Effects on natural seed regenerated Silver birch (Betula pendula Roth) and Downey birch (Betula pubescens Ehrh) by mechanical soil scarification and environmental factors

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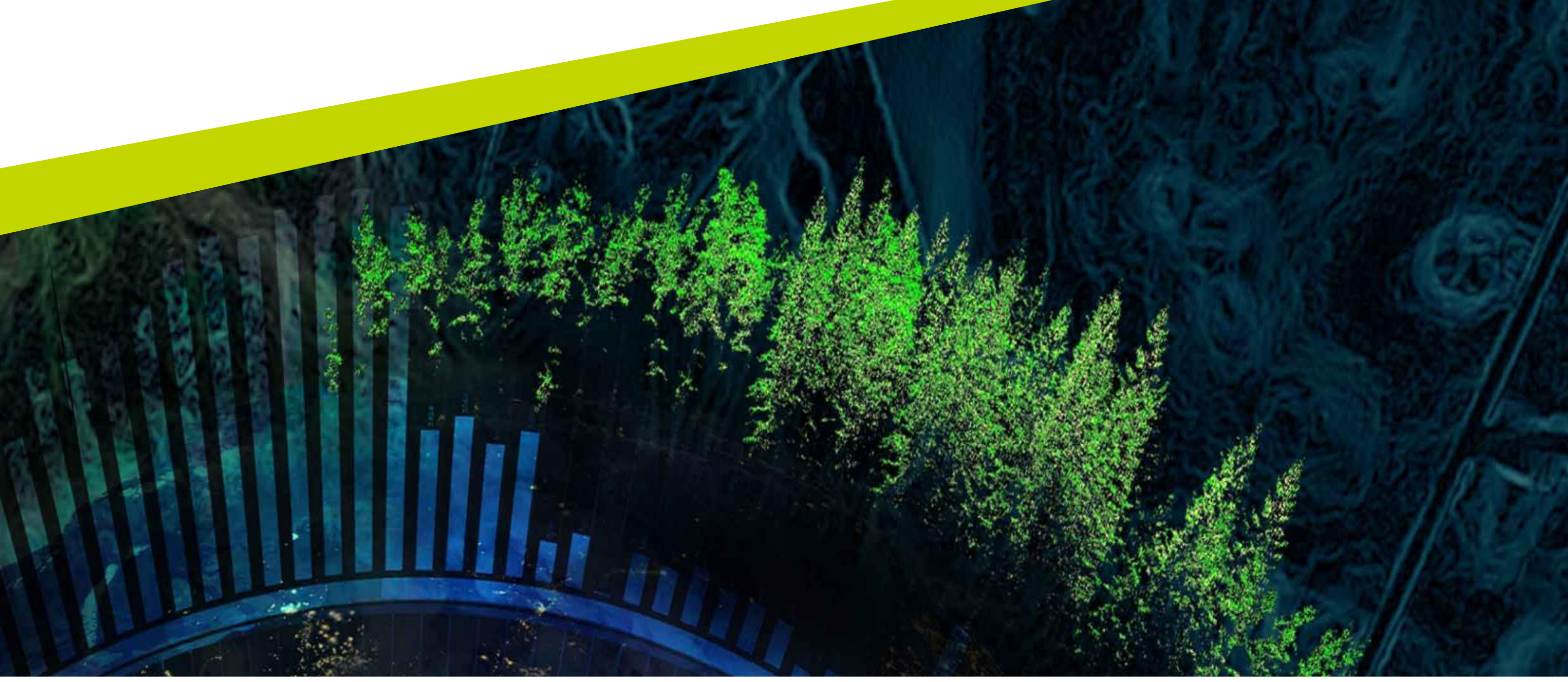

Effects on natural seed regenerated Silver birch (*Betula pendula* Roth) and Downey birch (*Betula pubescens* Ehrh) by mechanical soil scarification and environmental factors

Påverkan på naturligt fröföryngrad Glasbjörk (Betula pubescens Ehrh) och Hängbjörk (Betula pendula Roth) av mekanisk markberedning och omgivande faktorer

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Abstract

The awareness of forest biodiversity as well as the demand for a higher proportion of deciduous tree species in Swedish forests increases. As such, focus is shifting towards the management of naturally seed regenerated Silver birch (*Betula pendula* Roth) and Downey birch (*Betula pubescens* Ehrh). It is therefore essential to extend the knowledge of how birch seed regeneration is affected by management interventions as well as biotic and abiotic environmental factors. I selected 20 sites in northern Sweden that had been clear-cut between 2014 – 2019. Half of the sites had undergone mechanical scarification within two years after clear-cut. On all sites, a selection of biological, edaphic, and geographical factors along with naturally seed regenerated birch seedlings and saplings present were inventoried using a quadratic systematic grid of plots. Results showed that there was a trend towards a higher number of birch seedlings and saplings on not scarified sites. Also on not scarified sites, there were significantly shorter distances to seed trees and higher moss coverage in comparison to scarified sites, which according to correlation analysis increased number of seed regenerated birch seedlings and saplings. This work illuminates the importance of regarding multiple factors when regenerating birch by seed. Further research that captures the effect by a wide selection of biotic and abiotic environmental factors together with management interventions on birch seed regeneration is needed.

Keywords: Natural birch regeneration, birch seed regeneration, soil scarification

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1. Introduction

Silver birch (*Betula pendula* Roth) and Downey birch (*Betula pubescens* Ehrh) are the most common, as well as for forestry most important, deciduous species in Sweden (Karlsson & Nilsson 2005, Hynynen et. al. 2009). Birch constitutes 11% of the standing total volume and 65% of the standing total hardwood volume in Sweden (Dubois et. al. 2016) and is the dominating deciduous species used in timber, veneer and plywood production (Tiebel et. al 2020). Birch is a pioneer species and is known for having a large seed crop, long seed spreading distances by wind and fast juvenile growth (Liu & Evans 2021). It provides forests with high ecological values through improving soil fertility, the rate of soil nutrient cycling, and increasing biodiversity by supporting many invertebrate species, birds and mammals with habitats (Liu & Evans 2021). Over the past decades, people are becoming more aware of the importance of biodiversity in mitigating risks of pests and climate related stress to forests (ibid), accompanying the ongoing global climate change. As a result, a higher proportion of deciduous species can be expected in western Europe within the coming decades, challenging today's typical homogenous forests (Dubois et. al. 2020).

The interest for broadleaved trees, such as birch, seems to increase among forest owners. Since birch may be more adaptable to the future climate than other species in Sweden (Dubois et. al. 2020), birch could possibly generate valuable products for future markets. Due to the high economic, ecological and societal potential of birch, it is an undervalued species in forestry (ibid). In addition, the emerged standards upheld by certifications (e.g. FCS and PEFC) contribute to the incentives for landowners to increase the proportion of deciduous forest of their land (FSC 2020, PEFC 2017). There seem to be a broad-scale movement towards implementing birch in Swedish forests which is driven by landowners, society and other stakeholders. Thus, the importance of understanding how environmental factors affect birch implementation increases.

Natural birch seed regeneration after clear-cutting may be the most rational choice for landowners to increase the proportion of deciduous forest of their land. Natural regeneration by seed is successful on sites dominated by Scots pine (Pinus sylvestris) or Norway spruce (Picea abies) (Hynynen et. al. 2009), making the method appropriate on most forest sites in Sweden. It is also a cheaper method compared to planting (ibid). Naturally regenerating birch from seed trees after clear-cutting is also a well-known management practice involving closely situated seed trees (Liu & Evans 2021) dispersing their seed crop by wind over the site. Birch seed trees have particularly abundant seed fall every 2-3 years in northern Europe (Hynynen et. al. 2009) and on those occasions the chances of successful regeneration increases. Most seeds disperse within 100 m of the seed tree (Liu & Evans 2021) but spreading distances may vary depending on e.g. seed crop of a tree, wind, aspect and other related field conditions which can make regeneration hard to predict and variable depending on location (Tiebel et. al 2020). Tiebel et. al. (2020) studied downhill birch seed dispersal in the Thuringian Forest, a mountainous area in Germany, and recorded a mean distance of 380 m. Shorter distances has also been recorded in a study in Wytham Woods, Oxfordshire, UK where neighboring forest were denser, suggesting that forest structure of the surrounding environment is important for seed regeneration of birch (Liu & Evans 2021). Furthermore, Granström & Fries (1985) found that most seeds (94%) die within one year after seed fall and that there were a die off rate of 50% per year the following 2 years. This indicates a high seed die off rate in the beginning after a seed fall that declines over time. Seeds stored in the soil could potentially be capable of germinating more than 5 years after seed fall (Granström & Fries 1985). Birch seed regeneration is known for being cheap and to produce large amounts of seeds, but the dispersed seeds may need a disturbed soil seedbed in order to sprout (Granström & Fries 1985).

Mechanical soil scarification is recommended in summer or autumn before seed-fall to improve the seedbed of naturally regenerated birch seeds (Karlsson & Örlander 2000, Karlsson 2001). Although seedling density variation can increase with increased scarification intensity (Saursaunet et. al. 2018) and different types of mechanical scarification may be more effective on different soils (Karlsson 1996), mechanical soil scarification is according to several studies a prerequisite for seed germination and abundant seedling emergence (e.g. Hynynen et. al. 2018, Saursaunet et. al. 2018, Karlsson 1996). Mechanical soil scarification removes competing ground vegetation, exposes mineral soil, reduces competition for light, nutrient and water (Saursaunet et. al. 2018) as well as stabilizes soil moisture conditions (Oleskog & Sahlén 2000). Karlsson et. al. (2002) investigated the effect of ploughing, inversion and rotary cultivation on Silver birch seedling height on silty and sandy soils in Sweden. After three growing seasons, birches treated by any scarification type showed an increase in height growth in both types of soils in comparison to the untreated control. However, although more uncommonly, soil scarification have been reported to have a negative effect on birch seed regeneration. On clear-cuts in southern Sweden on sandy-silty mesic sites, Karlsson

& Nilsson (2005) found fewer birch seedlings on scarified sites in comparison to the untreated control. The negative effect may be explained by performing scarification after a particularly rich seed-fall resulting in less seeds entering scarified patches. While scarification in most studies has been shown to have a positive effects on the establishment of a new generation of birch, it remains unclear how and to what extent differences in environmental biotic and abiotic factors after clear-cut affect birch regeneration and the role of scarification in this context.

Besides the important roles of management interventions and seed sources available, birch seed regeneration is affected by a range of biotic and abiotic environmental factors (e.g. pH, light, seed source availability, soil moisture, fertility and competing ground vegetation; Neuvonen et. al. 1991, Hynynen et. al. 2009, Duibos et. al. 2016, Holmström et. al. 2016). Competing ground vegetation that emerge after clear-cut have been mentioned as an especially important factor by several studies since it may reduce establishment and survival of birch seedlings and saplings (Hynynen et. al. 2009, Dubois et. al. 2020, Karlsson et. al. 2002, Holmström et. al. 2017). Another factor known to affect germination of birch seeds is the availability of organic material in the top soil layer. Humus can hold large volumes of water, which facilitate germination of birch seeds (Kempe & Stener 2006). Humus also contains valuable nutrients such as nitrogen and phosphorus, which may increase height growth of seedlings and saplings (Kempe & Stener 2006, Saursaunet et. al. 2018, SLU 2020). Hence, removing humus layer by scarification may reduce growth of birch seedlings and saplings (Kempe & Stener 2006). Furthermore, scarification are in general connected to several positive effects that are important for seed regeneration of birch; such as removing ground vegetation competition and increasing seedbed temperature (Saursaunet et. al. 2018). However, higher seedbed temperature in combination with low soil moisture on clear-cuts may negatively affect seed germination and cause seedling mortality (Karlsson 1996). As such, successful birch regeneration is often determined by a multitude of factors operating at the same time. Which factors as well as their relative importance are difficult to tease apart by reasoning alone and are to a large degree uninvestigated by other studies. Therefore, a broad-scale inventory capturing a selection of these factors will benefit landowners' understanding of how to promote natural regeneration of birch after clear-cutting.

Here, I will describe how a selection of biological, meteorological, edaphic, and geographical factors and forest management practices (the use or non-use of soil scarification) associate with the presence of seed regenerated birch seedlings and saplings on recent clear-cuts in northern Sweden. The purpose is to improve the knowledge of the role of environmental factors contributing to birch regeneration in the presence and absence of mechanical soil scarification. I will also discuss how these findings may be relevant for practical forest management.

The questions that this study aims to answer are:

1. To what extent do natural regeneration of birch by seed differ depending on whether or not a clear-cut site is scarified or not?

2. Which environmental abiotic and/or biotic factor(s) contribute the most to explain the presence of naturally regenerated birch seedlings and saplings and do the impact of these factors work in the same direction on scarified and not scarified sites?

2. Materials and method

2.1. Study area and stand selection

The study area is located in north-eastern Sweden and covers a latitude of 200 km and the terrain is mainly flat (Table 1). The forest structure of the area is representative for forests in northern Sweden and include cultivated stands of Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) with elements of deciduous trees, mainly birch. Mechanical soil scarification is a common soil preparation method of the area and the cultivation method is most often clear-cutting, leaving clear-cut areas ranging from less than one to several tens of hectares. The effective temperature sum of the area varies 300° C where lower sums are found in south and higher in north.

On 17th September 2021 I selected 20 sites within this area (Figure 1) that were approximately 1 ha large and had undergone clear-cut between 2014-2019. Out of the 20 sites, half of them had undergone mechanical soil scarification within 2 years after clear-cut and the rest had not (Table 1). Mechanical soil scarification is defined as either disc-trenching or mounding with excavator or scarifier and will henceforth be regarded as one type of mechanical scarification. The sites are positioned around the inland of Umeå, reaching Skellefteå in the north and Örnsköldsvik in the south (Figure 1). The sites are owned and cultivated commercially by Holmen AB. Characteristics for most of the sites were podzolic soils, and a field layer dominated by bilberry (*Vaccinium myrtillus*) and other Ericaceous dwarf shrubs. On each scarified and not scarified site, seed trees were often found at the edges of the site.

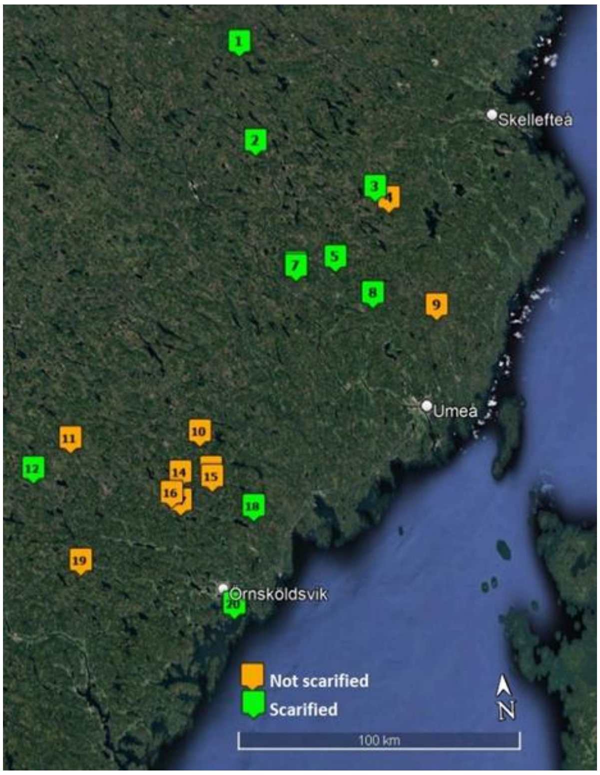

Figure 1. *Map showing the geographical position and site identification number (1-20) of the 20 sites used for this study. Half of the sites are scarified (green markers) and half of them are not (orange markers). The sites are distributed in northern Sweden around the inland of Umeå. See Table 1 for site characteristics of each site.*

Table 1. *Site characteristics of each individual site, arranged by identification number (IN) corresponding to figure 1, used in this study; latitude and longitude in SWEREF 99 (Lat, Long), size in hectare (ha), clear-cut year (y), meters above sea level (MASL), soil moisture type (MT), soil type (ST), site productivity (P) and information about whether or not the site had undergone scarification or not (S).*

IN	Lat, Long	ha	y	MASL	ETS	MT*	ST	P	S
1	7220119, 693069	8.95	2016	376	743	Moist	Sandy/ fine sandy moraine	3	Yes
2	7183560, 699193	0.6	2018	226	895	Moist	Highly decomposed peat	1.6	Yes
3	7166783, 742510	2.98	2019	271	866	Mesic	Lowly decomposed peat	2.8	Yes
4	7162697, 747442	0.66	2018	249	886	Mesic	Lowly decomposed peat	2.5	No

5	7141213, 728171	2.18	2018	268	880	Moist	Sandy/ fine sandy moraine	4.2	Yes
6	7138919, 713814	4.45	2017	230	914	Moist	Sandy moraine	4.3	Yes
7	7137897, 714007	2.34	2019	197	944	Moist	Very fine sandy/silty/clayey moraine	3.8	Yes
8	7128189, 741641	3.02	2014	233	862	Moist	Moraine	3.8	Yes
9	7123829, 764585	2.91	2015	123	967	Mesic	Sandy/ fine sandy moraine	4.9	No
10	7078530, 679753	0.34	2016	256	920	Moist	Sandy/ fine sandy moraine	3.6	No
11	7076050, 633384	0.95	2019	301	879	Moist	Very fine sandy/silty/clayey moraine	4.4	No
12	7065288, 620220	1.72	2015	295	890	Moist	Highly decomposed peat	1.9	Yes
13	7065505, 683795	0.41	2019	218	905	Mesic	Sandy/ fine sandy moraine	6	No
14	7063949, 672909	0.27	2019	215	907	Moist	Sandy/ fine sandy moraine	3.8	No
15	7062447, 684247	0,74	2018	170	954	Moist	Very fine sandy/silty/clayey moraine	4,3	No
16	7056668, 669799	1	2019	242	899	Mesic	Highly decomposed peat	3.8	No
17	7053995, 673034	0.55	2017	171	953	Moist	Very fine sandy/silty/clayey moraine	3.3	No
18	7051964, 699092	1.68	2015	146	981	Mesic	Very fine sand	5.5	Yes

19	7032662, 637514	1.18	2019	289	908	Mesic	Sandy/find sandy moraine	4.9	No
20	7017416, 692351	2.37	2016	53	1032	Moist	Sandy moraine	4.9	Yes

2.2. Inventory design

In each of the 20 sites, seven circular sample plots of 3.14 m^2 (r = 1 m) was laid out in a quadratic systematic NS-EW grid (Figure 2) and the start was randomized.

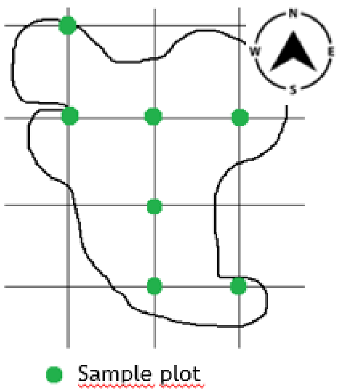

Figure 2. *Overview of the inventory design with an example of a laid out quadratic systematic NS-EW grid and sapling plots in a site.*

Since the sites were of varying area and the aim was to have seven plots in each site, the grid size varied. The grid sides was calculated as:

$$F = \sqrt{A/m}$$

where F = length of grid sides, A = site area, m = number of plots = 7. A compass was used to determine cardinal direction and a 50 m measuring tape was used to walk the correct distances. When sample plot centers was positioned onto a stone or stump, measurements supposed to be taken from the center was moved to nearest possible spot in any direction from the plot center. The expected number of plots were 140 (20 sites * seven expected plots in each site) but since the shape of the sites did not fit the shape of the inventory grid, a total of 122 plots were ultimately inventoried. The measurements took place in late September and early October 2021.

2.3. Data collection

First, I counted the total number of alive seedlings and saplings of Silver birch and Downey birch regenerated by seed present in each plot. Seedlings and saplings are here defined as all birches younger than seven years that have been regenerated by seed. Birch seedlings and saplings that were vegetatively regenerated were not counted. Alive seedlings and saplings that I counted included birches that had experienced browsing, pathogens, pests or other attacks, but these were required to show signs of proceeded growth. If > 10% of the branches were dry, I interpreted this signifying suppressed vitality and the birch was not counted. Silver birch and Downey birch were not separated to the species level because they are both common in Sweden (Duibos, H. et. al. 2016) and can be hard to differentiate at a young age (Saursaunet et. al. 2018). Second, I made a visual estimation by eye of the coverage (%) of mosses, grasses, herbs, brackens, dwarf shrubs and shrubs (aboveground trees and plants with wooded stem that are able to grow over one meter in height in their life time) in each plot. The total sum of coverage could add up to over 100 % since individual species could vertically overlap each other. In addition, I estimated the percentage of the plot that was unavailable for vegetation. These obstructions included stones, rocks, stumps and residues from clear-cut. Third, in the center of each plot, the depth of the humus layer was measured (maximum 30 cm) with a ruler that was inserted vertically into the soil. If the center fell on an surface unfit for humus sampling, such as on stones, roots or water bodies, sampling was carried out as close to the center as possible. The depth of the humus layer was determined by the depth of the Of and Oh layer. The Of layer is composed of visible structures of degrading organic material (> 50 %) and strongly degraded organic material without any visible structure (remaining portion). The Oh layer is composed of at least 75 % of degrading organic material of which at least 50 % consists of strongly degraded organic material without any visible structure (SLU 2020). Forth, A separate humus profile sample was collected from the center of each sample plot using a PVC pipe (2.7 mm in inner diameter) that were pressed maximum 30 cm into the ground. The samples were stored in a refrigerator at + 6 °C until the data collection period had ended, after which they were brought to the lab in Umeå. At the lab, soil pH was determined using a Mettler Teledo MP220 pH meter. The samples of each site separate were mixed together and sieved through a 4 mm steel net and mixed with deionized H_20 to achieve a water:soil weight ratio (scale accuracy = .00 grams) of 3:1. Then the solution was stirred for 10 minutes using a magnetic stirrer. The factor Soil pH is assumed to be the same on all plots on each site. Finally, I determined the distance from each plot center to the closest birch seed tree (diameter > 10 cm in dbh). Since the seed travel distance can be affected by the density of neighboring trees (Liu & Evans 2021) I also recorded whether the seed trees was positioned in an open field or in a nearby forest (mean tree height > 13m). Seed trees found at forest edges that was not fully enclosed was recorded as if they were positioned in an open field.

2.4. Statistical analysis

All data analysis were performed at plot level. Sites characteristics (Table 1) at site level (e.g. soil moisture and site productivity) were excluded from the analysis because the sites were consciously selected - there were no random effect that determined how the site characteristic data were related.

Prior to all tests, residuals of each variable were explored in histograms in order to reveal whether or not they appear to be normally distributed or not. The variables was then checked for normality using the Shapiro-Wilk normality test. If the distribution was shown to be normal, a parametric test were performed, otherwise a nonparametric test were performed. Data on distance to seed tree, when data for all sites ($n = 122$) was analyzed, was normally distributed after being logarithmically transformed. No other data were normally distributed.

To answer my first question, a Wilcoxon rank sum test was performed to detect differences in number of birch seedlings and saplings between scarified sites and not. For this, I grouped number of seedlings and saplings depending on whether or not the plot was situated on a scarified site ($n = 62$) or not ($n = 60$). For each of the two groups, the mean (and standard error; SE) plot number of birch seedlings and saplings was calculated and the plot mean was then upscaled into mean birches per hectare (birches/ha).

To answer my second question, several tests were performed. First, to assess the difference in magnitude of each environmental factor between scarified and not scarified sites, a Wilcoxon rank sum test or a Welch two sampled t-test was performed. The test type depended on whether or not the data of each factor were normally distributed or not. The test was performed on each factor separately, grouped by whether or not the plot was situated on a scarified site or not. For each group, mean, median and SE was calculated. Second, to illustrate how the environmental factors and numbers of seedlings and saplings are related to each other as well to compare scarified and not scarified sites, a principal component analysis (PCA) using the prcomp function, was performed. The data included plots independent on whether or not it was located on a scarified site or not. The PCA were plotted using the autoplot function and the plots were color coded depending on whether or not the plot was positioned on a scarified site or not. Third, a Spearman's rank correlation or a Pearson's correlation test was performed testing the correlation between each environmental factor (e.g. humus layer depth and pH) and the number of seedlings and saplings present in each plot. The test was performed on data from both scarified and not scarified sites (n = 122). Lastly, a Spearman's rank correlation test was performed testing the correlation between each environmental factor and the number of birch seedlings and saplings on scarified sites (n = 62) and not scarified (n = 60) sites separately.

All tests were performed in R version 4.1.2. and the significance level was set to 0.05.

3. Results

3.1. Naturally seed regenerated birch seedlings and saplings

I found on average 23 800 birch seedlings and saplings per hectare on plots that were positioned in scarified sites, and 42 000 seedlings and saplings per hectare on plots that were situated in not scarified sites (Figure 3). Thus, there were 71% more birches in sites which had not undergone scarification. However, this difference was not statistically significant (p=0.091). There was a high variation in birch density between the plots and a high number of null plots (14 plots on scarified and 13 on not scarified sites).

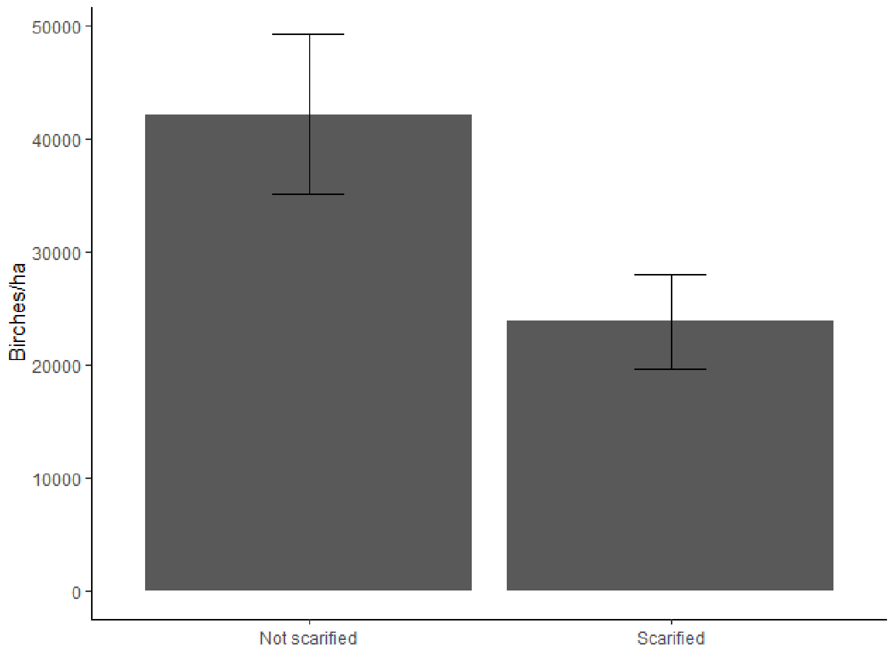

Figure 3. *Mean ± SE of naturally seed regenerated birch seedlings and saplings per hectare found on scarified (n = 62) and not scarified sites (n = 60) separate selected in the northern district of the forest company Holmen AB*

3.2. Environmental factors on scarified and not scarified sites

The species composition of the ground vegetation were similar in all sites. The most common mosses were Peat moss (*Sphagnum*) and Common haircap (*Polytrichum commune*). Other vegetation were Ericaceous dwarf shrubs and varying tall and short grasses. Shrubs mostly consisted of small elements of Rowan (*Sorbus aucuparia*) and Aspen (*Populus tremula*). Although herbs were uncommon, the most frequently occurring herb were Fireweed (*Chamaenerion angustifolium*). Wilcoxon rank sum test revealed that there were a significantly higher mean coverage of mosses on sites that were not scarified (44 %; Table 2) in comparison to the mean coverage on scarified sites (29 %). Other than that, there were no major and significant differences in ground vegetation coverage between scarified sites that had undergone scarification and sites that had not (Table 2).

The mean humus depth was 16 cm for both scarified and not scarified sites, and soil pH was slightly acidic (4.7 and 4.8 respectively; Table 2) There were no significant differences in humus depth or soil pH between scarified and not scarified site. However, there was a trend towards higher pH on sites that had not undergone scarification. The distance from plot centers to seed trees differed significantly between scarified and not scarified sites and was in general 8 m greater on sites that had undergone scarification (Table 2) than on sites that were not scarified. In addition, in essence all seed trees were found at edges of the sites, independent on whether or not the site were scarified or not.

Table 2. *Mean ± SE and median of each inventoried environmental factor on scarified (n = 62) and not scarified (n = 60) sites separate selected in the northern district of the forest company Holmen AB. The p-value (p) for Distance to seed tree are derived from Welch two sampled t-test and rest Wilcoxon rank sum test, testing if factors mean differ between scarified and not scarified sites. Mosses, Grasses, Herbs, Dwarf shrubs, Shrubs and Obstructions denote the coverage by each of these on each plot. Humus layer depth denote the depth of the humus layer in the center of each plot. Soil pH denote the soil pH in the center of each plot. Distance to seed tree denote the distance from each plot center to the closest seed tree. Significant effects (p < 0.05) are marked as bold.*

	Scarified sites		Not scarified sites		
Factor	**Mean ± SE**	**Median**	**Mean ± SE**	**Median**	**p**
Mosses (%)	29.0 ± 4.2	8.5	44.6 ± 4.5	42	**0.037**
Grasses (%)	46.2 ± 4.6	45	50.2 ± 4.0	50	0.475
Herbs (%)	15.5 ± 2.3	8	13.3 ± 2.4	6	0.247
Dwarf shrubs (%)	15.5 ± 2.5	7.5	19.9 ± 2.7	14	0.166
Shrubs (%)	9.4 ± 2.8	0	3.3 ± 1.0	0	0.571
Obstructions (%)	11.2 ± 2.4	4	10.7 ± 2.8	1	0.157
Humus layer depth (cm)	16.6 ± 1.5	16.5	16.5 ± 1.5	12.5	0.792
Soil pH	4.7 ± 0.0	4.63	4.8 ± 0.1	4.46	0.071
Distance to seed tree (m)	22.3 ± 1.9	18	14.4 ± 1.3	12.5	**0.000**

3.3. Correlations between environmental factors and number of seedlings and saplings

In the PCA, the first and second principal component (PC1 and PC2) explained 18.42% and 16.22% of the total variation of the data. Obstructions as well as mosses and number of seedlings and saplings explained most of the variance of PC1 and humus layer depth and grasses explained most of the variance in PC2. The ordination analysis revealed significantly positive effects of coverage of mosses on the number of seedlings and saplings present (Figure 4, Table 3). It also showed a great overlap of the plots situated in sites that had undergone scarification and the plots in sites that was not scarified indicating overall low soil scarification impact on factors. The factors are also widely spread out in all directions, indicating overall weak correlations between each factor and number of birch seedlings and saplings present.

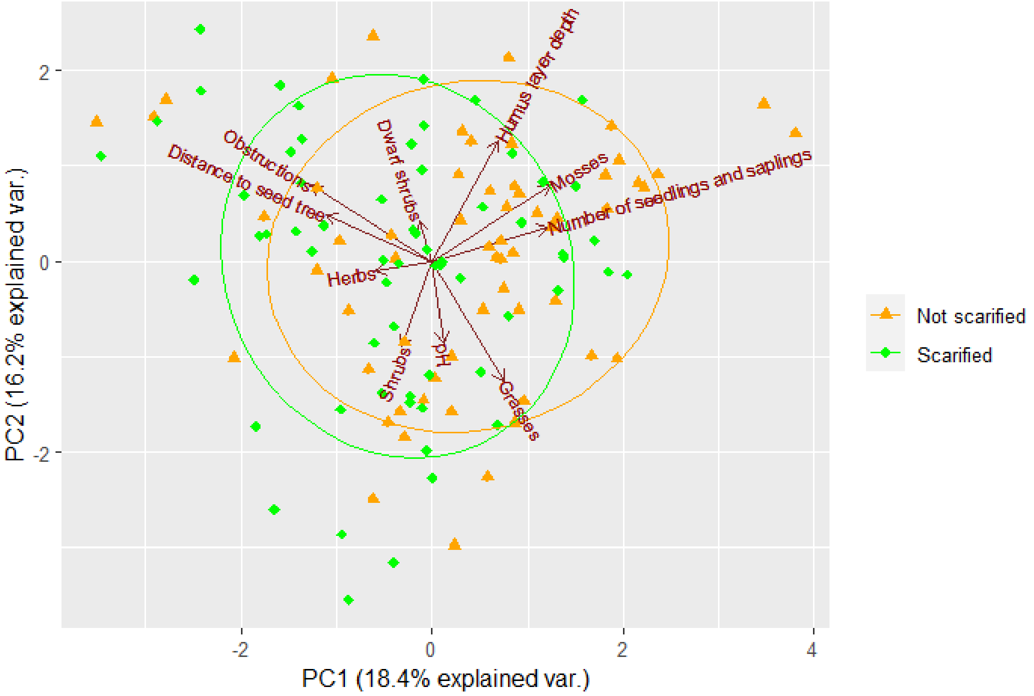

Figure 4. *PCA of each plot (n = 122) with data of each inventoried environmental factor and number of birch seedlings and saplings present. The plots are grouped by whether the plot was located in a site that had undergone scarification or not. Number of seedlings and saplings denote number of birch seedlings and saplings found in each plot. Mosses, Grasses, Herbs, Dwarf shrubs, Shrubs and Obstructions denote the coverage by each of these on each plot. Humus layer depth denote the depth of the humus layer in the center of each plot. pH denote the soil pH in the center of each plot. Distance to seed tree denote the distance from each plot center to the closest seed tree.*

When plots from all sites were analyzed together, the number of birch seedlings and saplings was significantly positively correlated to moss cover and humus layer depth, and significantly negatively correlated to distance to seed trees (Table 3). Other correlations were non-significant.

Table 3. *Correlations (ρ), with p-values (p) between each inventoried environmental factor and number of birch seedlings and saplings found across all plots (n = 122) on scarified and not scarified sites. On Distance to seed tree, Pearson's correlation was performed and for the rest Spearman's rank correlation was performed. Significant effects ($p < 0.05$) are marked as bold. Mosses, Grasses, Herbs, Dwarf shrubs, Shrubs and Obstructions denote the coverage by each of these on each plot. Humus layer depth denote the depth of the humus layer in the center of each plot. Soil pH denote the soil pH of each plot. Distance to seed tree denote the distance from each plot center to the closest seed tree.*

Factor	ρ	p
Mosses	0.31	**0.000**
Grasses	0.03	0.738
Herbs	- 0.04	0.635
Dwarf shrubs	- 0.09	0.308
Shrubs	0.02	0.819
Obstructions	- 0.16	0.070
Humus layer depth	0.21	**0.018**
Soil pH	- 0.10	0.289
Distance to seed tree	- 0.27	**0.002**

Furthermore, when data was analyzed for scarified and not scarified sites separately, it was evident that moss coverage positively correlated significantly with the number of birch seedlings and saplings on both scarified and not scarified sites (Table 4). Analyzing scarified and not scarified sites separately also showed that obstructions and pH negatively correlated with number of birch seedlings and saplings on sites that were not scarified but had no effect on sites that were scarified. In addition, humus layer depth and distance to seed tree did not correlate significantly (but close), with number of birch seedings and saplings on neither type of sites.

Table 4. *Spearman's rank correlation (ρ), with p-values (p) between each factor and number of birch seedlings and saplings found in plots on scarified sites (n = 62) and not scarified sites (n = 60) respectively. Mosses, Grasses, Herbs, Dwarf shrubs, Shrubs and Obstructions denote the coverage by each of these on each plot. Humus layer depth denote the depth of the humus layer in the center of each plot. Soil pH denote the soil pH of each plot. Distance to seed tree denote the distance from each plot center to the closest seed tree. Significant effects (p < 0.05) are marked as bold.*

	Scarified sites		Not scarified sites	
Factor	**ρ**	**p**	**ρ**	**p**
Mosses	0.28	**0.028**	0.32	**0.014**
Grasses	0.03	0.824	-0.01	0.934
Herbs	- 0.12	0.369	-0.04	0.778
Dwarf shrubs	- 0.08	0.528	-0.12	0.348
Shrubs	- 0.08	0.552	0.19	0.140
Obstructions	- 0.11	0.398	-0.26	**0.045**
Humus layer depth	0.19	0.132	0.24	0.069
Soil pH	0.24	0.057	-0.28	**0.029**
Distance to seed tree	- 0.16	0.203	-0.24	0.066

4. Discussion

There was no significant differences in the number of seedlings and saplings between scarified and not scarified sites. However, there was a trend towards a higher number of birch seedlings and saplings on not scarified sites. This finding differs from previous studies, performed in similar environments and soil conditions in Sweden, which have shown that mechanical soil scarification significantly increase the abundance of seed regenerated birch (Karlsson 1996, Karlsson 2002). I can think of two explanations for these opposing results. First, negative scarification effects on wet sites may be explained by birch seedlings and saplings on scarified suffering from oxygen deficit on scarified patches (Örlander et. al. 1990). This may be a plausible explanation since 8 out of 10 of the scarified sites were classified as moist. Second, scarified sites may have been exposed to one or two seed falls after clear-cut prior to scarification and it is possible that the scarifier have destroyed those seeds and newly emerged seedlings, resulting in a lower number of birch seedlings and saplings on those sites. This explanation have been presented by other studies to be a likely explanation to negative scarification effects on the abundance of birch seedlings and saplings (Karlsson & Nilsson 2005). Furthermore, the trend towards a higher number of birch seedlings and saplings on not scarified sites could have been caused by other factors, such as moss coverage and distance to seed trees.

Moss coverage correlated positively and significantly with number of birch seedlings and saplings on both scarified and not scarified sites separately as well as when all sites were analyzed together, even though moss cover differed significantly between sites. The mean coverage of mosses on not scarified sites were 45 % in comparison to 29 % on scarified sites. This suggest that moss coverage, in low as well as in high magnitude, is important for improving birch regeneration on both scarified and not scarified sites. On not scarified sites, the chance of a seed being dispersed onto a moss patch is increased which could be a reason to why there was a trend towards higher number of birch seedlings and saplings on those sites. In addition, Peat moss (*Sphagnum*), which were one of the most common moss genus present, are known for being a good germination substrate (Karlsson 1996) as well as for increasing the establishment of birch seedlings due to its ability to hold large volumes of water (Granström & Fries 1985, Kempe & Stener 2006). However, a positive effect on birch seed regeneration by higher moss coverage exclusively may be unlikely since a reduction of ground vegetation often benefits natural seed regeneration (Saursaunet et. al. 2018). A higher moss coverage may be beneficial if it is in combination with other factors, such as higher soil moisture, which may prevent birch seeds from irrevocably drying out on the mosses. Furthermore, an explanation as to why there was a lower moss coverage on scarified sites could be that Peat moss, which were one of the most common moss genus, grows poorly on mineral soil exposed by scarifition due to unfavorable moisture conditions (Caners et. al. 2009).

The distance to seed tree was significantly shorter on not scarified sites which may be a key explanation to why nearly twice as many birch seedlings and saplings were found on not scarified sites. The not scarified sites were generally three times smaller than the scarified sites, resulting in that the distance to seed trees, which mainly was at the border of the clear-cuts, were generally shorter than for scarified sites, allowing a higher number of seeds per area reaching the clear-cut. This finding is supported by a study by Tiebel et. al. (2020) who measured birch seed densities in relation to the distance to the seed tree. They found that the seed density increased as the distance to seed tree decreased. Furthermore, distance to seed tree correlated negatively with number of birch seedlings and saplings when data of all sites were analyzed but not when the data was analyzed for scarified and not scarified sites separately. An explanation for why distance to seed tree did not seem to affect number of birch seedlings and saplings when scarified and not scarified sites were analyzed separately may the lower between-site variation in distance to seed tree, caused by the more similar site sizes. A lower variation in distance to seed tree could result in a lower chance of distance to seed tree causing variations in number of birch seedlings and saplings and thus a lower the chance of finding significant effects. However, I cannot rule out that the physical location of the sites have played a role. The scarified sites were generally situated further north and to the inland of Sweden as well as having generally lower productivity and effective temperature sum, both of which are known for facilitating birch seed germination and seedling growth (Hynynen et. al. 2009).

Humus layer depth did not differ between scarified and not scarified sites. This suggests that scarification did not affect the humus depth, which is unexpected since removing parts or the whole humus layer is one of the main reasons to scarify a site. An explanation to this could be that on 45 out of 122 plots, the humus layer were 30 cm or deeper which could mean that the scarifier was not able to reduce a large enough proportion of the humus layer in order for it to make a difference. Furthermore, humus layer depth significantly positively correlated with number of birch seedlings and saplings when all sites were analyzed but not when the sites were separated into scarified and not scarified. This suggests that a deeper humus depth is of importance for increasing number of birch seedlings and saplings, independent on scarification treatment. Although humus depth is often removed to have birch seeds, seedlings and saplings benefit from the mineral soil's ability to hold water (Kempe & Stener 2006, Oleskog & Sahlén 2000), birch seeds, seedlings and saplings mainly benefit from this ability on drier sites where water is more scarce (Kempe & Stener 2006). On wetter sites, the humus layer may be a better seed germination as well as growth increasing substrate than mineral soil since it is more nutritious and can hold larger amounts of water (Kempe & Stener 2006). In this study, most sites (13 out of 20) were categorized as moist, making a deeper humus layer beneficial for increasing number of birch seedlings and saplings.

Grasses were the most common ground vegetation and covered in general half of the plots on both scarified and not scarified sites. Grass coverage was expected to have an negative effect on number of birch seedlings and saplings but this was unsupported by the analyses. The expected negative effect by grasses may have been counteracted by mosses, which also were common on the sites. This could also be a reason to why moss coverage seemed to benefit birch seed regeneration. Furthermore, herb, dwarf shrub and shrub coverage did not correlate with number of birch seedlings and saplings in any correlation analysis and the general coverage of these species groups were low in comparison to moss and grass coverage, on both scarified and not scarified sites. This suggest that herbs, dwarf shrubs and shrubs are less important competitors to birch seedlings and saplings in comparison with other vegetation, at least in site circumstances as of in this study. In addition, no study that I am aware of has singled out any herbs, dwarf shrubs or shrubs as strong influencers on birch regeneration after clear-cut. Moreover, I expected a generic lower ground vegetation coverage on scarified sites since mechanical scarification removes ground vegetation. To my surprise, scarified and not scarified sites had very similar ground vegetation cover. An explanation to this may be due to some sites had been scarified several years before the inventory was carried out. This would allow ground vegetation longer time to reoccupy scarified patches (Fløistad et. al. 2017, Holmström et. al. 2016) and thereby reduce differences between scarified and not sites.

Obstruction coverage and pH significantly negatively correlated with number of birch seedlings and saplings, but only on sites that were not scarified. This suggest that birch seedlings and saplings on sites that are not scarified have an increased risk of suffering from obstructions and lower pH. However, neither of the two differed significantly between scarified ant not scarified sites, making it unclear as to why birch seedlings and saplings on not scarified in particular would suffer from them. I cannot explain these unclear results in ways other than that they may be evidences of a methodical error, that also have affected all performed tests. The error is that I have not corrected for multiple testing with the same data set. If multiple tests has been performed on the same dataset, the risk of suffering from type 1 error i.e. falsely finding statistically significant results increase (Streiner 2015). Hence, the p-values in this study should be regarded carefully.

Furthermore, although there were substantially more seedlings and saplings found on not scarified sites than on scarified sites, the difference was not statistically supported. The lack of difference could be explained by high between-site and between-plot variation caused by methodical errors. First, there was a high clear-cut age-difference between sites. The time of clear-cut differed between 2014 – 2019 amongst the sites, leaving more time for birch seedlings and saplings to occupy older clear-cuts, creating higher between-site variation. Second, in total, I found 27 null plots (out of a total of 122 plots) which generated great between-plot variation. Third, the plots in this inventory are larger and more than ten times fewer in comparison to other studies which inventoried birch seedlings naturally regenerated from birch seeds (Holmström et. al. 2016, Saursaunet et. al. 2018). Larger and fewer plots increase the risk of suffering from site density variation of birch seedlings and saplings. In future studies, in order to counteract the risk of suffering from high data variations in birch seedlings and saplings, more and smaller plots should be used in comparison to what was used in this study.

In practical forest management, several aspects brought up by this study should be considered when planning regeneration of birch by seed. In planning, before considering birch seed regeneration, site area should be regarded because the distance to seed trees may be affected as most seed trees seem to be situated at the edges of a site. As a consequence, this could reduce number of birch seedlings and saplings at larger sites (Liu & Evans 2021). However, there may be unknown economic reasons to scarify larger sites. In that case, leaving seed tree birches more evenly distributed on the site during clear-cut, mimicking a birch shelterwood system, could potentially increase seedling establishment (Karlsson 2001). Scarification, which did not increase naturally regenerated birch seedlings and saplings in this study, have shown to benefit birch regeneration in most other studies performed in similar environments as in this (Karlsson & Örlander 2000). As discussed above, a combination of lower moss coverage, longer distance to seed tree, lower productivity and effective temperature sum on scarified sites, may be an explanation to the lack of positive effect on birch seed regeneration by the mechanical scarification treatment. Hence, these environmental factors should be taken into consideration during the planning phase of selecting appropriate sites for scarification and natural birch seed regeneration. In addition, theoretical calculations show that the risk of failing with natural birch seed regeneration decreases with increasing amount of information about factors affecting birch seed regeneration (Karlsson 2004).

This work investigated the effect on natural seed regenerated birch seedlings and saplings on mechanically scarified and not scarified clear-cuts by a selection of biotic and abiotic environmental factors. Although mechanical scarification is a generally accepted treatment for improving chances of birch seed regeneration, a trend towards the opposite was found. It is possible that a lower moss coverage and longer distance to seed tree on scarified sites negatively influenced birch seed regeneration on those sites and may be the cause of these opposing results. This work brings forward the importance of taking into account other possibly influencing factors e.g. higher effective temperature sum, productivity and larger site area, which may have participated in increasing birch regeneration on not scarified sites. Finally, scarification may be important for birch regeneration, but biotic and abiotic environmental factors may together have even greater influence. Thus, more broad-scale studies of this sort is needed to increase the understanding of how biotic and abiotic environmental factors and management interventions affect birch seed regeneration after clear-cut. This kind on research is particularly important as naturally regenerated birch by seed may play a crucial role in future Swedish forests.

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