Natural regeneration on clear cuts in Southern Sweden

How fencing, soil treatment and distance from broad-leaved forest affect tree regeneration and ground vegetation

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Swedish University of Agricultural Sciences
Master Thesis no. 249
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Abstract

The forests of Europe have seen a dramatic shift in structure, species composition and area coverage in the last centuries. Large areas previously covered by a mixed broad-leaved forest are now used for agriculture or other land uses. Additionally the forest management saw changes with the optimization of wood production as a main goal, using monocultures of conifers and clear cutting becoming prevalent. This development, although so far economically successful, has major disadvantages. With the decline of suitable habitat, the biodiversity connected to broad-leaved ecosystems is now under threat. Furthermore frequent storm falls and pest outbreaks have hit monocultures severely and the uncertain effects of climate change on individual tree species has reinvigorated the economic argument for risk spreading and moving back to the more resilient mixed forests system. Thus, effective and preferably inexpensive methods are needed to restore preferred mixed broad-leaved forests in desired locations.

This paper will cover a research conducted on clear cuts that were made in 2011 in southern Sweden, previously covered with planted stands of Norway spruce, *Picea abies*. The aim was to examine the effects of soil treatment, fencing and distance from broad-leaved forest on the natural regeneration of woody species and on the ground vegetation. All naturally regenerated tree saplings that had reached a height of 30 cm were recorded and the ground vegetation was assessed with a cover estimate. The significance of the treatments on the quantity and height of saplings and the flora coverage was evaluated with a General linear model.

Five species represented 96% of the recorded tree regeneration, *Betula* spp. (*B. pendula, B. pubescens*), *Salix caprea*, *Pinus sylvestris* and *Populus tremula*. Statistical analysis focused on these species. The natural regeneration produced on average ca 4500 trees/ha. Fencing had a significant positive effect on the height of all the four most numerous species (*Betula* ssp., *S. caprea*, *P. sylvestris*, *P. tremula*) and on the *P. sylvestris* regeneration. Soil scarification increased the quantity of *S. caprea* and *P. sylvestris*. Notably, distance from a broadleaved forest had no significant impact on height or quantity of overall individuals or within species. The models were most suited to predict the observed variance for *S. caprea* and *P. sylvestris* (R-sq. ~50-68%) while least apt at explaining the variance in *Betula* ssp. (R-sq. ~26-36%).

The results indicate that distance from broad-leaved forest is not an important factor in the early stages of natural forest regeneration. Pioneer tree species dominate the clear cuts and saplings of noble broadleaves are either not present or very scarce. Unstable seed production, short seed dispersal and unfavourable conditions on new clear cuts might limit the colonization of noble broadleaves and connected ground flora. Though fencing and soil treatment had a positive effect on number and height of individuals of some species, the plots without any treatment (no fence, no soil treatment) managed to produce roughly 3000 seedlings/ha containing a mix of species. The ratio of *P. sylvestris* and *S. caprea* present is, however, much lower without treatment. These species are important for forest biodiversity and their increased density alone might justify fencing. Future research is needed to document the progression and what species will prevail after this initial colonization phase.

Keywords:
Natural regeneration, forest restoration, pioneers, noble broadleaves, Picea abies, soil scarification, fencing, distance from broad-leaved forest, Raslångens ekopark.

Innehåll

Introduction

For the past centuries, Sweden has seen a considerable change in its forest cover and composition (Hultberg, 2015). Large swaths of deciduous temperate forests have been lost to other lands uses. Through this transition, a large share of land has been converted to forest dominated with Norway spruce *Picea abies*. This trend is not isolated to Sweden, but can be observed throughout Europe (Lindbladh & Bradshaw, 1998). In Europe it is estimated that 6-7 million ha of land, that mostly contained broad-leaved forest previously, has been converted to *P. abies* outside its natural range (Teuffel et al., 2004). Additionally the current popular clear cutting management systems (Matthews, 1989) in Northern Europe drastically alter elements of the forest structure if compared to their historical range of variability. More than 90% of productive forests in Fennoscandia are currently under intensive forest management (Halme et al., 2013).

Although economically interesting for many forest owners, this development can be seen to have disadvantages. Firstly, there is the risk spreading argument. A mixed forest is more resilient (Thompson et al., 2009) than monocultures against events like storms, pest outbreaks (Jactel et al., 2011) and the on-going climate change (Kolström, et al., 2011; Schlyter et al., 2006). According to Schlyter et al. (2006) the big storm in 2005 (Gudrun) was equal to 63% of the total volume damaged during the previous century. Secondly, declining noble broad-leaved forest cover can have severely negative effects on dependent biodiversity. Since most of the biodiversity that is currently under threat in Sweden is associated with noble broad-leaved forest (Berg et al., 1994) (Björse & Bradshaw, 1998), the task to increase suitable habitat is urgent. Fundamental to the success of such a task is knowledge; what factors can we influence that can impact desired forest restoration (Halme et al., 2013) (Stanturf, 2005)?

Browsing can have a very strong impact on species composition and forest structure (Côté et al., 2004). The number of ungulates in Sweden has increased dramatically in the last century (Lidberg et al., 2011) intensifying this effect. Since browsers have certain diet preferences, the browsing pressure tends to affect tree species unevenly. Research has shown that browsers prefer many of the broad-leaved species found in Sweden, like *Quercus robur*, *Alnus glutinosa*, *Fagus sylvatica*, *Tilia cordata* and *Betula pendula* above *Picea abies* (Kullberg & Bergström, 2010). However browsing concerns are not constricted to broadleaves. According to estimations by the National Board of Forestry in 2003-2004, 40-50% of *Pinus sylvestris* stems in Sweden had damages caused by moose (Lidberg et al., 2011).

Research done by Staffan Hörnberg (2001) analyzing browsing data accumulated by the Swedish National Forest Inventory, indicates that 91% of browsed vegetation in Sweden between the years 1969–1972 and 1983–1987 consisted of the following six species (in order of foraging preference): *Betula* spp., *Salix* ssp, *Pinus sylvestris*, *Juniperus communis*, *Sorbus aucuparia* and *Populus tremula*. Unsurprisingly, research has found that fencing increases the recorded height of young trees in stands, varying according to factors like species and abundance of available browsing material (Persson et al., 2005) (Olesen & Madsen, 2008) (Bergquist et al., 2009), but also survival of seedlings (Gill & Beardall, 2001). Studies from both North America and Europe show that sustained heavy grazing and browsing reduces the richness of biological communities (Fuller & Gill, 2001). Fencing can thus be a useful method of facilitating desired broadleaved regeneration and its associated biodiversity.

Soil treatment can greatly improve growing conditions for radicles, since removal of the organic soil layer improves the availability of the more stable moisture regime that rests in the mineral soil beneath. The soil treatment can also remove the present competition from ground vegetation (Hille & Ouden, 2004), increases nutrient mineralization and temperature in the soil (Örlander et al., 1990). Research has indeed found that these factors improve regeneration and seedling survival (Karlson et al., 2002) (Bergquist et al., 2009) (Karlsson & Örlander, 2000) (Grigoriadis et al., 2014).

A factor that has not been closely looked at is how distance from a mixed noble broad-leaved forest influences the regeneration on clear cuts. Some noble broad-leaved species, like beech *Fagus sylvatica*, have short average seed dispersal (Götmark et al., 2005) limiting the range they can naturally regenerate and making distance from mother trees an important factor. Also unknown is how treatments like fencing and soil scarification interacting with the distance will influence the final result. This thesis will address these questions.

The research covered in this thesis is part of a project which aims to examine the effect of fencing, soil scarification and distance from broad-leaved forest on planted *Fagus sylvatica*, the ground vegetation and the natural regeneration of woody species. This thesis will focus on the natural regeneration and ground vegetation, but not the planted *F. sylvatica*.

The aim of this research is to test the following hypotheses.

I. Greater number of individuals will emerge in soil treated plots than in non-treated.
II. Fencing will hinder browsing, increasing height of individuals, particularly for species preferred by browsers.
III. Fencing will increase the number of individuals equal or higher than 30cm (minimum size documented) during the time period of the research, thus increasing recorded density.
IV. Decreased distance from broadleaved forest should have a positive effect on both broad-leaved species richness and number.
V. Decreased distance from broad-leaved forest should have a positive impact on species richness of the ground flora.

Materials and methods

The study area

The experiment was set up in the Raslången ecopark, named after the Raslången Lake, in the north east of Scania, the southernmost province of Sweden. The park covers 1300 ha of which 72% is reserved for nature conservation. The forest is owned by the Swedish state forest company Sveaskog. The park is characterized by its broad-leaved forest, dominated by *F. sylvatica* occasionally mixed with oaks *Quercus* spp. This area is situated at a junction were the natural distributions of *P. abies* (from the north) and *F. sylvatica* (from the south) meet. The management goal of this area is to cut the current *P. abies* stands at the optimal harvesting age and convert into deciduous forest. This might benefit the park as a whole since its nature value is highly linked to the broad-leaved ecosystem present (Sveaskog, 2011).

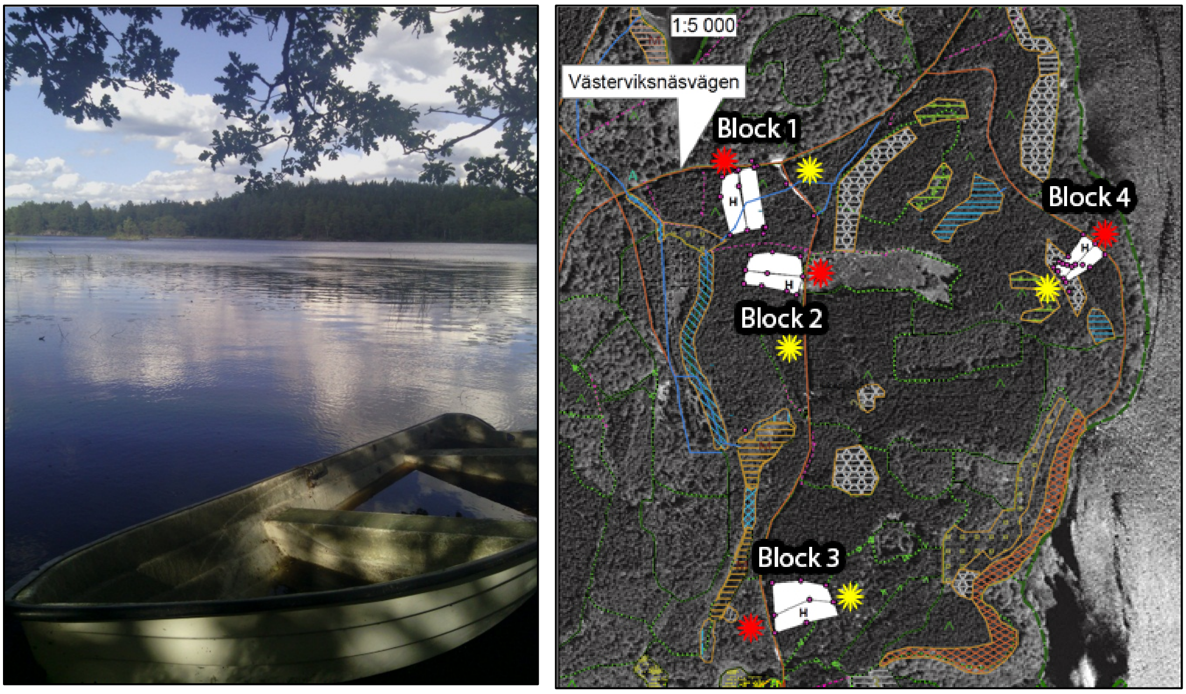

Figure 1. Left: The Raslången lake and forest. Right: Map of the research area showing the four blocks. Stars indicate the location of reference plots were cover data was collected. Red stars represent broad-leaved reference plot whilst yellow stars symbolize plots in conifer forest.

Research design

The experiment consists of 4 main blocks each covering approximately 1 ha (Figure 1). The blocks were laid out over an area which had previously been stands of *P. abies*, but had been clear cut in 2010-2011. Each block is divided into fenced (2 m high) and non-fenced halves which are again divided into two sections, one which has received soil scarification and one who hasn't. The inverting soil treatment method was used with the help of an excavator.

All of the blocks were then positioned in such a fashion that there is a broad-leaved forest on one side and a conifer forest on the other, adding the third variable (Fence, Soil scarification and distance from broad-leaved forest). Within individual blocks there are 8 plots (Figure 2) or 32 in total.

Since the predefined areas (previously marked with spray paint and ribbons) within the blocks were not always square (10m x 10m), sometimes the plots needed to take the shape of a rectangle but always equal to 100 m^2. The plots needed to fit within predefined transects where in previous work (Festin, 2013) beech had been planted.

The aim was to keep the plots as centered as possible within the predefined areas, and at least one meter from its edge. When approximately centered, a corner pole was erected in the form of a bamboo stick. Then using a measuring tape, estimation was made what dimensions the rectangular plot could take to fit within the area. Next, the 3 remaining corner poles were erected and with the help of spray paint, the outlines between the poles were highlighted. Furthermore, reference plots were made in adjacent stands on both sides of each block, one in a broad-leaved stand and one in a conifer stand (total 8 reference plots). The shape and size remained the same (100 m^2).

Field work

Each individual tree sapling within the plots that had reached a height of 30 cm was documented, both its height (measured with a folding ruler) and species. The exception to this was the planted beech and stump shoots or other larger remaining trees left on the clear cut. The height was measured from ground level to the highest living bud. This can matter for example in the case of *P. sylvestris*, which has needles that reach higher than the bud in autumn.

Additionally, a visual cover estimate for the ground flora was conducted using the Braun-Blanquet cover scale (Westhoff & Van Der Maarel, 1980). Each species found on the plot was given an estimated cover with visual assessment and categorized into the following categorize: + : <1%, 1: 1-5%, 2: 5-25%, 3: 25 -50%, 4: 50-75% 5: 75-100%. Three layers where classified and the cover estimated for them separately; ground layer (less than 1,5m height), shrub layer (between 1,5-5m) , lower tree level (between 5-15m), canopy (between 15-25m) and higher canopy (over 25m). Only a cover estimate was conducted on the reference plots. All count, cover and height data were gathered in August 2014.

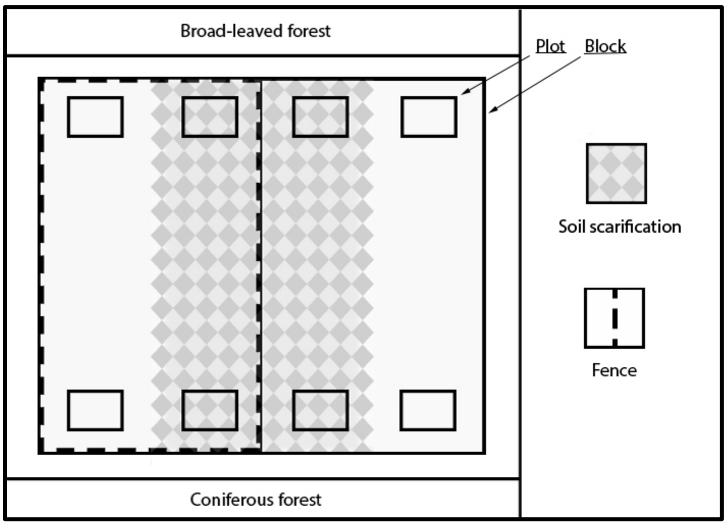

Figure 2. Illustration of the research setup.

Data analysis

For statistical analysis a General linear model (GLM) with the "Tukey" test was used to determine the effect of treatment variables (fencing, soil treatment, distance) on height, number of individuals and species richness. The Kolmogorov-Smirnov normality test was used to evaluate if data was normally distributed. The Box-Cox data transformation was used on non-normally distributed data before running the GLM. This was accomplished with the help of the statistical program *Minitab* 16 (Minitab Inc.). Graphs and general and calculations were conducted in both *Minitab* (Minitab Inc.) and *Microsoft Excel* (Microsoft, 2010). The two *Betula* species were pooled for these analyses. The amounts of *F. alnus*, *S. aucuparia*, *Quercus* spp., *P.abies*, *C. avellana* and *S. nigra* present in the plots were too low for further statistical analyses, and are thus excluded.

Results

Overview data

Treatments

In total, 1466 individuals of 11 woody species were recorded in the plots (Table 1). The two birch species (*B. pendula* and *B. pubescens)* were by far the most numerous, representing 54% of the total amount of recorded regeneration and were found in every plot. The three most numerous species/species groups (grouped *Betula* spp. counting as one) represent ~92% of the total amount of natural regeneration. The highest individual was a *Betula* spp. individual but *Sorbus aucuparia* had the tallest average height (Table 2).

Table 1. Average height and total number of recorded individuals of tree and shrub species in relation to the treatment variables.

Treatment variables->	Fenced	Non-fenced	Soil treatment	No soil treatment	Distance=0	Distance=1
Number of individuals	912	554	861	605	698	768
Average height (cm)	124	96	115	112	107	121
Total number of individuals	**1466**					
Total average height (cm)	**114**					

Species

Table 2. Overview data for species found in research plots. The species are arranged in order of recorded quantity, decreasing left to right. Each plot comprised of 100 m^2.

Species ->	***Betula* spp.**	***Salix caprea***	***Pinus sylvestris***	***Populus tremula***	***Frangula alnus***	***Sorbus aucuparia***	***Picea abies***	***Quercus* spp.**	***Corylus avellana***	***Sambucus nigra***
Total number of individuals	807	289	218	64	28	23	21	10	5	1
Percentage of plots present	100	71,9	78,1	46,9	40,6	43,8	37,5	28,1	15,6	3,1
Average number of individuals per plot	25,22	9,03	6,81	2	0,88	0,72	0,66	0,31	0,16	0,03
Maximum height (cm)	410	293	167	370	213	271	164	179	82	148
Average height (cm)	~125	~125	~64	~122	~114	~168	~49	~82	~54	~148

The total area of plots covered 0,32 ha (32 plots*100 m^2) with 1433 naturally regenerated individuals. Converting to whole ha, the natural regeneration produced 4478 trees/ha consisting roughly of 2500 *Betula. spp*., 900 *S. caprea*, 700 *P. sylvestris*, 200 *P. tremula* and a mix of ~ 200 individuals of the remaining six species (including ~30 *Quercus spp*.).

If we only look at the eight plots that had no fence or soil treatment (two in each block) the natural regeneration consisted of 2888 trees/ha comprised roughly of 1900 *Betula. spp*., 230 *S. caprea*, 140 *P. sylvestris*, 300 *P. tremula* and a mix of ~300 individuals of the other six species.

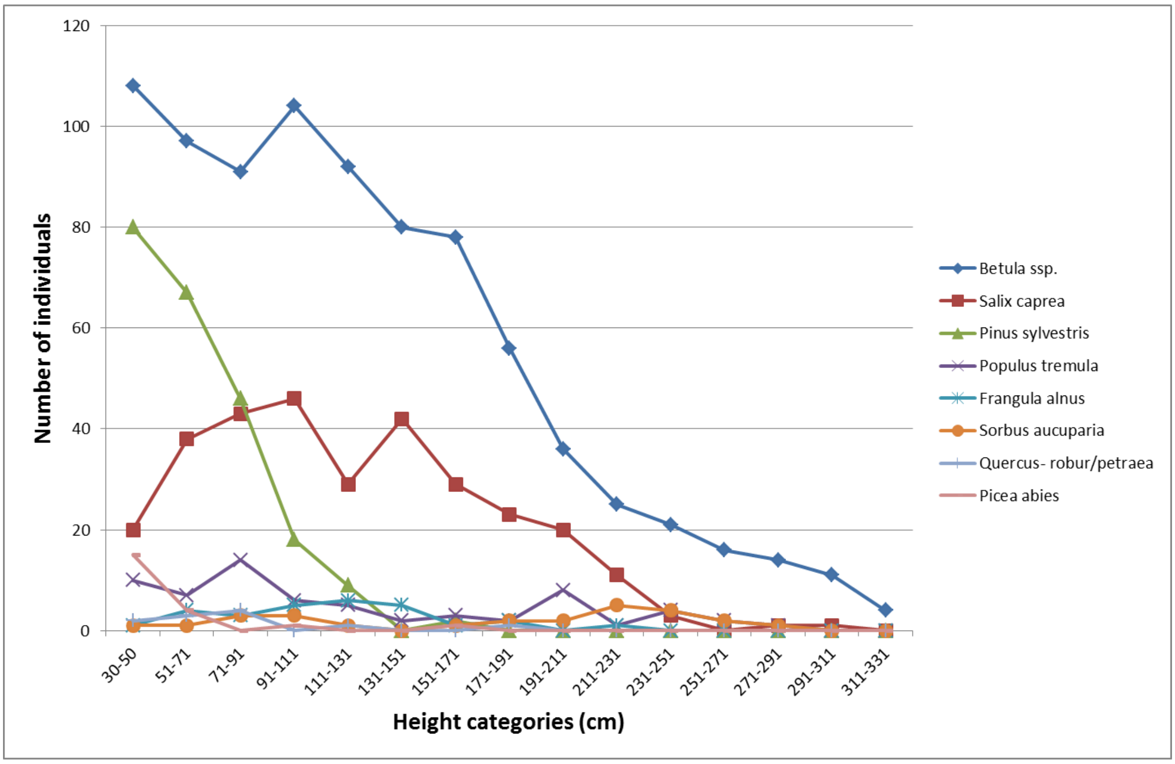

Figure 3. Height distribution for recorded individuals categorized by species.

The three most abundant species show distinct differences in height distribution (Figure 3). The two broad-leaved pioneers, *Betula* spp. and *S. caprea* have a wide range with many tall individuals, while almost none of the 218 *P. sylvestris* saplings had reached 1,50 m.

General linear model analysis

Quantity

Table 3. Effect of treatment variables on the number of individuals of different species present in plots (indicated with a P-value) when assessed with a General linear model. The predicting power of the overall model is indicated with R-squared. Grey shade over a tile underlines when a variable had a statistically significant impact on number of individuals (P<0,05). Degree of freedom was 31 for all analyses.

Source of variation	P-value				
	***Betula* spp.**	***Salix caprea***	***Pinus sylvestris***	***Populus tremula***	**All individuals**
Fence	0,180	0,097	0,000	0,715	0,039
Soil scarification	0,181	0,000	0,030	0,441	0,131
Distance	0,359	0,201	0,372	0,684	0,673
Block	0,399	0,393	0,001	0,033	0,096
	R-sq				
	26,03%	51,72%	67,76%	30,78%	36,64%

The most numerous species, Betula spp., was not significantly affected by the treatments (Table 3, Figure 4). Fencing significantly affected *P. sylvestris* increasing the amount of regeneration (height ≥ 30 cm) present in plots. Though the three other species did not show a significant response, the presence of a fence had an overall positive effect (P=0,039) on the overall number of individuals (Table 3, Figure 5). Soil scarification had a very strong positive effect on the amount of *P. sylvestris* and *S. caprea* regeneration. Distance was the only variable that had no significant impact on any of the species. Both *P. sylvestris* and *P. tremula* were greatly unevenly distributed among the blocks. For instance, there were 127 *P. sylvestris* recorded in block 3, whilst block 1 only contained 17 saplings. Expectedly the model shows a significant block effect (Table 3, Figure 4).

The model best explained the observed quantity of *P. sylvestris* and *S. caprea* and had the least predicting power for *Betula spp.*, which was the least affected by the treatment variables. The overall model explained 36,64% of the quantity variance observed for all individuals of all species (Table 3).

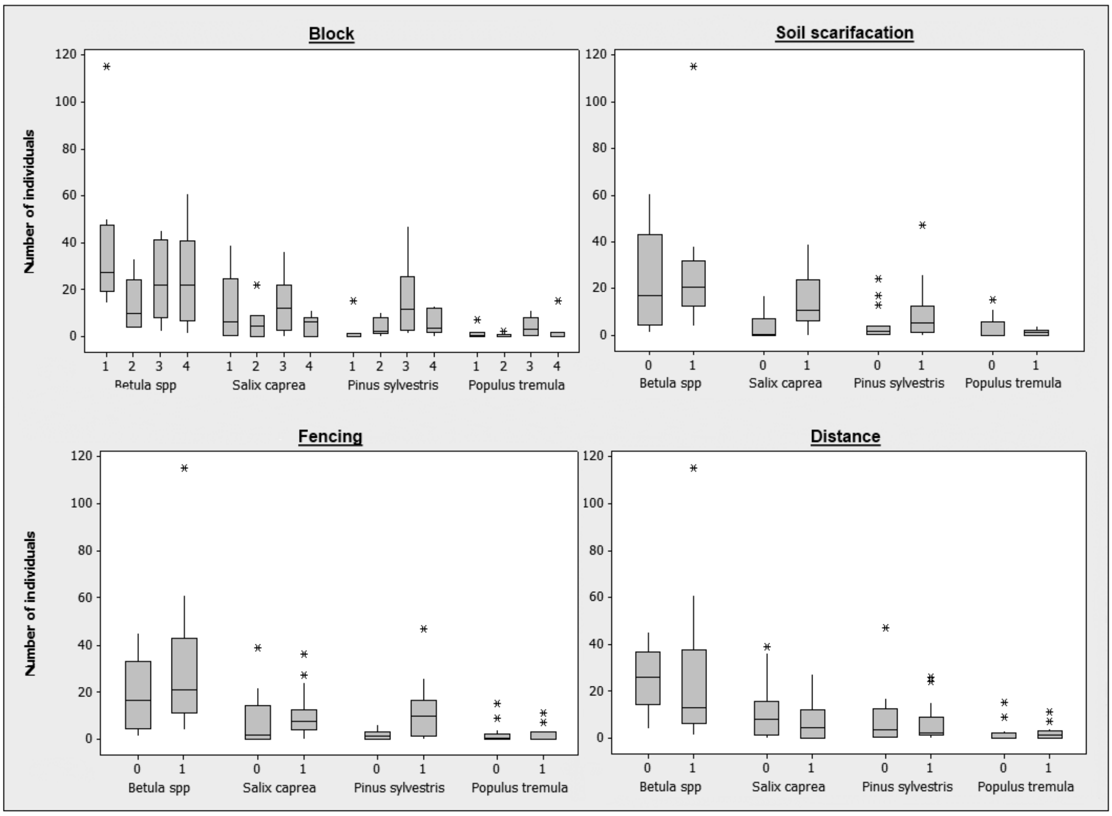

Figure 4. Box plots showing the distribution of average number of individuals within plots. The four most numerous species are displayed. For the variable, “soil scarification” and “fenced” the number “1” on the X-axis signifies treatment, correspondingly “0” represent no treatment. For the “distance” factor, “0” represents plots that were close to a broadleaved forest, “1” signifying plots that were further away.

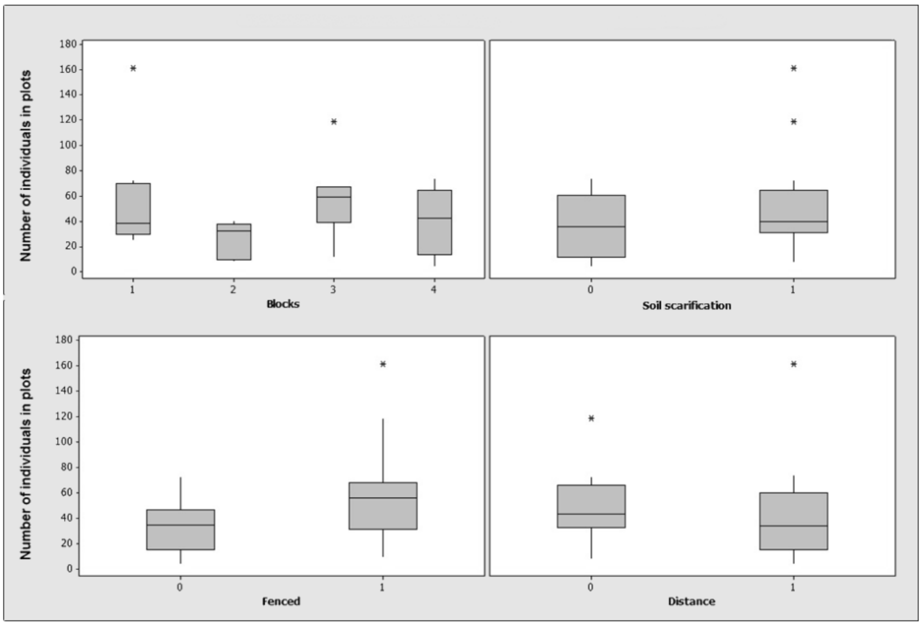

Figure 5. Box-plots showing the number of individuals occurring for all species in plots categorizes by treatment variables. For the variable, “soil scarification” and “fenced” the number “1” on the X-axis signifies treatment, correspondingly “0” represent no treatment. For the variable “Distance”, “0” represents plots that were close to a broad-leaved forest, “1” signifying plots that were further away.

Height

Table 4. Effect of treatment variables on the height of individuals of different species present in plots (indicated with a P-value) when assessed with a General linear model. The predicting power of the model is indicated with R-squared. Grey shade over a tile underlines were a variable had a significant impact on the height of individuals. "All individuals" calculation contains the number for all species recorded, not only the four shown in the table.

Source of variation	P-value				
	Betula spp.	***Salix caprea***	***Pinus sylvestris***	***Populus tremula***	**All individuals**
Fence	0,031	0,001	0,003	0,04	0,016
Soil scarification	0,617	0,100	0,413	0,685	0,554
Distance	0,466	0,628	0,751	0,401	0,440
Block	0,064	0,519	0,010	0,117	0,031
	R-sq				
	36,34%	61,63%	50,95%	67,19%	41,91%

Fencing had a significant positive effect on the height of individuals of all four species and on the total average height of woody species ≥ 30 cm (Table 4, Figures 6 & 7). The other two treatments (soil scarification, distance) did not influence the growth significantly. The difference between blocks was significant for *P. sylvestris* and close to significant for *Betula* spp. resulting in an overall block effect (P=0,031) on the average height of all individuals (Table 4, Figures 6 & 7).

Model strength

The model can better predict overall average height (41,91%) than number of individuals present (36,64%). The model explains between ~50-68% of the observed variance in height and quantity of *S. caprea* and *P. sylvestris*, while only ~26% (Quantity) and 36% (Height) for *Betula* spp. (Tables 3 & 4). Fencing was the only treatment that showed a significant impact on both height and number of all individuals. Distance from broadleaved forest did not significantly influence the observed variance in total or within species.

Species richness

The overall number of woody species present in plots was marginally positively affected by fencing (P=0,055) but not by the other treatment variables.

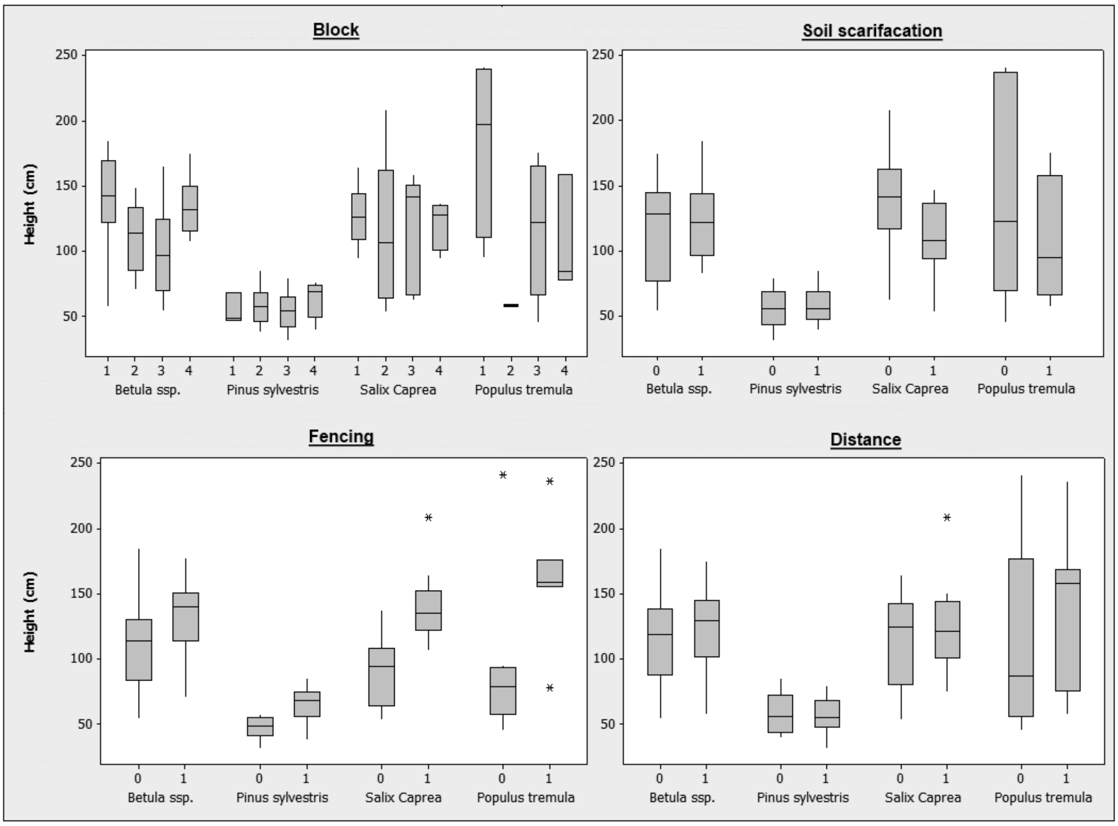

Figure 6. Box plots showing the distribution of average height of individuals with in plots. The four most numerous species are displayed. For the variable, “soil scarification” and “fenced” the number “1” on the X-axis signifies treatment, correspondingly “0” represent no treatment. For the “distance” factor, “0” represents plots that were close to a broadleaved forest, “1” signifying plots that were further away.

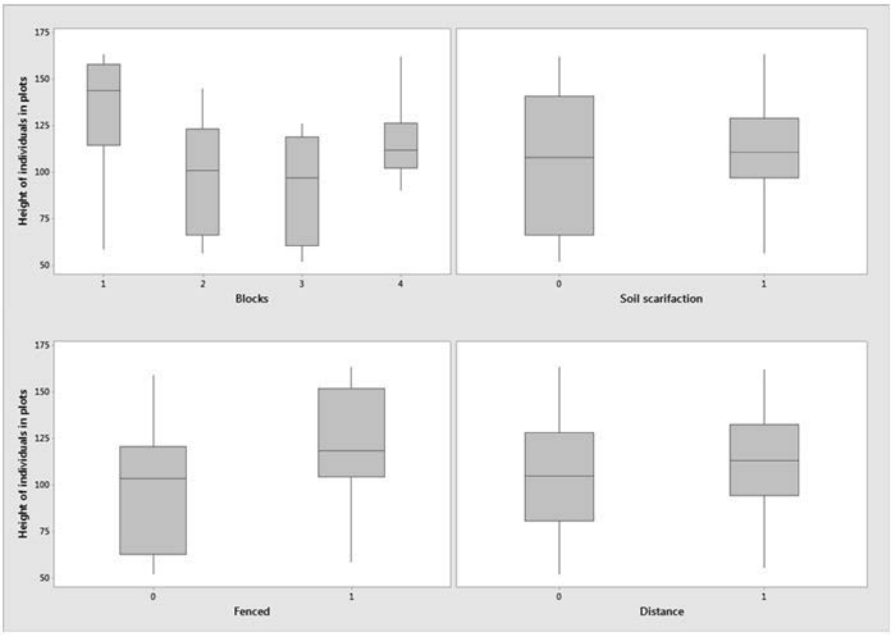

Figure 7. Box-plots showing the average height (cm) of individuals occurring for all species in plots categorizes by treatment variables. For the variable, “soil scarification” and “fenced” the number “1” on the X-axis signifies treatment, correspondingly “0” represent no treatment. For the variable “Distance”, “0” represents plots that were close to a broadleaved forest, “1” signifying plots that were further away.

Vegetation cover

The total number of both herbs and woody species present in plots was only affected significantly by the blocks (P=0,007). When excluding the woody species, the block effect is no longer present but soil scarification now has a positive effect on the herbal species richness (P=0,044). Number of herb species in the ground layer was not significantly affected by distance from broadleaved forest (P=0,420).

Table 5. Results from a General linear model using the coverage for the six herbaceous species most often found in the ground layer of plots. Significance of a treatment factor is indicated with a P-value. The predicting power of the model is indicated with R-squared. Grey shade over a tile underlines were a variable had a significant impact on coverage.

Source of variation	**P-value**					
	Epilobium angustifolium	***Deschampsia flexuosa***	***Carex pilulifera***	***Luzula pilosa***	***Veronica officinalis***	***Rubus idaeus***
Fence	0,000	0,597	0,538	0,066	0,461	0,017
Soil scarification	0,266	0,193	0,031	0,704	0,034	0,675
Distance	0,455	0,597	0,837	0,704	0,461	0,404
Block	0,088	0,000	0,109	0,000	0,000	0,002
	R-Sq					
	66,98%	69,17%	33,14%	74,51%	66,56%	52,88%

Four out of the six most numerous species showed a strong block effect. Fencing had a strong positive effect on the cover of *E. angustifolium* and *R. idaeus* whilst soil treatment had a positive effect on the cover of *C. pilulifera* and V*. officinalis* (Table 5). Fencing and soil scarification never had an impact on the same species. Overall the model explained over 50% of the variance in coverage for all the species except *C. pilulifera* (Table 5).

Discussion

Limitations

Setting a minimum height of woody species for documentation was necessary with the time and resources available. This however influences the strength of height evaluation, since in some plots no individuals of a given species had reached 30 cm but some might still be present. Consequently those plots give a zero value. Since browsing damages were not recorded specifically it’s hard to evaluate the browsing intensity in the area and thus the possible benefits the fence could have. Heterogeneity of plots *in situ* is always an issue when structuring and conducting experiments. Observing the blocks some appeared to have sections where soil amount and moisture was more abundant comparatively. Having soil and moisture analysed might have been advantageous when studying the results.

Woody species

The four most frequent species present in plots are all light demanding pioneers with effective seed dispersal (Götmark et al., 2005). *P. sylvestris* is the least effective seed disperser of the four but still has a reasonably high seed fall within the range of 100m of mother trees (maximum dispersal 1 km) (Sullivan, 1993). However there are large mature *P. sylvestris* individuals in the surrounding area (see Appendix, Table 6), harboring the possibility of plentiful seed production. The high occurrence of these species on the clear cut is thus not unexpected. However, since pioneers are fast growing in youth (Bryan, 1984) it's good to keep in mind their high potential to reach the 30 cm limit since the clear cut in 2011 and getting recorded. They might thus be overrepresented in the count date in relation to the entire regeneration in the area when including all seedlings.

The GLM results illustrate that fencing is a very influential factor; increasing the observed height of plants of all the four most numerous species and the total average height for the added individuals of all species. Soil scarification has a positive effect on the number of individuals for three out of the four most numerous species. Notably distance had no significant effect on height or quantity of individuals present in plots. The model can better predict the height of the individuals than stem density. The exception to this is *P. sylvestris*.

Block effects are not sought after and not optimal when comparing other treatment variables. The effect can indicate that the blocks or its surrounding was not homogeneous enough. Block effects were, however, not prevalent except for *P. tremula* and *P. sylvestris.* Block effects can be difficult to explain without appropriate data but for *P. sylvestris (*which experienced significant block effects for both height and quantity) part of the explanation could be found in the surrounding area. In the reference plots (Appendix, Table 6) adjacent to block 3 and 4 (which contained the majority of the regeneration) were numerous *P. sylvestris* in the higher canopy of the broad-leaved forest (distance 0). The contrary was observed in the other reference plots which most likely contributed greatly to the lack of observed regeneration in the nearby blocks.

Why there is also a block effect for the height of *P. sylvestris* and then on all the individuals of all species lumped is more challenging to explain. But as mentioned before, through means of observation there seemed to be variation in soil moisture and depth, which could have either favoured or disfavoured the growth in particular blocks. Various other unrecorded, situational environmental factors can then influence growth between the blocks.

As previously stated, the four species included in the GLM are all highly preferred by browsers (Hörnberg, 2001) (Sæther & Andersen, 1990), hence seeing a significant height increase within fenced plots for the four most numerous species and for all individuals of all species lumped was not unexpected. Other research has uncovered similar results (Bergquist et al., 2009) demonstrating the positive impact of fencing on height growth. Fencing marginally positively affected the overall number of woody species present in plots (P=0,055) which is consistent with other findings (Fuller & Gill, 2001). Removal of browsing increases the chance of an individual of any species (especially those preferred by browsers) to grow above the 30 cm minimum recording mark and thus be counted, contributing to the overall species richness.

Observed positive impact of removing the humus layer with soil scarification on regeneration has also been reported in previous studies (Jäärats et al., 2012), confirming the effectiveness of soil scarification as a management tool for certain species. Soil scarification can also have other beneficial effects, for example decreasing the negative effect of pine weevil (*Hylobius abietis*) on *Pinus sylvestris*, further increasing the positive effect of the treatment (Petersson et al., 2005).
The most numerous species present in the plots, *Betula spp*. is, however, not significantly affected. Research has found that sprouting of *Betula* spp. seeds (like *P.sylvestris*) is favoured by exposed mineral soil (Hynynen et al., 2010) (Nilsson et al., 2002). So it's peculiar that the *Betula* spp. regeneration does not respond to the treatment. No block effect is present for *Betula* spp., so possible soil variations between blocks is likely not an influential factor. An unaccounted factor is seed fall. Little to no *Betula* spp. was in the canopy in the reference plots (Appendix, Table 6), so larger seed sources might be scattered further away and provide certain blocks with higher supply of seeds, depending on distance to the seed source and the prevalent wind directions in the area. If this is the case, the seed dispersal over the blocks can be vastly uneven possibly altering the effect of soil scarification on the observed quantity of *Betula* ssp. seedlings.

Distance from broad-leaved forest was far from having any significant impact on height, stand density or species richness. As mentioned, the four most numerous species can all be considered pioneer species, with a vigorous production of light seeds which can travel far. This makes them excellent colonizers, rendering the distance from mother trees less critical. Consequently the distance factor does not play a big role in the observed regeneration since the regeneration of species currently dominating the clear cut is marginally dependent on the distance from the broadleaved forest edge.

The explanatory power of the model fluctuates dependent on species from lowest, 26%, of the variance explained for the quantity of *Betula spp*. to the highest, 68%, for quantity of *P. sylvestris*. This indicates that the factors affect the species unequally, but also that there are still important elements that are not accounted for. For instance fencing can expectedly have a greater effect on the number of recorded *P. sylvestris* than *Betula* spp. since browsed *Betula* spp. can sprout dormant axillary buds if the leader shoot is removed or damaged, avoiding height stagnation in the on-going growing season (Hynynen et al., 2010). For *P. sylvestris,* however, a new top shoot needs to come from last year's branch swirl if the leader is removed, loosing precious height. Additionally *Betula* spp. can tolerate more browsing (on other segments then the top shoot) than *P. sylvestris* before it stops growing (Speed et al., 2013).

Other species

Regeneration of *P. abies* was sometimes more vigorous (Appendix, Tables 7-10) than the count data shows (Table 2) since many of them had not reached the 30 cm height limit. *P. abies* is classified as a late successional species with slow initial growth (Engelmark & Hytteborn, 1999), especially compared to the most numerous pioneer species present in the plots (Hynynen et al., 2010). So a time delay can be expected, probably seeing more *P. abies* in the higher strata in the near future. Imaginably then we might see the distance factor affect the *P. abies* regeneration, since *P. abies* seed deposition rapidly decreases with distance (Dovciak et al., 2008). However, as mentioned before, the environment around the stands was not perfectly homogenous; the forest alongside the clear cuts consisted often of *P. abies*, or a mixed forest that possibly influences the regeneration. This may decrease the strength of the distance test for *P. abies* in this research area.

The very few *Corylus avellana* present resided mostly in plots close to the broadleaved forest (5 out of the 6 individuals). The density is too low to make any valid assumptions, but might be a hint of an emergence of a distance effect. Individuals of *Quercus spp*. were only ten (Table 2), but spread over the whole area across treatments. Seeds of *Quercus spp.* can travel far from the mother trees since the acorns are frequently dispersed by a number of animal species, in particular the blue jay (*Cyanocitta cristata*) (Ouden et al., 2004). The oak species are also very light demanding (Diekmann, 1996), making a clear cut a suitable place for colonization. The same patterns may apply to *S. accuparia*.

Why is there no observed regeneration of the other noble broadleaves in the plots close to the broadleaved forest? These nearby stands contain species like *Tilia cordata*, *Acer platanoides*, *Carpinus betulus* , *Fagussylvatica* and more importantly, contains regeneration of all those species in the ground layer (Appendix, Table 6).

There can be a several reasons behind the absence of regeneration of these species on the clear cut.

1. <u>Dispersal</u>
   All mentioned species have short average seed dispersal, with long-distance dispersal events that are rare (Georges et al., 2007). Perhaps the plots are simply out of reach for the majority of the seed fall, thus decreasing the likelihood of regeneration. In addition, part of the explanation for the low apparent spread from the broadleaved stand might lie in the fact that between all the broad-leaved stands and the blocks was a gravel road. A Swedish forest road is not particularly wide, but every added meter from the mother trees with short seed dispersal can have a considerable impact.

2. <u>Unsuitable site conditions</u>
   Studies have shown that establishment of *F. sylvatica* is very dependent on site condition like light and competition from herbaceous species. The species does very poorly in competition with grass in particular. Moderate shade also directly facilitates the emergence of *F. sylvatica* regeneration, but also indirectly by decreasing herb competition (Kunstler et al., 2006). These factors make clear-cuts a rather unsuitable place for regeneration, since it offers little shade and usually has high herbaceous competition.

   Soil conditions, e.g. high soil acidity, might be suboptimal for some of these species (*Tilia cordata*, *Acer platanoides*) in certain plots, or even whole blocks. Since there is no soil data we can't shed light on the possible influence or other environmental factors. There are several classifications available in regards to browsing susceptibility of tree species, but most of them classify noble broadleaves as either highly or intermediate susceptible both to deer (Gill, 1992) and moose (Stokland et al., 2003). Within the fenced plots the treatment should however have removed the imminent threat, but no regeneration was visible in the fenced plots either.

3. Low reproduction of seeds
   Forest trees can exhibit highly variable seed production, ranging from no seeds in some seasons to extremely high seed production in others often showing no correlation to obvious environmental factors (Wesołowski et al., 2014). The state of seed production in the surrounding broad-leaved stands is unknown, but could contribute to the overall results visible in this paper. For example, *T. cordata* is very depended on temperature at the time of flowering for successful fertilization (Pigott & Huntley, 1981). At the northern distribution limit in Europe, the years with sufficient conditions are few and far between (Marshall & Grace, 1992).

Herbaceous cover

Treatment effect on the most common herbaceous species

The effect of treatments on the cover of the six most common species present on the plots is largely in line with previous findings. *Veronica officinalis* can commonly be found on clear cuts (Falkengren-Grerup & Tyler, 1991) and grasses and sedges like *Deschampsia flexuosa* and *Carex pilulifera* have been found to grow on clear cuts, indifferent of fencing (Bergquist et al., 2009) as we observe. Fencing effects detected on the cover of *Epilobium angustifolium* (Table 5.) is expected since it's highly preferred by browsers (Senn et al., 2002).

The indifference to the treatments of *Luzula pilosa* might be due to its capability to retain a large seed bank in the mineral soil for long periods of time. When the time arrives, the seeds can sprout all over the area, and seemingly resisting browsing adequately. Previous work has shown it is not sensitive to browsing pressure (Mathisen et al., 2010). *Rubus idaeus* also typically has a large seed bank in northern forests ready to germinate when light becomes sufficient. However, the species is preferred by browsers (Falkengren-Grerup, 1995), thus the positive effect of fencing in this experiment is consistent with previous findings.

Species richness

Why did proximity to a broadleaved forest not produce higher herbaceous species diversity, since reference plots in broad-leaved stands contained a higher number of ground species than those in conifer forest (Appendix, Table 6)? Research conducted by Jörg Brunet on arable land in southern Sweden showed that nearby forest flora started colonizing stands when they were about 10 years old and then slowly but steadily increased (Brunet, 2007). These results might indicate that the ground flora needs more time to spread on to the clear cut, since it was only cut clear in 2010/2011. Some plants also require a forest habitat with long continuity. This might be due to the requirement for even and high humidity in the soil and shaded conditions (Falkengren-Grerup, 1995).

Conclusions

Results in relation to initial hypotheses

I. Greater number of individuals will emerge in soil treated plots than in non-treated.

   Outcome: Soil scarification significantly increased the stem density of certain species, however overall numbers of individuals were not significantly increased.

II. Fencing will hinder browsing, increasing height of individuals, particularly for species preferred by browsers.

   Outcome: Fencing did increase height growth of the four most numerous species and the average height of all individuals. Species with high browsing susceptibility, like *P. sylvestris* and *S. caprea* displayed stronger effects than the total response from total average of individuals.

III. Fencing will increase the number of individuals equal or higher than 30cm (minimum size documented) during the time period of the research, thus increasing recorded density.

   Outcome: Overall, fencing positively affected the total number of individuals present in plots. However, out of the four most numerous species only *P. sylvestris* separately showed a significant response.

IV. Decreased distance from broadleaved forest should have a positive effect on both broad-leaved species richness and number.

   Outcome: Distance from broadleaved forest did not have any significant effect

V. Decreased distance from broad-leaved forest should have a positive impact on species richness of the ground flora.

   Outcome: Distance from broad-leaved forest had no significant effect on the number of herbaceous species.

Management implications

Fencing and soil scarification costs money, which demands consideration whether the treatments are worth it. The justification varies greatly depending on the goal. If the goal is not a production forest but a mixed broad-leaved forest with high nature values, stem straightness and growth (MAI) are less important. Non-treated plots (no fence, no soil treatment) managed to produce roughly 3000 seedlings/ha containing a mix of species, which some might consider a success. The ratio of *P. sylvestris* and *S. caprea* present is, however, much lower without treatment and *Betula spp*. becomes even more dominant. The former two species are very important for biodiversity and their increased density alone might justify fencing.

Additionally, we do not know how continued browsing will further affect the species composition in the unfenced plots in time. Favoured species might be browsed extensively, causing a share of the population to perish or eventually loose in competition to less browsed species. This might additionally decrease the share of species like *P. sylvestris*, *S. caprea*, *Quercus spp*. and *S. aucuparia*.

Furthermore, advanced treatment like selective pre-commercial thinning might enhance the overall final results. As an example, the 30 individuals per ha (scaled data) for *Quercus spp*. individuals could be marked and helped until they have reached a sufficient height for escaping most of the imminent competition/browsing. These few individuals could then become a valuable asset for their natural values in the growing mixed forest.

Though distance from a broadleaved forest has had no impact on the results presented in this paper, this might result from a colonization delay due to current unfavourable conditions on the clear cut. Further research should be conducted to finally determinate possible distance effects. The findings of this study, however, suggest that close proximity to broadleaved forest is not important during the first years of natural forest restoration on clear cuts.

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Appendix

Cover data

Reference plots

Table 6. Cover estimates for reference plots. Cover scale: + : <1%, 1: 1-5%, 2: 5-25%, 3: 25 -50%, 4: 50-75% 5: 75-100%.

Referance plots

Block	1	1	2	2	3	3	4	4
Distance	0	1	0	1	0	1	0	1
Ground layer								
Acer platanoides	+							
Betula pendula/pubescence		+	+					
Carpinus betulus	+							
Corylus avellana			+		+			
Fagus sylvatica	+		1		+			
Frangula alnus			+	+	+			
Picea abies	+	+	1	+	+			
Populus tremula					+			
Quercus robur/Petraea		+	+	+	+		+	
Sorbus aucuparia		+	+	+	+			+
Tilia cordata	+							
Calamagrostis arundinacea					+			
Calluna vulgaris			1					
Deschampsia flexuosa			1		1			
Dryopteris carthusiana			+		+			
Dryopteris filix-mas	+							
Galium saxatile					+			
Maianthemum bifolium					+			
Melampyrum pratense					+			
Rauda-haerda grasid			+					
Solidago virgaurea					+			
Trientalis europaea L.					+			
Vaccinium myrtillus L.	+						+	
Vaccinium vitis-idaea L.			+		+			
Shrub layer								
Acer platanoides	+							
Betula pendula/pubescence			2					
Carpinus betulus	1							
Fagus sylvatica	1		1				1	
Picea abies			1				+	
Quercus robur/Petraea					+			
Sorbus aucuparia	+	+						
Tilia cordata	2							
Lower tree lvl								
Betula pendula/pubescence			1					
Carpinus betulus	1							
Fagus sylvatica			3				2	1
Picea abies		1			1		+	

Block plots

Table 7. Cover estimates for treatment plots in experimental block 1. Cover scale: + : <1%, 1: 1-5%, 2: 5-25%, 3: 25 -50%, 4: 50-75% 5: 75-100%. The orange highlighted coverage is from individual that have not naturally regenerated by seed since the site was clear cut in 2011 e.g. stump shoots from previously cut trees.

Block	**1**							
Plot number	9	10	13	14	15	16	12	11
Fence	0	0	1	1	1	1	0	0
Soil	1	0	1	0	0	1	1	0
Distance	0	0	0	0	1	1	1	1
Coverage								
Ground layer								
Betula pendula/pubescence	2	1	1	1		1	1	1
Frangula alnus								
Picea abies					+	+	+	+
Pinus sylvestris					1		+	+
Populus tremula								
Quercus robur/Petraea								+
Salix caprea	1	1	1		+		+	
Sorbus aucuparia							1	+
Tilia cordata					1			
Corylus avellana			+		+			
Juniperus						+		
Agrostis capillaris	1		1					
Athyrium filix-femina						+		
Calluna vulgaris					+	+	1	
Carex pilulifera	1	1	+	1	1	1	1	1
Carex spec.			+					
Ceratocapnos claviculata						+		+
Cirsium arvense						+		
Cirsium vulgare						+		
Deschampsia flexuosa	2	1	2	2	2	+	3	2
Dryopteris carthusiana					+	+		
Epilobium angustifolium	+	+	2	1	1	1	+	+
Galeopsis bifida/tetrahit	+	+		+	+			
Hieracium spec.			+					
Hypericum perforatum L.			+					
Juncus effusus	1	+	+		1	+		
Luzula pilosa					+			
Molinia caerulea					+			
Poa nemoralis				+				
Poaceae spec.						+		
Polypodium vulgare	+							
Potentilla erecta					+			
Rubus fruticosus	1	2	1	2	+	2	+	
Rubus idaeus	5	5	3	4	4	4	4	4
Rumex acetosella			1			1		
Salix spec.						+		
Scrophularia nodosa	+		+					
Solanum dulcamara	+			+				
Urtica urens			+					
Vaccinium myrtillus L.			+					+
Veronica officinalis	+	+	+					
Shrub layer								
Acer platanoides								
Betula pendula/pubescence	2	1	1	1	2	2	1	+
Carpinus betulus				1				
Populus tremula		+			+	1		
Quercus robur/Petraea				+				
Salix caprea	1	1	+	+	1			
Sorbus aucuparia	+			1	+	1		
Tilia cordata				2	1			

Table 8. Cover estimates for treatment plots in experimental block 2. Cover scale: + : <1%, 1: 1-5%, 2: 5-25%, 3: 25 -50%, 4: 50-75% 5: 75-100%. The orange highlighted coverage is from individual that have not naturally regenerated by seed since the site was clear cut in 2011 e.g. stump shoots from previously cut trees.

Block	**2**							
Plot number	22	21	23	24	18	17	19	20
Fence	1	1	1	1	0	0	0	0
Soil	0	1	0	1	0	1	1	0
Distance	0	0	1	1	0	0	1	1
Coverage								
Ground layer								
Betula pendula/pubescence			+				1	
Frangula alnus		+	+			+	+	
Picea abies		+	+	+	+	+	+	+
Pinus sylvestris		+	+			+	+	
Populus tremula						+		
Quercus robur/Petraea		+						+
Salix caprea		+				+		
Corylus avellana						+		
Agrostis capillaris	+	+				2	+	+
Calluna vulgaris		+	+	1		+	1	+
Carex pilulifera	+	+	1	+		2	1	1
Ceratocapnos claviculata								
Deschampsia flexuosa	3	3	3	3	3	2	5	3
Dryopteris carthusiana	+	+			+	+		2
Epilobium angustifolium	1	+	2	+	+	+	+	+
Juncus effusus		+		+		1	2	+
Luzula pilosa		+		+			+	
Potentilla erecta		+		+		+	+	+
Pteridium aquilinum				+	1			
Rubus fruticosus	+		+	+			+	
Rubus idaeus	3	3	2	2	3	5	1	2
Trientalis europaea L.								+
Vaccinium myrtillus L.		+						
Veronica officinalis		+			+	1		
Vicia sp.		+						
Viola riviniana		+						
Shrub layer								
Betula pendula/pubescence			+		+		+	
Fagus sylvatica					2			
Frangula alnus				1				
Salix caprea			1					

Table 9. Cover estimates for treatment plots in experimental block 3. Cover scale: + : <1%, 1: 1-5%, 2: 5-25%, 3: 25 -50%, 4: 50-75% 5: 75-100%. The orange highlighted coverage is from individual that have not naturally regenerated by seed since the site was clear cut in 2011 e.g. stump shoots from previously cut trees.

Block	3							
Plot number	26	25	28	27	29	30	31	32
Fence	1	1	1	1	0	0	0	0
Soil	1	0	0	1	1	0	1	0
Distance	0	0	1	1	0	0	1	1
Coverage								
Ground layer								
Betula pendula/pubescence	2	1	+	1	1	1	1	+
Frangula alnus			+					
Picea abies	+	+	+	+	+	+	+	+
Pinus sylvestris	2	1	1	1	+	+	+	+
Populus tremula	+		1	+	+	+	+	
Quercus robur/Petraea	+	+	+	+	+	+		
Salix caprea	1	1	+	1	+	+		
Sorbus aucuparia					+			
Corylus avellana	+					+		
Juniperus	+							
Agrostis capillaris	1	1	+	+	1	1	1	+
Calluna vulgaris	3	1	+	+	1	1	+	+
Carex pilulifera	1	1	+	1	1	+	1	1
Ceratocapnos claviculata			+		+	+		
Deschampsia flexuosa	2	2	1	+	2	2	1	1
Digitalis purpurea							+	
Dryopteris carthusiana	+		+		+			
Epilobium angustifolium	2	2	2	2	+	+	+	+
Galeopsis bifida/tetrahit					+	+		
Juncus effusus	+		+	+			+	
Lathyrus linifolius			+					
Luzula pilosa	+	1	1	1	+	+	+	+
Maianthemum bifolium						+		
Phleum pratense							+	
Pilosella officinarum								+
Potentilla erecta	+		+		+			
Rubus fruticosus	1		1	1	+	+	1	+
Rubus idaeus	3	2	4	4	3	4	5	4
Rumex acetosella				+	+	+		+
Vaccinium myrtillus L.	+				+	+		
Veronica officinalis	+	1	1	1	1	+	1	+
Viola canina	+							
Viola riviniana			+					
Shrub layer								
Acer platanoides								
Betula pendula/pubescence	2	1	1	1			+	
Fagus sylvatica		1						
Populus tremula	+		1	1				
Quercus robur/Petraea	1			2				
Salix caprea	2	+	1	1				
Sorbus aucuparia	+							

Table 10. Cover estimates for treatment plots in experimental block 4. Cover scale: + : <1%, 1: 1-5%, 2: 5-25%, 3: 25 -50%, 4: 50-75% 5: 75-100%. The orange highlighted coverage is from individual that have not naturally regenerated by seed since the site was clear cut in 2011 e.g. stump shoots from previously cut trees.

Block	4							
Plot number	5	6	8	7	2	1	4	3
Fence	0	0	0	0	1	1	1	1
Soil	1	0	1	0	1	0	1	0
Distance	0	0	1	1	0	0	1	1
Coverage								
Ground layer								
Betula pendula/pubescence	2	1		+	2	2	1	3
Frangula alnus	1	+						
Picea abies	+			+	+	+	+	
Pinus sylvestris	+	+		+	1	1	1	
Populus tremula		1						+
Quercus robur/Petraea		+		+	+	+		
Salix caprea	+	+			1	1	1	1
Sorbus aucuparia				+				
Agrostis capillaris		1				+	2	
Athyrium filix-femina								+
Calluna vulgaris	1		1		1	2	1	
Carex pilulifera	2	1	1	1	2	1	2	+
Crepis paludosa						+		
Deschampsia flexuosa	1	1	2	1	2	1	2	+
Dryopteris filix-mas								1
Epilobium angustifolium	+	+	+	+	2	3	1	2
Galeopsis bifida/tetrahit	1		+			+		+
Hieracium spec.						+		
Juncus effusus	+				+	+	+	2
Luzula pilosa	1	1	+	1	1	1	1	+
Melampyrum pratense	+				+	+		
Potentilla erecta	+				1	1		
Rubus fruticosus			1			1	+	1
Rubus idaeus	5	5	5	5	4	4	4	3
Senecio sylvaticus	1	+		+				
Stellaria media				+				
Veronica officinalis	1	1	2	1	1	1	2	+
Viola sp.	+							
Shrub layer								
Betula pendula/pubescence	1	1	+	+	1	1	1	2
Frangula alnus						+	+	
Populus tremula							+	
Quercus robur/Petraea						1		
Salix caprea					1	+	+	
Sorbus aucuparia			+					

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