cover of mineral soil than depth, so cover of mineral soil was included in the models. No other variables showed signs of being correlated. I checked if my response variables were normally distributed. Average height and live biomass were normally distributed, but cover of bilberries and necromass were a bit skewed to the left. To control if my variables fulfilled the assumptions I used residual plots. I transformed the response variables cover of bilberries, necromass and live biomass by using a log (y+1) transformation in R, to fulfil the assumption of equal variance in the response variables for all my explanatory variables. After log-transformation the response variables fulfilled the assumption of equal variance for the different explanatory variables. Arcsine-square transformation of percentage cover was also evaluated, but log-transformation gave better distribution of residuals.

When I analysed my data using cover of bilberry as a response variable I found one outlier with extreme bilberry cover (95 %). Most of my observations of bilberry cover are between 0-20 percent. I therefore tested the data with and without the outlier; ending up with I four analyses when testing my first hypothesis. There were no major differences in the final models with or without the outlier. The only differences were among the co-variables. Therefore I will present the results from both tests in the cases where the outlier was present in the dataset.

2.6.2 Data analysis

To analyse the effect of high versus low intensity scarification on bilberry abundance (hypothesis 1), I used only stands that were scarified in 2012. The full models for hypothesis 1 included cover of bilberries (as response variable, table 2), scarification intensity or the scarification variables cover of mineral soil, cover of humus, tracks, and the co-variables other species, cover of other species, stones, trees and dead wood (as explanatory variables, table 2).

To investigate the effect of time in scarified stands on the abundance of bilberry (hypothesis 2), I analysed cover of bilberries and average height as response variables. For this analysis I used only the stands scarified with low intensity from all three years (2008, 2009 & 2012). I used the scarification variables rather than scarification intensity as explanatory variables since there were only stands with low scarification intensity from 2008 and 2009. I included year scarified as well as the same co-variables as in the previous analysis (table 2).

When I analysed to see if scarification reduces available bilberry forage for moose (hypothesis 3), I used live biomass and necromass as response variables, scarification intensity or the scarification variables together with year scarified (explanatory variables, table 2). To test my hypothesis I therefore made two analyses; one for live biomass and one for necromass. I included year scarified in this analysis because I included the stands from all years and intensities in the analysis. All co-explanatory variables were used in the analysis of hypothesis 3.

Table 2. The different response- and explanatory variables used in the statistical analysis. Co-variables are in cursive. * Analysed separate from the scarification variables. ** Analysed separate from scarification intensity.

Hypothesis 1		**Hypothesis 2**		**Hypothesis 3**	
Y-variables:	**X-variables:**	**Y-variables:**	**X-variables:**	**Y-variables:**	**X-variables:**
Percentage cover of bilberries	Scarification intensity (high/low) *	Percentage cover of bilberries	Year scarified (2008/2009/2012)	Live biomass	Scarification intensity (high/low) *
	Percentage cover of mineral soil **	Average height	Percentage cover of mineral soil	Necromass	Year scarified (2008/2009/2012)
	Percentage cover of humus **		Percentage cover of humus		Percentage cover of mineral soil **
	Percentage cover of tracks **		Percentage cover of tracks		Percentage cover of humus **
	Other field layer vegetation species		*Other field layer vegetation species*		Percentage cover of tracks **
	Cover of other field layer vegetation species		*Cover of other field layer vegetation species*		*Other field layer vegetation species*
	Cover of stones and water		*Cover of stones and water*		*Cover of other species*
	Cover of trees		*Cover of trees*		*Cover of tones and water*
	Cover of dead wood		*Cover of dead wood*		*Cover of trees*
					Cover of dead wood

3. Results

3.1 Scarification intensity and cover of bilberries

When I analysed the effect of scarification intensity on the cover of bilberries, scarification intensity was not significant either with ($L_{15} = 0.61$; $p = 0.435$, appendix A) or without the outlier ($L_{14} = 0.84$; $p = 0.361$, appendix A). Thus, I have only presented here the results from the analysis of the scarification variables.

When I analysed the effect of scarification variables on the cover of bilberries, I found no strong differences between the models of scarification variables with- and without the outlier. Therefore I presented here the model with outlier; the other model is presented in appendix B. The only difference between the two was that cover of other field layer vegetation species is present in the final model with the outlier, and not in the final model without the outlier (appendix B).

I found that all three scarification variables had a negative effect on the cover of bilberries. With an increase in the cover of mineral soil ($L_{15} = 9.37$; $p = 0.002$, figure 3A), cover of humus ($L_{15} = 14.20$; $p < 0.001$, figure 3B) and cover of tracks ($L_{15} = 7.10$; $p = 0.008$, figure 3C) the cover of bilberries decreased. Cover of dead wood also had a negative effect on bilberry cover ($L_{15} = 11.36$; $p < 0.001$, figure 3D). With a higher cover of other field layer vegetation species, there was a higher cover of bilberries (slope 0.03 ± 0.010, $L_{15} = 11.83$; $p < 0.001$), however this variable may be under influence by the outlier.

Among the field layer vegetation species ($L_{7} = 11.36$; $p < 0.0001$, figure 4) I found that there was higher cover of bilberries when *Vaccinium vitis-idaea* was present in the plot than with *Calluna vulgaris, Vaccinium uliginosum* and other spp. (figure 4). I also found that was a higher cover of bilberry when *Empetrum nigrum*, *Calluna vulgaris* and *Deschampsia* spp. was present than with *Carex* spp. or other species. (figure 4).

During the backwards selection of this model I removed cover of stones and water ($L_{17} = 3.11$; $p = 0.078$) and cover of trees ($L_{16} = 3.57$; p 0.059) as they showed no significant relationship with bilberry cover.

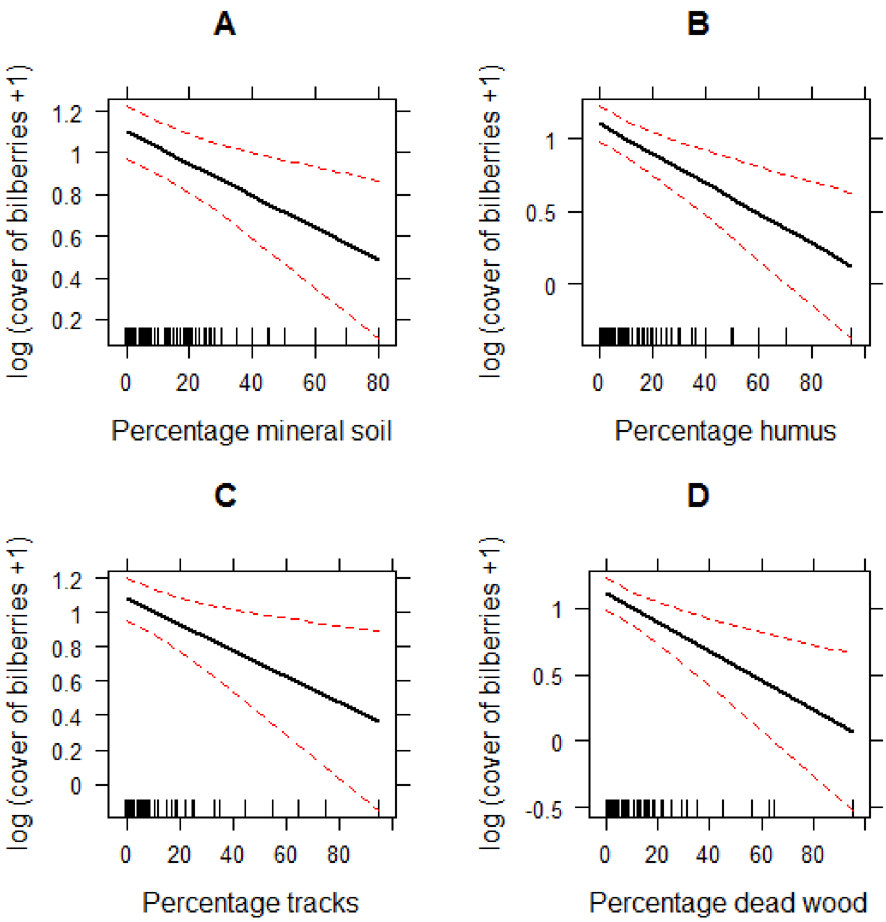

Figure 3. Effect plot of the relationship between the bilberry percentage cover and, A: Percentage cover of exposed mineral soil with 95% CI. B: Percentage cover of turned humus with 95% CI. C: Percentage cover of driving tracks with 95% CI. D: Percentage cover of dead wood with 95% CI.

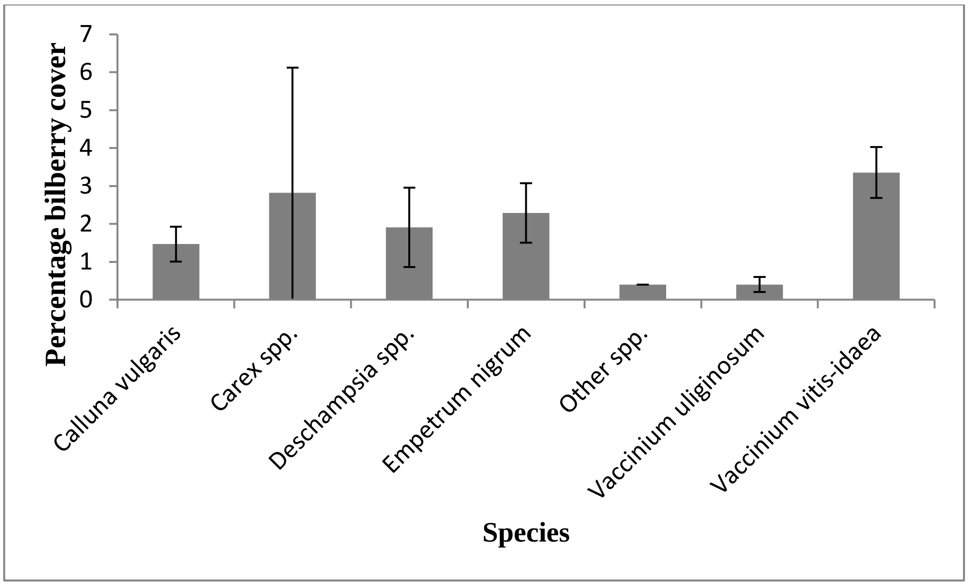

Figure 4. Percentage bilberry cover with 2*SE in plots depending on which other field layer vegetation species was present in the plot, in stands scarified at high and low intensity in 2012 based on original data.

3.2 Cover- and average height of bilberries with time

3.2.1 **Cover of bilberries**

When I analysed if the cover of bilberries would decrease with time since scarification, I found a significant difference between the years (figure 5). Stands scarified in 2012 had a lower cover of bilberry than stands treated in 2008 and 2009 ($L_{17} = 15.64$; $p < 0.001$, figure 5). I found the same effect here as for the stands scarified in 2012, there was a decrease in the cover of bilberries with an increase in cover of mineral soil ($L_{17} = 6.06$; $p = 0.014$, figure 6A) and cover of humus ($L_{17} = 5.03$; $p = 0.025$, figure 6B).

In addition, cover of bilberry decrease with cover of stones and water (slope -0.01 ± 0.004, $L_{17} = 10.05$; $p = 0.002$. I found that cover of trees had a positive linear relationship with cover of bilberries (slope 0.05 ± 0.004, $L_{17} = 3.87$; $p = 0.049$). During the backwards selection I removed cover of tracks ($L_{20} = 0.16$; $p = 0.690$), cover of dead wood ($L_{19} = 2.17$; $p = 0.141$) and cover of other field layer vegetation species ($L_{18} = 3.14$; $p = 0.076$) from the model, as they showed no significant relationship with cover of bilberry.

Bilberry cover varied with species of field layer vegetation present ($L_{10} = 70.15$; $p < 0.0001$), and that there was a higher cover of bilberries in areas where *Vaccinium vitis-idaea* is the dominating field layer species than with *Deschampsia* spp. *Calluna vulgaris*, *Carex* spp. and other spp. (figure 7). *Empetrum nigrum* and *Calluna vulgaris* gave also higher bilberry cover as the dominant field vegetation specie than *Carex* spp. and other spp. (figure 7).

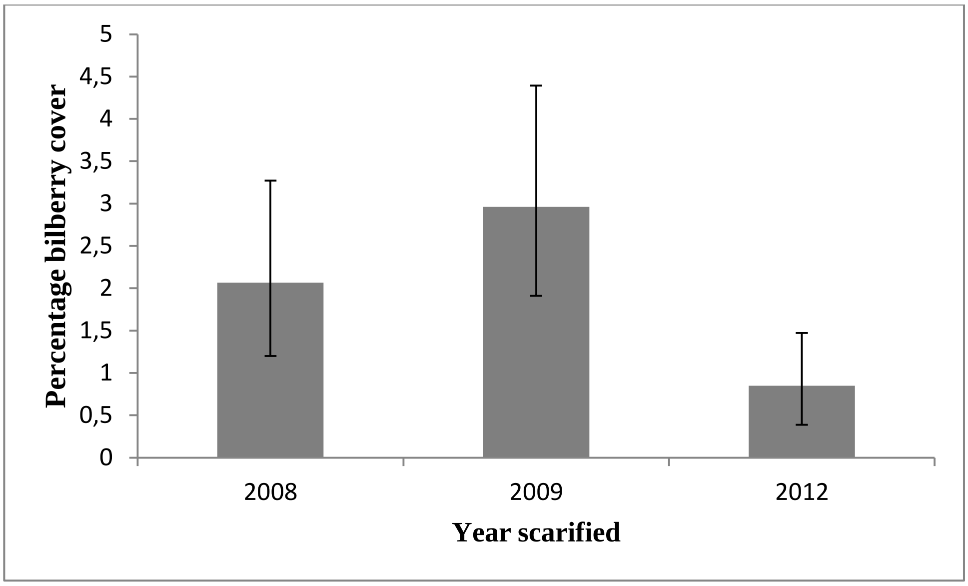

Figure 5. The mean percentage cover of bilberries from stands scarified at low intensity with 2*SE in 2008, 2009 and 2012.

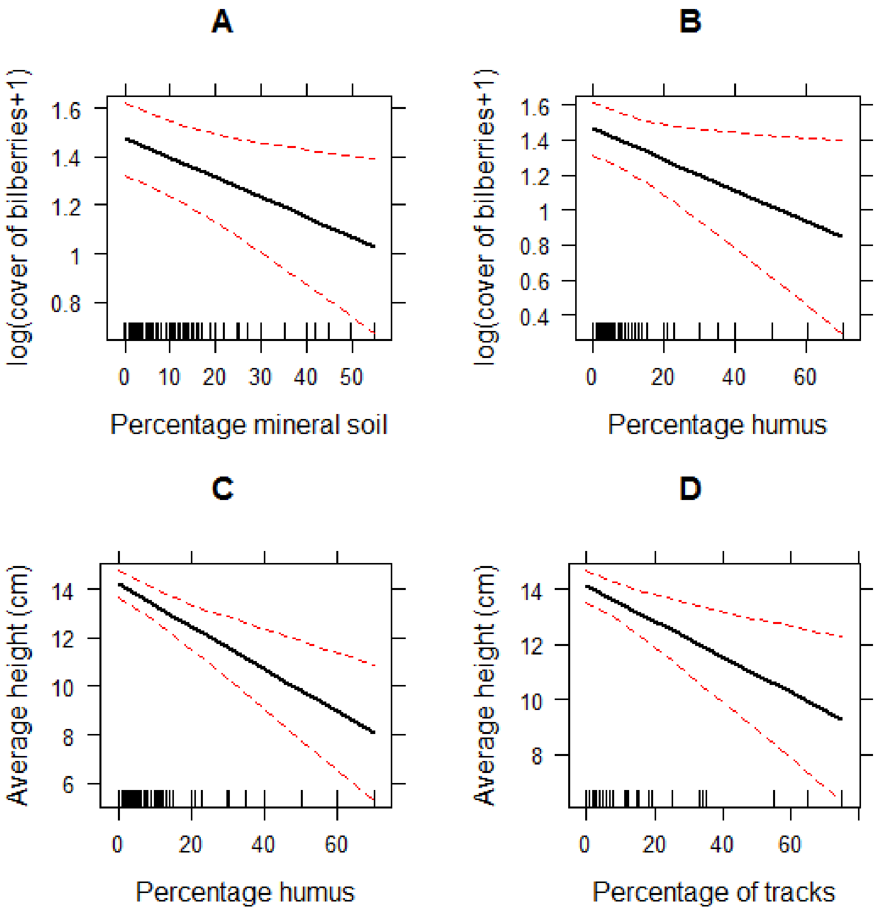

Figure 6. Effect plot of the relationship between the bilberry percentage cover and A: Percentage cover of exposed mineral soil with 95% CI. B: Percentage cover of turned humus with 95% CI. The average height and C: Percentage cover of humus with 95% CI. D: Percentage cover of driving tracks with 95% CI.

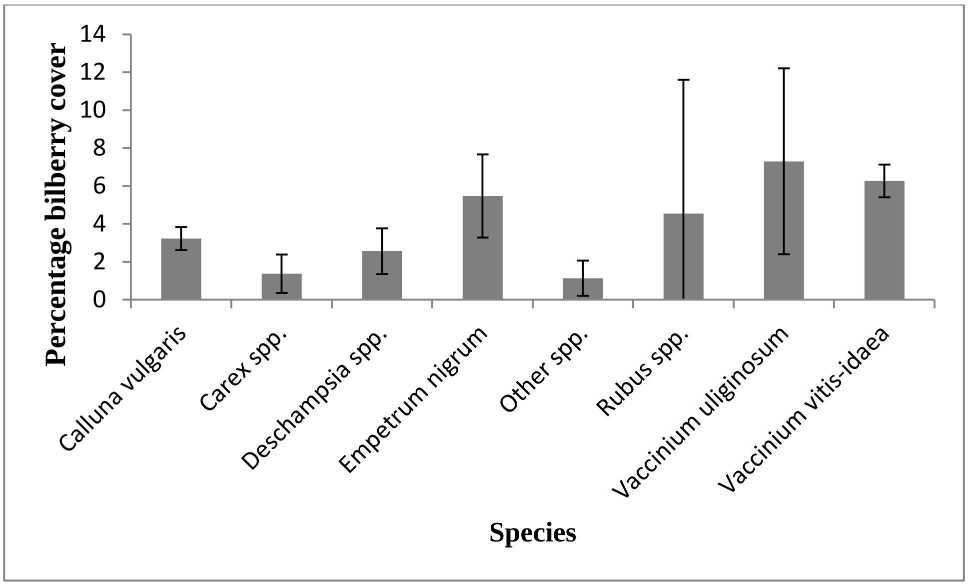

Figure 7. Percentage bilberry cover with 2*SE in plots depending on which other field layer vegetation species was present in the plot, in stands scarified at low intensity in 2008, 2009 and 2012 based on original data.

3.2.2 Average height

I found a significant difference in average bilberry height between the years scarified (L_{16} = 17.44; $p < 0.001$). The average height was higher in the stands scarified in 2009 than in the stands scarified in 2008 and 2012 (figure 8). There was no difference between 2008 and 2012 (figure 8). With a high percentage of humus (L_{16} = 17.79; $p < 0.0001$, figure 6C) and tracks (L_{16} = 9.95; p = 0.002, figure 6D) there was a lower average height of bilberries in the stands. The average height of bilberries was positively correlated with the height of other field layer vegetation (slope 0.07 ± 0.025, F_{16} = 6.86; p = 0.009).

Bilberry height varied with the presence of other plant species (L_{9} = 24.10; p = 0.002), and if the dominating field layer species where *Vaccinium vitis-idaea*, *Empetrum nigrum* or *Vaccinium uliginosum* the bilberries would have a greater average height than with *Carex* spp. (figure 9).

During the backwards selection I removed the variable cover of water and stones (L_{20} = 0.01; p = 0.907), cover of dead wood (L_{19} = 0.97; p = 0.323), cover of trees (L_{18} = 0.84; p = 0.359) and cover of mineral soil (L_{17} = 2.36; p = 0.124) which showed no significant relationship with height of bilberry.

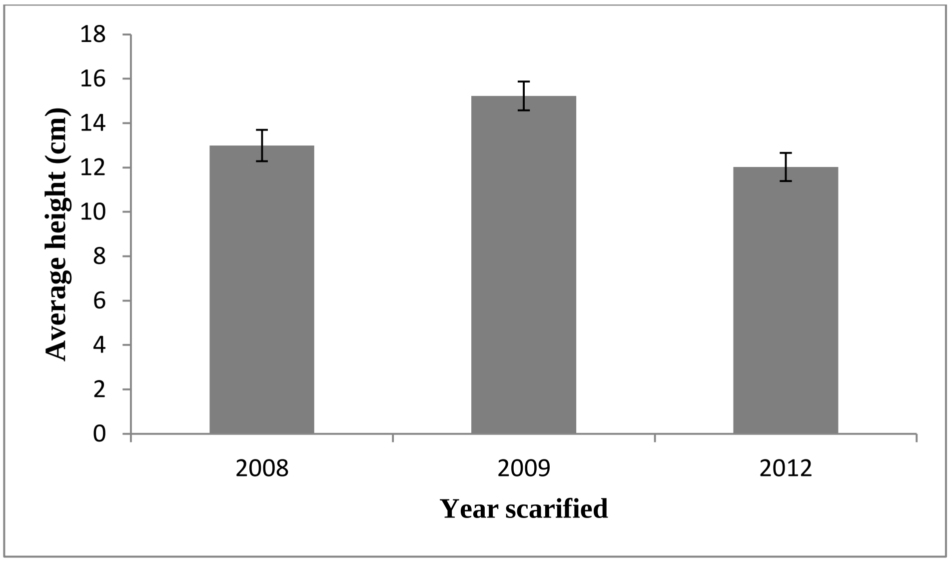

Figure 8. The mean average height (cm) of bilberry in stands scarified at low intensity with 2*SE in 2008, 2009 and 2012.

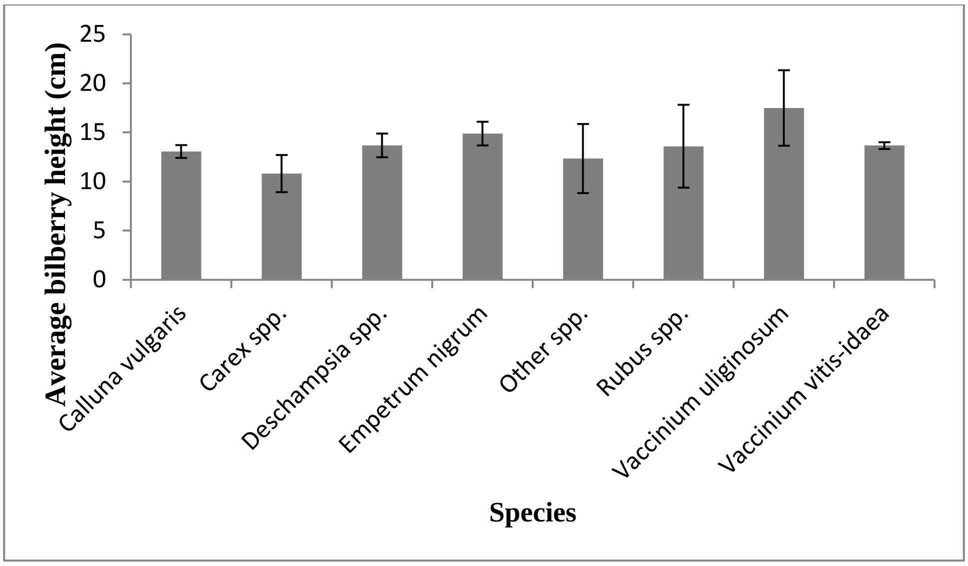

Figure 9. The mean average height (cm) with 2*SE of bilberry depending on which other field layer vegetation species was present in the plot, in stands scarified at low intensity in 2008, 2009 and 2012 based on original data.

3.3 Available forage for moose

3.3.1 **Live biomass**

When I analysed the model including scarification intensity I did not find a significant effect on bilberry live biomass ($L_{17} = 0.72$; $p = 0.397$). The results from the test of scarification intensity and live biomass are therefore presented in appendix C. I will here only present the results from the model with scarification variables.

The results from analysing the scarification variables shows that there was less live biomass in the stands scarified in 2012 than in the ones from 2008 and 2009 ($L_{17} = 27.16$; $p < 0.0001$, figure 10). There were no difference between 2008 and 2009 in amount of live biomass (figure 10).

I found that all scarification variables, cover of mineral soil ($L_{17} = 13.12$; $p < 0.001$, figure 11A), cover of humus ($L_{17} = 14.14$; $p < 0.001$, figure 11B) and cover of tracks ($L_{17} = 9.46$; $p = 0.002$, figure 11C) showed a negative linear relationship with live bilberry biomass. Cover of trees showed a positive relationship with the amount of live biomass in the stands (slope 0.06 ± 0.030, $L_{17} = 4.13$; $p = 0.042$).

Live biomass of bilberry varied with the presence of other plant species ($L_{10} = 62.30$; $p < 0.0001$), and when bilberry is accompanied by *Vaccinium vitis-idaea* it gave higher amounts of live biomass than *Calluna vulgaris, Deschampsia* spp. and other spp. (figure 11). When *Empetrum nigrum* or *Calluna vulgaris* where the dominant field layer species it gave higher amounts of live bilberry biomass than other species. (figure 11).

During the backwards selection I removed cover of other field layer species ($L_{20} = 0.1*10^{-2}$; $p = 0.921$), cover of dead wood ($L_{19} = 0.65$; $p = 0.421$) and cover of stones and water ($L_{18} = 2.42$; $p = 0.299$) which showed no significant relationship with live biomass of bilberry.

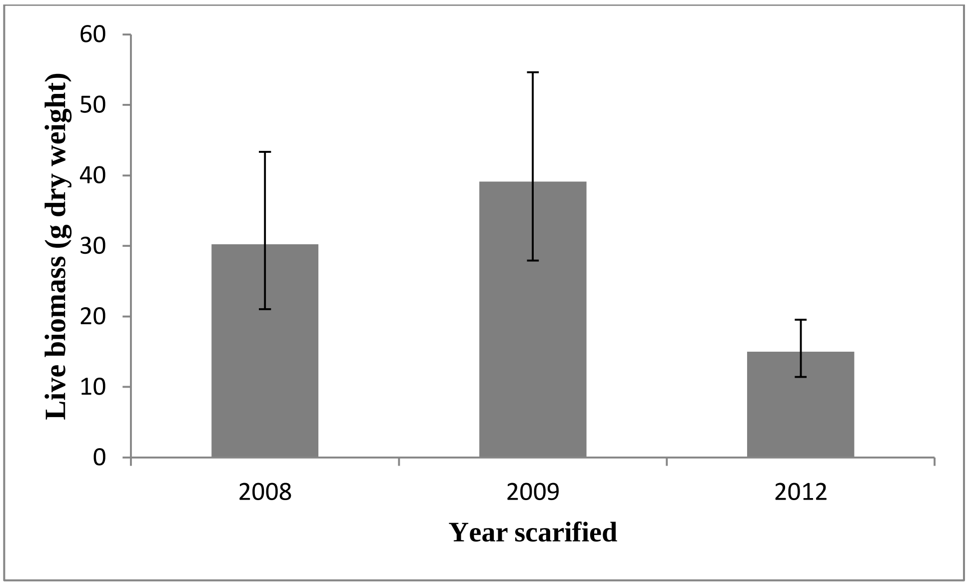

Figure 10. The mean live biomass (g dry weight) of bilberry in stands scarified with both low- and high intensity with 2*SE in 2008, 2009 and 2012.

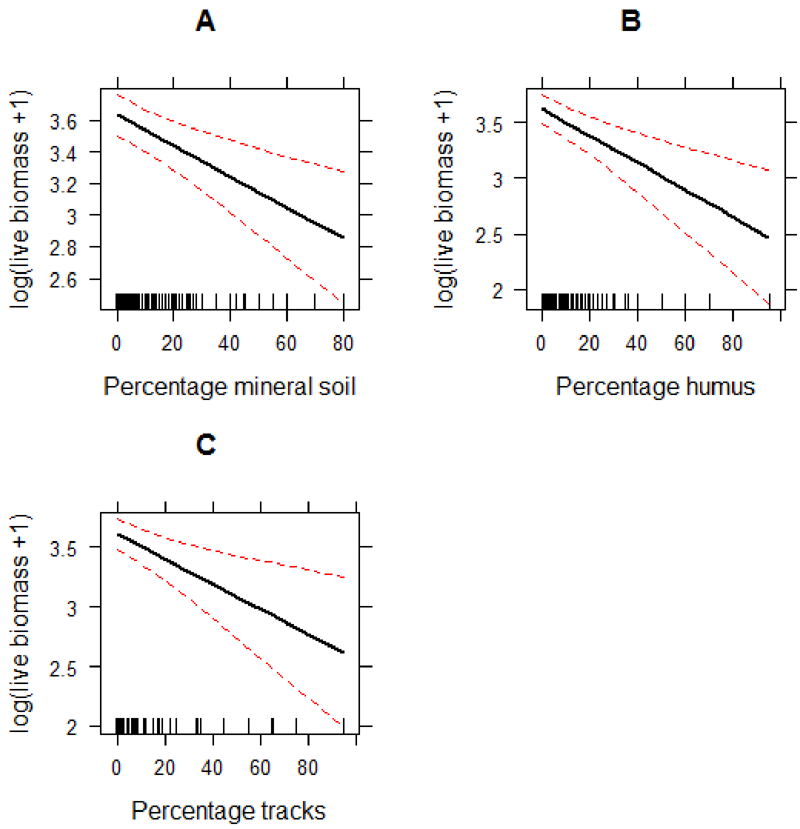

Figure11. Effect plot of the relationship between the live bilberry biomass and. A: Percentage cover of exposed mineral soil with 95% CI. B: Percentage cover of turned humus with 95% CI. C: Percentage cover of tracks with 95% CI.

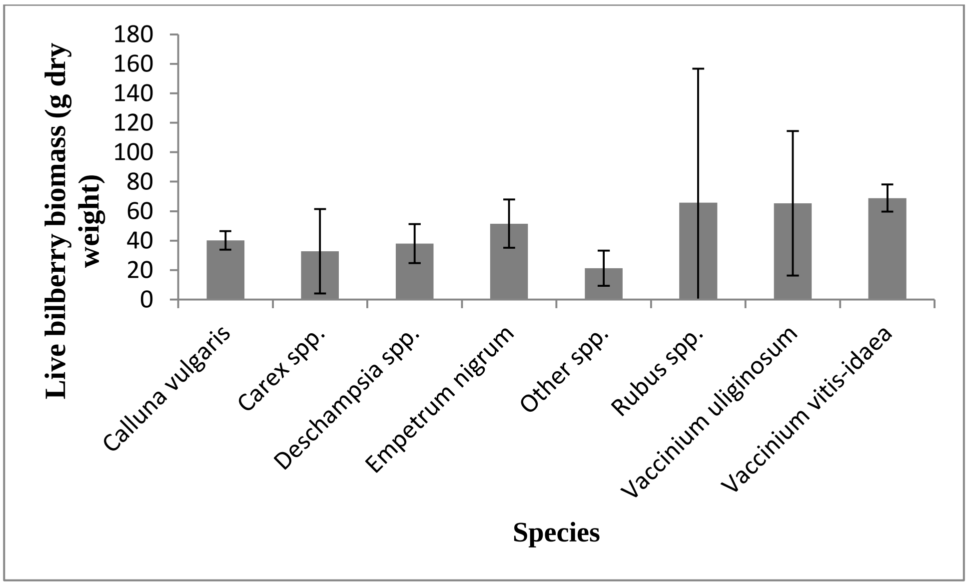

Figure 12. The mean live biomass (g dry weight) with 2*SE of bilberry depending on which other field layer vegetation species was present in the plot, in stands scarified at high and low intensities in 2008, 2009 and 2012 based on original data.

3.3.2 **Necromass**

I found scarification intensity not to have a significant effect on the bilberry necromass ($L_{17} = 0.12$; $p = 0.977$), and I have therefore presented the results from the model with scarification variables. The results from the analyses of scarification intensity and necromass can be found in appendix D.

I found that there was significant difference in necromass among years ($L_{17} = 6.99$; $p = 0.030$) though this was not strong (figure 13). Bilberry necromass decreased with increasing cover of humus (slope -0.01 ± 0.004, $L_{17} = 5.00$; $p = 0.025$).

I found that cover of stones and water was negatively related to bilberry necromass (slope -0.02 ± 0.006, $L_{17} = 7.77$; $p = 0.005$). Cover of other field layer vegetation species (slope -0.01 ± 0.007, $L_{17} = 4.06$; $p = 0.044$) and cover of dead wood (slope -0.03 ± 0.005, $L_{17} = 46.09$; $p < 0.0001$, table 3) was negatively correlated with bilberry necromass.

Necromass of bilberry varied with the presence of other plant species ($L_{10} = 56.37$; $p < 0.0001$), and when bilberry is accompanied by *Vaccinium vitis-idaea* it gave higher amounts of necromass than with *Calluna vulgaris, Empetrum nigrum, Rubus* spp., *Deschampsia* spp., *Carex* spp. and other spp. (figure 14). When bilberry was accompanied by *Empetrum nigrum* it gave higher amounts of biomass than with *Calluna vulgaris, Rubus* spp., *Deschampsia* spp., and other spp (figure 14). I also found that if bilberry was accompanied by *Calluna vulgaris* and *Carex* spp. this would give higher amounts of necromass than with *Deschampsia* spp., and other spp. (figure 14).

During the backwards selection I removed cover of mineral soil ($L_{20} = 0.8*10^{-3}$; $p = 0.977$), cover of trees ($L_{19} = 0.03$; $p = 0.869$) and cover of tracks ($L_{18} = 0.06$; $p = 0.815$) which showed no significant relationship with necromass of bilberry.

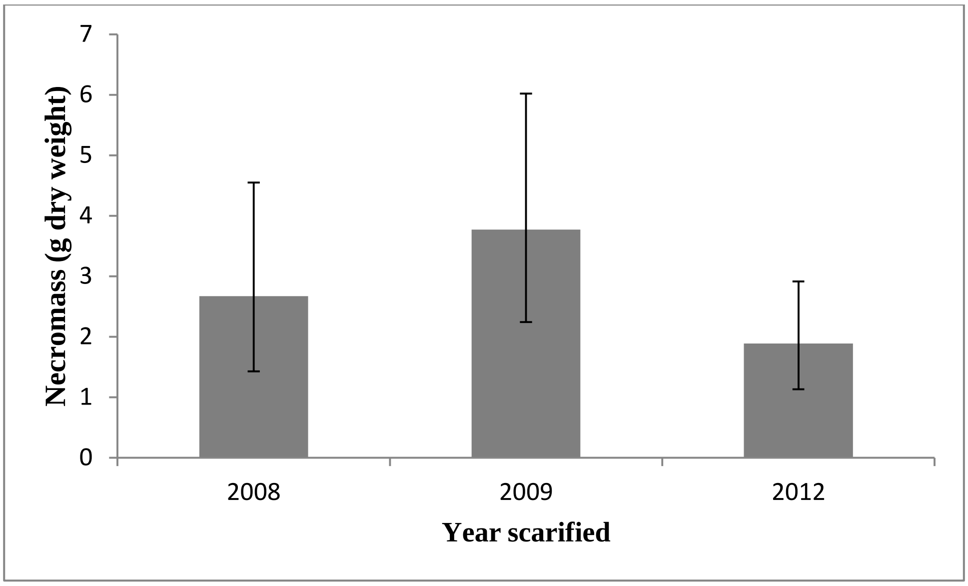

Figure 13. The mean necromass (g dry weight) of bilberry in stands scarified with both low- and high intensity with 2*SE in 2008, 2009 and 2012.

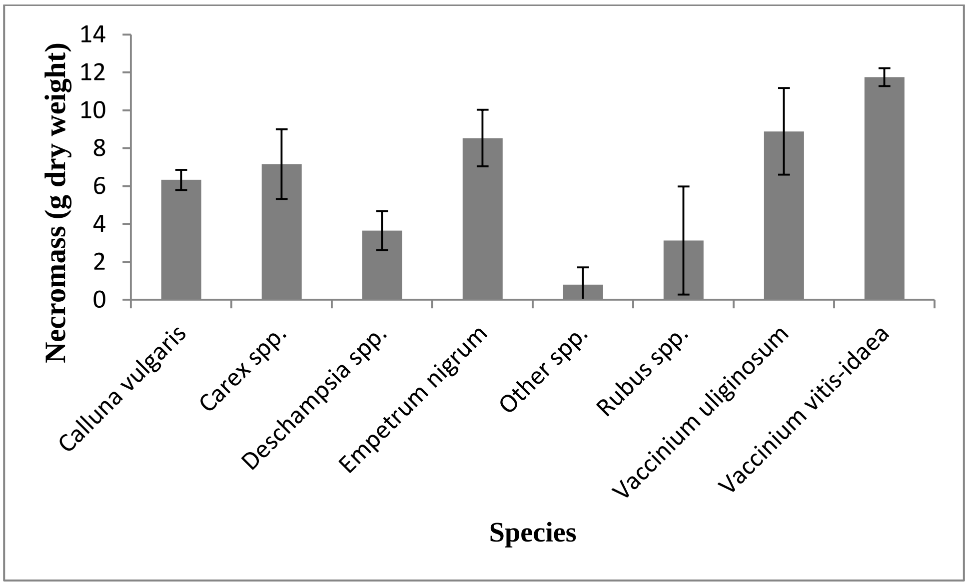

Figure 14. The mean necromass (g dry weight) with 2*SE of bilberry depending on which other field layer vegetation species was present in the plot, in stands scarified at high and low intensities in 2008, 2009 and 2012 based on original data.

4. Discussion

4.1 High intensity scarification reduces bilberry cover

In my results from analysing the scarification variables all three of the variables cover of mineral soil, cover of humus and cover of tracks showed a clear negative relationship with cover of bilberries. When analysing the effects on scarification intensity and bilberry cover, I found that scarification intensity did not significantly affect bilberry cover. This means that I found an effect of scarification intensity in the plot level, but not at stand level. This supports my hypothesis but also shows that there is a lot of variation in scarification intensity within stands that is only detected when using a small scale measurement. The effect of scarification variables on bilberry, support hypothesis 1, that high intensity scarified stands there was a lower percentage bilberry cover than in stands scarified with low intensity.

Bilberry is greatly affected by forestry operations, and has been found to rapidly decrease in abundance after clear-cuts (Bråkenhielm & Persson 1980; Bråkenhielm & Liu 1998). The removal of canopies increases the exposure to sunlight and can cause stress on the bilberry plants through drought and solar radiation (Wagner, Fischer & Huth 2011; Nybakken, Selas & Ohlson 2013). Scarification could increase or strengthen the effects following a clear-cut, an understanding of the effects scarification is therefore very important. It is not clear if it is the scarification (Palviainen *et al.* 2007), or cutting intensity (Bergstedt, Hagner & Milberg 2008) exert the greatest reduction in bilberry abundance. But scarification is found to have a long-term effect on the field layer flora and species composition (Haeussler, Bartemucci & Bedford 2004; Bergstedt, Hagner & Milberg 2008). Scarification removes humus and exposes mineral soil; which has an effect directly on the plants through removal and, damages to plants above and below ground. The removal of roots can be quite severe and have a long lasting effect. Palviainen *et al.* (2007) found in their study, that field layer vegetation had very little root biomass in their scarified furrows. The scarified patches with exposed mineral and turned humus could provide bilberry with “new” patches to grow in without competition. After the clear-cut the stand will experience increased sun exposure, and together with scarification this will lead to higher temperatures especially in the exposed mineral soil (Kubin & Kemppainen 1994; Aleksandrowicz-Trzińska *et al.* 2014). With increasing soil temperatures there can be an increase in evaporation, and as bilberry prefers moderately wet soil this can have a very negative effect on bilberry. This increase in sunlight, exposed patches to sprout in and more available nutrients can offer good opportunities for pioneer species. Nieppola (1992) found that one such pioneer species, *Deschampsia flexuosa* occurred more 2-8 times as much in young stands as mature stands.

Driving tracks after scarification might be an underestimated source of temporary damage on bilberry. As Hamberg *et al.* (2010) found trampling by people to be harmful for bilberry, it plausible to think that heavy machines can have a bigger effect. There is concern that machines used for harvest during a clear-cut can cause severe damages to bilberry and that even this can affect cover of bilberry after clear-cutting (Atlegrim & Sjöberg 1996). But as clear-cuts in Norway primarily is done during winter and on snow, it is therefore reason to believe that driving on bare ground which is done when scarifying can pose as a bigger problem, especially with high intensity scarification. As machines will have to drive more lines/transects in the stand to reach a high exposure of mineral soil, this can potentially lead to more damages on the bilberry caused by driving. The potential damage caused by the belts is not the only potential problem than can occur due to increased driving in the stand. The machines used to scarify are often the same used in other forestry operations, and weight pressure leading to soil compacting is therefore an issue. In forestry there has been focus on limiting the permanent tracks left after clear-cutting. The forwarder, which is commonly used for scarification can weigh from 10-25 tons (Komatsu forest 2014). There are measures taken to reduce the weight, such as 8 wheels, broader wheels and driving with belts on all wheels. However, bilberry has a complex root system and often reproduce vegetative, thus damages to the roots or basal shoots can reduce bilberry cover (Flower-Ellis 1971).

In the analyses of scarification variables I found that cover of dead wood had a negative effect on bilberry cover. During logging a harvester will be cutting several trees in one place before moving on, leaving piles of wood debris in the stand. That cover of dead wood showed a negative relationship with bilberry can be explained by that debris will act as an impenetrable cover preventing sun light from reaching the ground or bilberries growing through. However in the field, there were bilberry growing in open areas in the piles where light was available. Another explanation to this could be that piles of wood debris are preventing bilberry from being registered as cover. Bilberry had the highest percentage coverage when accompanied by *Vaccinium vitis-idaea*. This is explained by that *Vaccinium vitis-idea* occurs commonly on the same vegetation types as bilberry in pine forests (Ritchie 1955). This also applies to *Empetrum nigrum* and *Calluna vulgaris* which were also positively correlated with coverage of bilberry (Gimingham 1960; Bell & Tallis 1973), though *Calluna vulgaris* is more light-demanding than bilberry. Interestingly I found that when *Deschampsia* ssp. occurred together with bilberry in the plots there would be higher cover of bilberry than together with *Carex* spp. Though this could be explained by that many of the *Carex* species are found on wet and peaty soils (Lid & Lid 1994), which is not the preferred habitat for bilberry.

Cover of other field layer vegetation was found to have a positive relationship with the cover of bilberry in the test with the outlier, but not when the outlier was removed. I suspect therefore that the effect of percentage other field layer vegetation cover is caused by the outlier. In the analyses of scarification intensity I found cover of other field layer vegetation to have a positive relationship with bilberry cover. This is probably because the scarification variables were not included in this model, as the scarification will remove cover of other field layer vegetation species as well as bilberry. Therefor an increased coverage of scarification in the plot would mean a reduced coverage of any field layer vegetation species. Both covers of stones and water, and trees were found to have a positive effect on cover of bilberry in the model including scarification intensity. This is also explained by the absence of scarification variables in the model, as both stones and trees can act as physical obstacles to scarification, as well as providing some shade.

When scarifying a stand there are areas impossible to scarify due to e.g. large boulders, also the machine operator will avoid driving closely to the seed trees left in the stand to regenerate it. Areas covered by water or close to water cover such as streams or wet areas also left undisturbed. A high cover of stones, water or trees can therefore explain some of the variation in how much of a stand have been scarified, meaning that even if treated with high intensity a large proportion of trees, stones or water will limit the treatment. When clear-cutting, the operators and forest owners are required to leave a buffer zone of a certain width depending on the streams size (Living forests s.a.). The certification standard Living forests (s.a.) requires that 10 trees/hectare per stand are left when clear-cutting as retention trees, preferably clustered. These are left in the stand to die naturally to ensure a certain amount of dead wood in a stand for conservation purposes. The retention trees are sometimes left in groups in the edge of the stand or in an un-accessible area for clear-cutting. This will also be an area within the stand where there will be a limited amount of scarification, which might have a higher cover of bilberry. That cover of trees have a positive effect on cover of bilberry concurs with the findings of (Nielsen, Totland & Ohlson 2007).

4.2 Bilberry cover and height varied with time since scarification

4.2.1 **Cover**

I found a difference in the percent cover of bilberry in stands of different ages since scarification, there was significantly higher coverage of bilberry in the older stands scarified in 2008 and 2009 than in the younger ones from 2012. As there where a higher cover of bilberry in the oldest stands, a possible explanation could be that bilberry compensates for damage by regrowth, and that competition with establishing pioneer species not yet has had time to reduce the abundance of bilberry. As well that many dwarf-shrubs such as bilberry are capable of vegetative reproduction. Though, Palviainen *et al.* (2007) found in their study that field vegetation was slow to regrow in scarification furrows, and as clear-cuts have poor growth conditions for bilberry (Atlegrim & Sjöberg 1996) the regrowth might be limited. Though, since bilberry is not the only plants removed during the scarification; their competitors will also be affected negatively by scarification.

After a clear-cutting there will be an increase in the amount of available nutrients, this combined with a reduced competition pressure should facilitate increased regrowth. But bilberry has been found not to have increased growth with increased amounts of nitrogen (Strengbom, Näsholm & Ericson 2004), this increased nutrient availability would rather facilitate pioneer species. Pioneer species are adapted to fast growth in open areas with a high nutrient and light availability. Many of the typical pioneer species that follows in the succession of a clear-cutting needs some time to establish in the stand as they might have a very low abundance in a mature stand if even present (Nieppola 1992). Therefore it can be a form of time lag before bilberry cover declines as a result of competition with establishing pioneer species. This is supported by Nieppola (1992) who found that the decrease in cover of many species regularly found in mature stands was strong up to four years after a clear-cut. I can only therefore say that I found partial support for my hypothesis 2, meaning that if there is some form of compensatory regrowth it is limited. And that this might depend more on the severity of the scarification on bilberry plants and reproductive parts of bilberry in addition to poorly suited habitat for bilberry growth (Atlegrim & Sjöberg 1996; Haeussler, Bartemucci & Bedford 2004).

As all stands were scarified at low intensity by the same method, and where selected to have the same site index distribution, they should be rather similar. However, the difference in the stands of different ages could be caused by variation in the stands before scarification or differences in climate variables during the years after clear-cutting and scarification. There is a small difference in sample size between the years, with three more samples from 2012 compared to 2009 and four more from 2012 than 2008. This could also create an effect between the years, but the sample size difference is not big enough for this to be likely, this applies to both cover and average height of bilberry.

As seen in the previous tests of scarification variables, I again found that coverage of exposed mineral soil and turned humus reduced coverage of bilberry at a plot level. Cover of turned humus showed the same relation with bilberry average height as found for bilberry cover, and I expect the effect on both. As cover of tracks was not significant, it is probable that it is more of a temporary damage above ground level than what exposed mineral soil and turned humus is. Though, it could also be explained by that the effect of tracks on cover is less pronounced when just looking at stands scarified at low intensities. When looking at the coverage of bilberry in stands scarified at different times, cover of water and stones showed a negative relationship with cover of bilberry. This being opposite of what I found just looking at stands from 2012, a possible reason for this relationship could be that water and stones is a permanent cover preventing bilberry from growing. Cover of trees showed the same pattern as found when investigating the effect of scarification as they have some common data, so this pattern also applies when investigating older scarified stands.

The species co-occurring with bilberry in the plots had different effects on bilberry cover. Again *Vaccinium vitis-idaea* was the species that when accompanying bilberry would give the highest cover, compared to if bilberry was accompanied by *Deschampsia* spp., *Calluna vulgaris, Carex* spp. and other species. The find that there was a low abundance of bilberry when accompanied by *Deschampsia* spp. was a logical result, as *Deschampsia* spp. and especially *Deschampsia flexuosa* is a typical pioneer species in the succession following a clear-cut stand and (Nieppola 1992). *Deschampsia flexuosa* is adapted to rapid growth after establishing in clear-cuts and have been found to grow well with bilberry (Hester, Miles & Gimingham 1991), and as *Deschampsia flexuosa* is the superior competitor it will eventually overgrow bilberry plants and kill them.

That there was a lower cover of bilberry when accompanied by *Carex* spp. can be caused by that *Carex* spp. are often found in less suitable areas for bilberry such as wet soils that can contain a lot of peat (Gimingham 1960; Lid & Lid 1994). Both *Empetrum nigrum* and *Calluna vulgaris* gave higher cover bilberry when accompanying bilberry than if bilberry was accompanied by *Carex* spp. Though, they can grow in less suitable areas for bilberry (Gimingham 1960; Bell & Tallis 1973), they both are commonly found together with bilberry as field layer vegetation (Fremstad 1997). It is difficult to clearly interpret the low bilberry cover when bilberry was accompanied by the group other species, as this is a group consisting of completely different orders of plants. Therefor grouping them together can be questioned, but these were all species with only one observation therefore treating them separately would not be an alternative.

4.2.2 **Height**

The analyses of average height revealed that the average height of bilberry was higher in the stands scarified in 2009 than the ones scarified in 2008 and 2012. This is an interesting finding, and could further support that bilberry is capable of some regrowth in the scarified stands, before the establishment of competitors will affect bilberry. Kull and Aan (1997) found that an increased competition for light can lead to a decrease in species in the field vegetation, and that when this occur forbs mainly decreases while graminoids increase. Therefore the differences in height, with 2009 having the highest average height could be a response to increased competition that occurs after the establishment of pioneer species. In the competition for light, graminoids dominate because of their high nitrogen usage efficiency (Kull & Aan 1997). In addition Moola and Mallik (1998) found in their study that the biomass growth of *Vaccinium myrtilloides* increased after clear-cuts, but that this was not caused by an increase in available sunlight. It is therefore plausible that bilberry will have the same response. This could explain why average height was lower in 2008 than 2009, as with time the pioneer species will dominate and overgrow bilberry.

Of the scarification variables cover of humus and cover of tracks were both found having a negative correlation with the average height of bilberry. The negative relationship between humus and bilberry average height could be explained by that scarification effects the bilberry growth. Through higher temperatures in the soil (Wetzel & Burgess 2001) and with a subsequent increased evaporation from the soil. It has been found that stands only clear-cut, have had lower water content I bilberry than in un-cut areas (Atlegrim & Sjöberg 1996).

Though, another explanation could be that with a lowered competition for light, the height growth might be less important for bilberry. When looking at average height in the stands scarified at different times, it was an interesting finding that the cover of tracks showed a negative effect on the average height of bilberry in low intensity scarified stands. This can further support my theory, that driving in the stand might be underestimated as a potential source of damages to bilberry both above and below ground. Though this damage, at least above ground can have a more temporary effect then the removal of whole plants and roots. I found two co-variables showing a positive correlation with bilberry average height. Trees cover had a positive correlation with bilberry average height, further supporting that presence of trees in the plot had a positive effect. As cover of other field layer vegetation was positively correlated with average height of bilberry, this can be explained by competition. With an increasing cover of another field layer species the competition for light, can cause more height growth. Pioneer species such as *Deschampsia flexuosa* have been found to increase their abundance with increased light, and being a superior competitor with increased light, bilberry might increase height growth as response to the increased competition (Kull & Aan 1997; Strengbom, Näsholm & Ericson 2004; Mathisen *et al.* 2010).

That bilberry was accompanied by *Vaccinium vitis-idaea, Empetrum nigrum or Vaccinium uliginosum* the average height was greater than with *Carex* spp. can be explained by the habitats they are found in. *Carex* spp. grows in less favourable habitat for bilberry and it usually grows higher that bilberry which could cause the bilberry to exert height growth (Lid & Lid 1994), however, another explanation could be that *Carex* spp. can grow dense in mats or tussocks overgrowing the bilberry (Lid & Lid 1994). Bilberry is not so commonly found with *Vaccinium uliginosum* as with *Vaccinium vitis-idaea* and *Empetrum nigrum* (Fremstad 1997), caused by different preferences in growth habitats (Jacquemart 1996). Bilberry usually grows lower than *Vaccinium uliginosum* (Lid & Lid 1994; Jacquemart 1996), so when they do co-exist, bilberry might exert height growth as a response for light competition

4.3 Available forage for moose

When the cover of bilberry decreases, this corresponds to a decrease in the amount of biomass in the stand, supporting hypothesis 3. This reduction in biomass (both live biomass and necromass) can have an effect on the moose forage availability. As mentioned earlier bilberry is a forage of great importance to the moose especially in autumn and in spring (Cederlund, Ljungqvist & Markgren 1980). High intensity scarification may potentially decrease moose forage availability through the removal of bilberry. However, during the succession in a forest stand after a clear-cut several other palatable species for moose e.g. fireweed will increase in abundance. But many of these palatable pioneer forbs will mainly be browsed in summer. Though species such as *Deschampsia flexuosa* can be forage in the same period through the year, it is a less important forage for moose looking at quantity consumed (Cederlund, Ljungqvist & Markgren 1980). With the arrival of snow cover, moose will shift from bilberry and other dwarf-shrubs to twigs of shrubs and trees (Markgren 1974; Cederlund, Ljungqvist & Markgren 1980). It is therefore plausible to expect moose to forage on bilberry (preferred forage to pine) if there is no or little snow cover through the winter. Månsson (2009) found that the food selection of moose can vary between years, due to variation in climate, such as snow depth. Moose can cause severe damages to Scots pine regenerations, as Scots pine for moose is a more energetically profitable to forage on (Härkönen 1998). Therefore keeping a high cover of bilberry in the stand could release some of the browsing pressure off Scots pine at least in late autumn and early spring. Moose have a medium preference for Scot's pine, but the selection of plant to forage on will be less important if the overall quality of forage is low, meaning that the moose will go for quantity (Edenius *et al.* 2002). This was further supported by Månsson (2009), who found that browsing pressure on Scots pine was reduced with increased forage availability in the landscape.

That bilberry is negatively affected by clear cutting (Bråkenhielm & Persson 1980; Bråkenhielm & Liu 1998) will affect forage availability for moose, but then there might be an additional effect by scarification. This could mean that an already lower bilberry cover can be reduced even more by the alterations in microclimate such as increased sun exposure (Kubin & Kemppainen 1994) and higher soil temperatures in the exposed mineral soil (Bedford & Sutton 2000). Though it is natural in the forest succession that bilberry will be outcompeted by pioneer species (Bråkenhielm & Liu 1998), the high intensity scarification might reduce important moose forage more than with just a low intensity scarification. This is important to keep in mind as the bilberry will not have increase in abundance until the stand is in the thinning stage, decades later (Parlane *et al.* 2006).The results from analysing necromass are a bit more inconclusive, the low amounts of necromass in 2012 are correlated with the low bilberry cover in the same year. There was no big difference in the amounts of necromass in the different years; this would not affect moose forage. Though plants with a large proportion of their biomass being necromass could be less preferred than plants with a low proportion of necromass, but this is difficult to predict.

5. Conclusions

I conclude that high intensity scarification will lower the abundance of bilberry at plot level. As this was not found at a stand level, the variation of scarification within a stand will only be detectable on a small scale. This also means that scarification variables such as cover of exposed mineral soil, turned humus and tracks is a better measurement of the effects of scarification on bilberry than stand-scale intensity. This can prove useful for future research looking at the effects scarification have on bilberry. The cover and average height of bilberry in stands scarified at different times varies, and I suspect there is a form of time-lag possible with a limited amount of regrowth before bilberry is outcompeted by pioneer species. As bilberry has been found to have negative effects from clear-cuts (Bråkenhielm & Persson 1980), it is not clear what direct effects scarification will have through the exposure of mineral soil and turned humus. As there is little research done looking at the effects of scarification on bilberry, this should be increased in future especially the long-term effects of scarification.

Though, the goal of high intensity scarification is to achieve a high enough number of future stems out of browse height for moose, reducing the negative impact moose browsing have on Scots pine regenerations. But it should be as important to minimize the reduction of other forages sources for moose as well as reduce browsing on Scots pine. Especially in the management perspective, as bilberry is an important species in the boreal forest for many other species (Fernandez-Calvo & Obeso 2004), and for moose it is important in certain periods of the year (Cederlund, Ljungqvist & Markgren 1980). High intensity scarification can therefore further complicate the problem of browsing damages caused by moose, by lowering an alternative food source, and should therefore be avoided.

References

Aleksandrowicz-Trzińska, M., Drozdowski, S., Brzeziecki, B., Rutkowska, P. & Jablońska, B. (2014) Effects of different methods of site preparation on natural regeneration of Pinus sylvestris in Eastern Poland. *Dendrobiology,* **71,** 73-81.

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.

Atlegrim, O. & Sjöberg, K. (1996) Response of bilberry (Vaccinium myrtillus) to clear-cutting and single-tree selection harvests in uneven-aged boreal Picea abies forests. *Forest Ecology and Management,* **86,** 39-50.

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.

Bell, J. & Tallis, J. (1973) Empetrum Nigrum L. *The Journal of Ecology***,** 289-305.

Bergquist, J., Örlander, G. & Nilsson, U. (1999) Deer browsing and slash removal affect field vegetation on south Swedish clearcuts. *Forest Ecology and Management,* **115,** 171-182.

Bergstedt, J., Hagner, M. & Milberg, P. (2008) Effects on vegetation composition of a modified forest harvesting and propagation method compared with clear-cutting, scarification and planting. *Applied vegetation science,* **11,** 159-168.

Bergstedt, J. & Milberg, P. (2001) The impact of logging intensity on field-layer vegetation in Swedish boreal forests. *Forest Ecology and Management,* **154,** 105-115.

Bergström, R. & Hjeljord, O. (1987) Moose and vegetation interactions in southwestern Europe and Poland. *Swedish Wildlife research,* **Supplement 1,** 213-228.

Bråkenhielm, S. & Liu, Q. (1998) Long-term effects of clear-felling on vegetation dynamics and species diversity in a boreal pine forest. *Biodiversity & Conservation,* **7,** 207-220.

Bråkenhielm, S. & Persson, H. (1980) Vegetation dynamics in developing Scots pine stands in central Sweden. *Ecological Bulletins***,** 139-152.

Cederlund, G., Ljungqvist, H. & Markgren, G. (1980) Foods of moose and roe-deer at Grimsö in Central Sweden results of rumen content analysis. *Swedish Wildlife research,* **11,** 171-247.

Edenius, L., Bergman, M., Ericsson, G. & Danell, K. (2002) The role of moose as a disturbance factor in managed boreal forests. *Silva Fennica,* **36,** 57-67.

Fernandez-Calvo, I. & Obeso, J. (2004) Growth, nutrient content, fruit production and herbivory in bilberry Vaccinium myrtillus L. along an altitudinal gradient. *Forestry,* **77,** 213-223.

Flower-Ellis, J.G.K. (1971) *Age structure and dynamics in stands of bilberry (Vaccinium myrtillus L.).* Royal college of Forestry, Stockholm.

Fremstad, E. (1997) *Vegetasjonstyper i Norge [Norwegian vegetation types]*. NINA: Norsk institutt for naturforskning, Trondheim.

Gimingham, C. (1960) Calluna Salisb. *The Journal of Ecology***,** 455-483.

Haeussler, S., Bartemucci, P. & Bedford, L. (2004) Succession and resilience in boreal mixedwood plant communities 15–16 years after silvicultural site preparation. *Forest Ecology and Management,* **199,** 349-370.

Hamberg, L., Malmivaara-Lämsä, M., Lehvävirta, S., O'Hara, R.B. & Kotze, D.J. (2010) Quantifying the effects of trampling and habitat edges on forest understory vegetation–a field experiment. *Journal of environmental management,* **91,** 1811-1820.

Hedmark university college (s.a.) *Skogbruk og elg - kan økt fôrproduksjon redusere beiteskader?* Forestry and moose- can increased forage production reduce damages caused by browsing? Retrieved from http://www.hihm.no/Hovedsiden/Campus-Evenstad/Forskning/Forskningsprosjekter/Skogbruk-og-elg

Hedwall, P.O., Brunet, J., Nordin, A. & Bergh, J. (2013) Changes in the abundance of keystone forest floor species in response to changes of forest structure. *Journal of vegetation science*, **24,** 296-306.

Heikkilä, R. (1991) Moose browsing in a Scots pine plantation mixed with deciduous tree species. *Acta forestalia fennica*, **224,** 2-13.

Hester, A., Miles, J. & Gimingham, C. (1991) Succession from heather moorland to birch woodland. II. Growth and competition between Vaccinium myrtillus, Deschampsia flexuosa and Agrostis capillaris. *The Journal of Ecology***,** 317-327.

Härkönen, S. (1998) Effects of silvicultural cleaning in mixed pine-deciduous stands on moose damage to scots pine (Pinus sylvestris). *Scandinavian Journal of Forest Research*, **13,** 429-436.

Hörnberg, S. (2001) The relationship between moose (Alces alces) browsing utilisation and the occurrence of different forage species in Sweden. *Forest Ecology and Management*, **149,** 91-102.

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.

Jacquemart, A.-L. (1996) Vaccinium uliginosum L. *Journal of ecology***,** 771-785.

Karlsson, C., Sikström, U., Örlander, G., Hannerz, M. & Hånell, B. (2009) *Skogskötselserien: Naturlig föryngring av tall och gran.* [Silviculture series: Natural regeneration of Scots pine and Norway spruce]. Retrieved from http://www.skogsstyrelsen.se/Global/PUBLIKATIONER/Skogsskotselserien/PDF/04-Naturlig%20foryngring%20av%20tall%20och%20gran.pdf

Komatsu forest (2014) *Produktoversikt: Lassbærer.* [Product overview: forwarders]. Retrieved from http://www.komatsuforest.no/default.aspx?id=18090&ptid=0&rootID=18090

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**.

Kull, O. & Aan, A. (1997) The relative share of graminoid and forb life-forms in a natural gradient of herb layer productivity. *Ecography*, **20,** 146-154.

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

Lid, J. & Lid, D.T. (1994) *Norsk flora [Norwegian flora]*. Det Norske Samlaget, Gjøvik.

Living forests (s.a.) *Standard for sustainable forest management in Norway.* Retrieved from http://www.levendeskog.no/levendeskog/vedlegg/51Levende_Skog_standard_Engelsk.pdf

Markgren, G. (1974) The moose in Fennoscandia. *Naturaliste canadien*, **101,** 185-194.

Mathisen, K., Buhtz, F., Danell, K., Bergström, R., Skarpe, C., Suominen, O. & Persson, I.L. (2010) Moose density and habitat productivity affects reproduction, growth and species composition in field layer vegetation. *Journal of vegetation science*, **21,** 705-716.

Moen, A. (1999) *National Atlas of Norway: Vegetation*. Norwegian Mapping Authority, Hønefoss.

Moola, F. & Mallik, A. (1998) Morphological plasticity and regeneration strategies of velvet leaf blueberry (Vaccinium myrtilloides Michx.) following canopy disturbance in boreal mixedwood forests. *Forest Ecology and Management,* **111,** 35-50.

Månsson, J. (2009) Environmental variation and moose Alces alces density as determinants of spatio-temporal heterogeneity in browsing. *Ecography,* **32,** 601-612.

Nielsen, A., Totland, Ø. & Ohlson, M. (2007) The effect of forest management operations on population performance of Vaccinium myrtillus on a landscape-scale. *Basic and Applied Ecology,* **8,** 231-241.

Nieppola, J. (1992) Long-term vegetation changes in stands of Pinus sylvestris in southern Finland. *Journal of vegetation science,* **3,** 475-484.

Nybakken, L., Selas, V. & Ohlson, M. (2013) Increased growth and phenolic compounds in bilberry (Vaccinium myrtillus L.) following forest clear-cutting. *Scandinavian Journal of Forest Research,* **28,** 319-330.

Palviainen, M., Finér, L., Laurén, A., Mannerkoski, H., Piirainen, S. & Starr, M. (2007) Development of ground vegetation biomass and nutrient pools in a clear-cut disc-plowed boreal forest. *Plant and soil,* **297,** 43-52.

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.

Pastor, J., Dewey, B., Naiman, R., McInnes, P. & Cohen, Y. (1993) Moose browsing and soil fertility in the boreal forests of Isle Royale National Park. *Ecology,* **74,** 467-480.

Persson, I.L., Pastor, J., Danell, K. & Bergström, R. (2005) Impact of moose population density on the production and composition of litter in boreal forests. *Oikos,* **108,** 297-306.

Ritchie, J. (1955) Vaccinium Vitis-Idaea L. *The Journal of Ecology***,** 701-708.

Ritchie, J. (1956) Vaccinium myrtillus L. *The Journal of Ecology***,** 291-299.

Statistics Norway (2014) *Skogkultur, 2013.* [Silviculture, 2013]. Retrieved from http://ssb.no/jord-skog-jakt-og-fiskeri/statistikker/skogkultur/aar/2014-04-29?fane=tabell&sort=nummer&tabell=174353

Steinset, T.A. (2000) *Norsk skoghåndbok* [Norwegian handbook of forestry]. Landbruksforlaget, Grønland.

Strengbom, J., Näsholm, T. & Ericson, L. (2004) Light, not nitrogen, limits growth of the grass Deschampsia flexuosa in boreal forests. *Canadian Journal of botany,* **82,** 430-435.

Uusitalo, J. (2010) *Introduction to forest operations and technology*. JVP Forest Systems Oy, Hämeenlinna.

Wagner, S., Fischer, H. & Huth, F. (2011) Canopy effects on vegetation caused by harvesting and regeneration treatments. *European journal of forest research,* **130,** 17-40.

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.

Wam, H.K., Hjeljord, O. & Solberg, E.J. (2010) Differential forage use makes carrying capacity equivocal on ranges of Scandinavian moose (Alces alces). *Canadian Journal of Zoology,* **88,** 1179-1191.

Wetzel, S. & Burgess, D. (2001) Understorey environment and vegetation response after partial cutting and site preparation in Pinus strobus L. stands. *Forest Ecology and Management,* **151,** 43-59.

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.

Østgård, J. (1987) Status of the moose in Norway in the 1970's and early 1980's. *Swedish Wildlife research*, **Supplement 1,** 63-68.

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6. Appendix A: Effects of scarification intensity on the cover of bilberries

The only difference between the models with/without the outlier in bilberry cover where that cover of stones and water was included in the final model with the outlier.

With outlier:

I found positive significant effect of cover of other field layer vegetation species (L_{15} = 23.81; $p < 0.0001$, table A1), Cover of trees (L_{15} = 4.85; $p = 0.028$, tableA1) and cover of stones and water (L_{15} = 4.01; $p = 0.045$ table A1) on bilberry cover. Cover of dead wood showed a negative correlation (L_{15} = 5.75; $p = 0.016$, table A1) with cover of bilberry.

Among the field layer vegetation species significant (L_{9} = 31.23; $p < 0.001$, table A1) I found that there was higher cover of bilberries when *Vaccinium vitis-idaea* were accompanying bilberry in the plot than when *Calluna vulgaris, Vaccinium uliginosum* and other species were. I also found that was a higher cover of bilberry when *Empetrum nigrum, Calluna vulgaris* and *Deschampsia* spp. was accompanying bilberry than when *Carex* spp. or other species were.

During the backwards selection of this model I removed scarification intensity (L_{15} = 0.61; $p = 0.435$) as it showed no significant relationship with bilberry cover.

Table A1. Statistical results from the analysis of bilberry cover and intensity with outlier not back transformed. *Calluna vulgaris* is presented in the intercept and the categorical estimates should be interpreted as relative to intercept.

	Estimate	**SE**
Intercept	0.57	0.127
Field layer vegetation species		
Carex spp.	0.29	0.217
Deschampsia spp.	-0.06	0.223
Empetrum nigrum	0.27	0.159
Other species	-0.18	0.633

Vaccinium uliginosum	-0.24	0.370
Vaccinium vitis-idaea	0.41	0.112
Cover other field layer vegetation	0.05	0.010
Cover of stones and water	0.01	0.006
Cover of trees	0.05	0.024
Cover of dead wood	-0.01	0.003

6.1.1 **Without outlier:**

I found that both cover of other field layer vegetation species ($L_{13} = 25.15$; $p < 0.0001$, table A2) and cover of trees ($L_{13} = 5.11$; $p = 0.024$, table A2) to give a positive correlation with the cover of bilberry. Cover of dead wood showed a negative correlation with the cover of bilberry ($L_{13} = 6.21$; $p = 0.013$, table A2). Among the field layer vegetation species significant ($L_{7} = 31.78$; $p < 0.0001$, table A2), giving the same effects as described in the results with the outlier.

During the backwards selection I removed cover of stones and water ($L_{15} = 0.58$; $p = 0.448$) and scarification intensity ($L_{14} = 0.84$; $p = 0.361$) as they showed no significant relationship with bilberry cover.

Table A2. Statistical results from the analysis of bilberry cover and intensity without outlier not back transformed. *Calluna vulgaris* is presented in the intercept and the categorical estimates should be interpreted as relative to intercept.

	Estimate	**SE**
Intercept	0.57	0.123
Field layer vegetation species		
Carex spp.	0.28	0.209
Deschampsia spp.	-0.03	0.215
Empetrum nigrum	0.27	0.153
Other species	-0.18	0.610
Vaccinium uliginosum	-0.25	0.356

Vaccinium vitis-idaea	0.41	0.108
Cover other field layer vegetation	0.05	0.009
Cover of trees	0.05	0.023
Cover of dead wood	-0.01	0.003

7. Appendix B: Scarification variables and cover of bilberries without outlier

I found that cover of mineral soil ($L_{14} = 11.24$, $p < 0.001$; table B1), cover of humus ($L_{14} = 10.64$; $p = 0.001$, table B1) and cover of tracks ($L_{14} = 6.89$, $p < 0.009$; table B1) all had a negative correlation with the cover of bilberry. Cover of dead wood also had a negative correlation with bilberry cover ($L_{14} = 5.82$; $p < 0.016$, table B1). I found field layer vegetation species to be significant ($L_{8} = 18.70$; $p < 0.009$, table B1), giving the same effect as described in appendix A.

During the backwards selection of this model I removed cover of stones and water ($L_{17} = 0.31$; $p = 0.578$), cover of other field vegetation ($L_{16} = 3.06$; $p = 0.08$) and cover of trees ($L_{15} = 3.69$; $p = 0.055$) as they showed no significant relationship with bilberry cover.

Table B1. Statistical results from the analysis of bilberry cover and scarification variables without the outlier not back transformed. *Calluna vulgaris* is presented in the intercept and the categorical estimates should be interpreted as relative to intercept.

	Estimate	**SE**
Intercept	1.87	0.692
Cover of mineral soil	-0.05	0.014
Cover of humus	-0.05	0.016
Cover of tracks	-0.04	0.017
Field layer vegetation species		
Carex spp.	3.00	1.250
Deschampsia spp.	0.90	1.285
Empetrum nigrum	1.14	0.912
Other species	1.49	3.734
Vaccinium uliginosum	-0.51	2.135
Vaccinium vitis-idaea	2.12	0.645
Cover of dead wood	-0.05	0.019

8. Appendix C: Scarification intensity and live biomass

When I tested scarification intensity and live biomass I found a significant difference between the years; there was lower amounts of bilberry biomass in 2012 than in 2008 and 2009 ($L_{13} = 27.16$; $p < 0.0001$, table C1). I found no difference between 2008 and 2009 (table C1). I found cover of trees to have a positive correlation with live bilberry biomass ($L_{14} = 5.08$; $p < 0.024$, table C1).

Live biomass of bilberry varied with the presence of other plant species ($L_{7} = 68.03$; $p < 0.0001$, table C1) and when bilberry was accompanied by *Vaccinium vitis-idaea* it gave higher amounts of live biomass than *Calluna vulgaris, Deschampsia* spp. and other species were. When *Empetrum nigrum* or *Calluna vulgaris* where accompanying bilberry, it gave higher amounts of live bilberry biomass than other species were.

During the backwards selection I removed cover of dead wood ($L_{18} = 0.01$; $p = 0.919$), scarification intensity ($L_{17} = 0.72$; $p = 0.397$), cover of stones and water ($L_{16} = 0.96$; $p = 0.328$) and cover other field vegetation specie ($L_{15} = 1.09$; $p = 0.297$) as they showed no significant relationship with bilberry cover.

Table C1. Statistical results from the analysis of live biomass and scarification intensity not back transformed. *Calluna vulgaris* and the year 2008 is presented in the intercept and the categorical estimates should be interpreted as relative to intercept.

	Estimate	**SE**
Intercept	3.66	0.165
Year scarified		
2009	0.25	0.210
2012	-0.78	0.179
Field layer vegetation species		
Carex spp.	-0.35	0.218
Deschampsia spp.	-0.27	0.171
Empetrum nigrum	0.37	0.143

Other species	-0.34	0.467
Rubus spp.	-0.69	0.405
Vaccinium uliginosum	0.15	0.346
Vaccinium vitis-idaea	0.42	0.089
Cover of trees	0.07	0.030

9. Appendix D: Scarification intensity and necromass

I found that there was significant difference in necromass among years ($L_{15} = 6.57$; $p = 0.038$, table D1) though this was not strong (table D1). Cover of stones and water ($L_{15} = 6.94$; $p = 0.008$, table D1) and cover of dead wood ($L_{15} = 43.70$; $p < 0.0001$, table D1) both gave a negative correlation with bilberry necromass.

Necromass of bilberry varied with the presence of other plant species ($L_{8} = 58.23$; $p < 0.0001$, table D1) and when bilberry is accompanied by *Vaccinium vitis-idaea* it gave higher amounts of necromass than with *Calluna vulgaris*, *Empetrum nigrum*, *Rubus* spp., *Deschampsia* spp., *Carex* spp. and other species. When bilberry was accompanied by *Empetrum nigrum* it gave higher amounts of biomass than with *Calluna vulgaris*, *Rubus* spp., *Deschampsia* spp., and other species. I also found that if bilberry was accompanied by *Calluna vulgaris* and *Carex* spp. this would give higher amounts of necromass than with *Deschampsia* spp., and other species.

During the backwards selection I removed cover of trees ($L_{18} = 0.05$; $p = 0.826$) and cover other field vegetation specie ($L_{16} = 3.26$; $p = 0.071$) as they showed no significant relationship with bilberry cover.

Table D1. Statistical results from the analysis of necromass and scarification intensity not back transformed. *Calluna vulgaris* and the year 2008 is presented in the intercept and the categorical estimates should be interpreted as relative to intercept.

	Estimate	**SE**
Intercept	1.74	0.190
Year scarified		
2009	0.26	0.238
2012	-0.22	0.203
Field layer vegetation species		
Carex spp.	0.21	0.271
Deschampsia spp.	-0.67	0.212

Empetrum nigrum	0.34	0.178
Other species	-0.94	0.582
Rubus spp.	-1.33	0.504
Vaccinium uliginosum	0.05	0.428
Vaccinium vitis-idaea	0.39	0.111
Cover of stones and water	-0.02	0.006
Cover of dead of wood	-0.03	0.005