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Effects of spot mounding and inverting on growth of conifers, exposed mineral soil and natural birch regeneration

Highlights

- There were 21% fewer naturally regenerated birches ha^{-1} in inverted areas (22 951) compared to spot mounded areas (29 086).
- Spot mounding exposed slightly, but not statistically significantly, larger area of mineral soil than inverting.
- There was no difference in seedling mortality or growth between the site preparation methods.

Abstract

In Nordic forests, consistent evidence about better seedling survival rate and increased growth due to site preparation have been obtained in numerous studies. Proper site preparation method can reduce costs of the whole regeneration chain through its effects on survival of planted seedlings, abundance of natural regeneration and competition in early stand development. This study compared the natural regeneration of birches (silver birch (*Betula pendula* Roth) and downy birch (*B. pubescens* Ehrh.)), amount of exposed mineral soil, and growth of planted seedlings between spot mounding and inverting site preparation methods. Present study was conducted in eight forest stands established in 2012 or 2015. Even though difference was not statistically significant, inverting exposed less mineral soil than spot mounding and thus reduced the natural regeneration of birch seedlings by 6135 seedlings ha^{-1} compared to spot mounding. However, the variation between regeneration areas was remarkable. There was no difference in seedling mortality or growth between the site preparation methods. In order to achieve high growth of conifers, moderate amount of exposed mineral soil and thus less naturally regenerated birch, inverting should be favored over spot mounding.

1   Introduction

Site preparation is usually the first silvicultural treatment after clear cutting (Örlander et al. 1990). Site preparation methods can be divided into methods that only remove humus layer and reveal mineral soil and methods that also form a mound. Methods only removing humus are disc trenching and patch scarification. Methods forming mounds are spot mounding, ditch mounding and inverting. All mounding methods have in common that humus and mineral soil layers are inverted (Örlander et al. 1990; Sutton 1993; Örlander et al. 1998; Luoranen et al. 2007).

Site preparation results in a better survival rate and increased growth of seedlings in Nordic forests (Örlander et al. 1996; Hallsby and Örlander 2004; Saksa et al. 2005; Kankaanhuhta et al. 2009; Hjelm et al. 2019; Sikström et al. 2020) but also in boreal forests of North America (Bedford and Sutton 2000; Simard et al. 2003; Thiffault et al. 2010). Site preparation creates favorable growing conditions for planted seedlings and improves germination conditions of seeds by, for example, increased soil temperature, enhanced root growth and nutrient uptake, reduced competition from vegetation, and decreased damage risk caused by the pine weevil (*Hylobius abietis* (L.)) (Örlander et al. 1996; Nilsson and Örlander 1999; de Chantal et al. 2003; Nordborg et al. 2003; Heiskanen and Rikala 2006; Norlander et al. 2011; Heiskanen et al. 2013; Mjöfors et al. 2015).

Site preparation also has negative effects. For example, winter desiccation damage can occur when temperature increases on mounds and evaporative loss cannot be replenished because roots and soil are still frozen (Christersson et al. 1988; Langvall et al. 2001). Higher temperature in prepared soil leads to earlier budbreak in spring which might increase the risk of spring frost (Johansson et al. 2005). Site preparation also exposes seedlings to frost heave in fine-textured soil causing deformation and upward thrust of the ground surface (Heiskanen et al. 2013). Mineral soil exposed in site preparation improves the germination conditions of seeds, enhancing abundant natural regeneration of unwanted deciduous trees (Karlsson and Örlander 2000; Lehtosalo et al. 2010; Sikström et al. 2020). In planted conifer stands, this response often leads to a need for young stand management operations to ensure growing conditions for economically more valuable conifer trees by removing competing deciduous trees (Uotila et al. 2012).

Given the increasing cost of young stand management, customized site preparation can reduce costs of the whole regeneration chain through its effects on abundance of natural regeneration and competition in early stand development (Uotila et al. 2014; Official Statistics of Finland 2020). Generally, these site preparation's effects are controlled through the amount of mineral soil exposure (Uotila et al. 2010). For example, continuously advancing site preparation machines, such as disc trenchers or ploughing devices, expose usually more than half of soil surface area. Intermittently working but continuously advancing site preparation machines, such as continuously advancing mounders, expose considerably less mineral soil, normally 30 to 40% of the soil surface. With excavator-based site preparation equipment, the site preparation track can be precisely directed and the area of exposed mineral soil surface can be much lower (15–25% of the soil surface) (Sikström et al. 2020).

To reverse the trend of increasing costs in young stand management, it would be beneficial to find out if there are differences between currently used mounding methods on the natural regeneration of deciduous trees. The primary objective of this study was to compare the amount natural regeneration of birches (silver birch (*Betula pendula* Roth) and downy birch (*B. pubescens* Ehrh.)), amount of exposed mineral soil, and growth of planted seedlings between spot mounding and inverting site preparation methods. Our secondary objectives were to study the quality of site preparation, success of seedling establishment and distribution of soil surface disturbance categories between these two techniques.
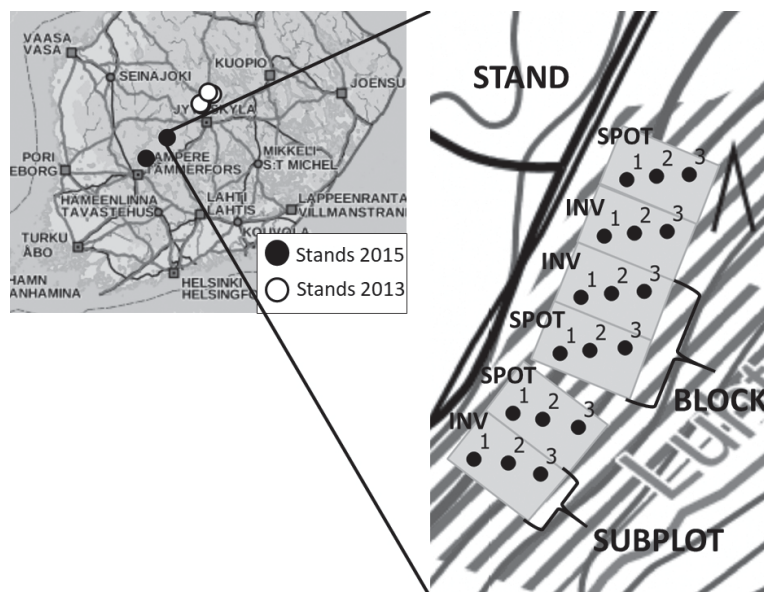
Fig. 1. Locations of six research stands in Finland and experimental design of the study within the stand. SPOT = spot mounding, INV = inverting.

2 Materials and methods

2.1 Stands and site preparation methods

Comparison of spot mounding and inverting was done altogether at six forest stands in central Finland (Fig. 1, Table 1). Site preparations were done in late autumn 2012 ($n=4$) and in spring 2015 ($n=2$). The first four stands were planted in spring 2013 and the latter two in spring 2015 with Norway spruce (*Picea abies* (L.) H. Karst) ($n=5$) or Scots pine (*Pinus sylvestris* L.) ($n=1$). From two stands at 2012 stumps were harvested for energy purposes.

At each stand, three to four blocks (40 m × 60 m) were established. Each block was then split into two subplots (20 m × 30 m) for spot mounding and inverting, which were randomized. For the follow up measurements, a set of three circular sample plots (r = 3.99 m) was established on a diagonal line. Data consisted of 23 blocks, 46 subplots, and 138 sample plots (69 for both site preparation methods). Altogether 1306 planted seedlings were measured (653 by both methods). The experimental design within a stand is illustrated in Fig. 1.

Table 1. Main characteristics of the six research stands to study the effects of spot mounding and inverting.

Stand	Regen. year	Tree species	Number of blocks	Site type[a]	Stump harvesting	Soil texture	TWI[b]±SD	Stoniness±SD, cm	Particles <0.063 mm±SD, %
1	2013	Spruce	4	MT	No	Medium-coarse	7.4±0.5	11.2±4.8	34.4±3.4
2	2013	Spruce	3	MT	No	Medium-coarse	6.8±1.2	12.8±4.9	45.0±4.7
3	2013	Spruce	4	OMT	Yes	Medium-coarse	6.4±0.6	14.1±2.6	40.9±10.6
4	2013	Spruce	4	OMT	Yes	Medium-coarse	7.5±0.6	10.1±4.3	30.2±6.0
5	2015	Pine	4	MT	No	Fine	8.9±2.1	25.5±2.8	57.5±14.0
6	2015	Spruce	4	MT	No	Fine	10.0±1.6	24.8±4.5	47.5±19.0

[a] Forest site type: MT = *Myrtillus* type forest, OMT = *Oxalis-Myrtillus* type forest. Soil fertility: MT < OMT (Cajander 1926).
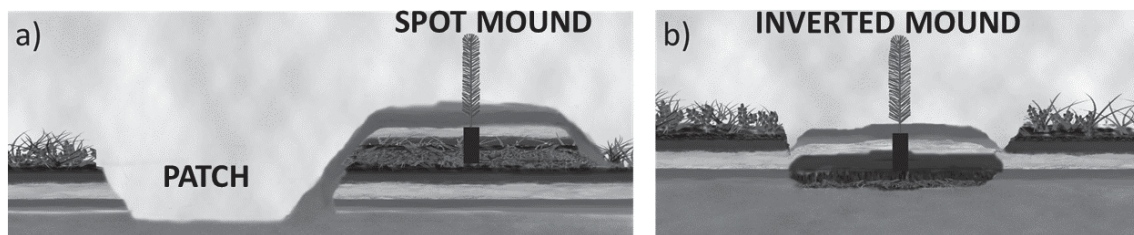[b] TWI refers to the Topographic Wetness Index (Salmivaara et al. 2017).

Fig. 2. Schematic illustration for the treatments of the study: a) spot mounding and b) inverting (Luoranen et al. 2007). In spot mounding, humus and mineral soil are inverted and placed beside the patch onto undisturbed soil whereas in inverting, inverted mound is returned to the patch it came from.

There were two excavators and two operators, one of whom worked at 2012 and the other at 2015. A bucket developed especially for inverting was used for both spot mounding and inverting. In spot mounding, a volume of soil including both humus and mineral layers, is inverted onto undisturbed soil resulting in a patch from which the soil was taken and a mound. Correspondingly, in inverting the soil is returned to the patch it came from resulting in only a mound (Fig. 2). Thus, inverted planting spots are about at the same level as the surrounding ground whereas spot mounded are elevated. The target density of mounds was 1800 mounds ha^{-1} for both soil preparation methods.

2.2 Fieldwork

The first inventory was done at the first autumn after planting. All mounds and seedling were measured. The size of mounds was measured for length, width and height (cm). The planting depth (depth of soil layer above the seedling container, cm) and height of seedlings were recorded before or after growing season at spring (April/May) or at autumn (September/October). The planting depth was observed with a measuring stick near the stem. It was also noted if a seedling was planted on a mound or elsewhere, or if there was an empty mound. Texture of the soil surface was measured from the square sample plots (area of 1 m^2) located on a diagonal line of the subplot at intervals of one meter after planting. Surface of the soil was classified as disturbed (mound, patch, otherwise disturbed) or undisturbed (undisturbed, stone, stump) at the accuracy of 3% occurrence. All fieldwork was done by the same people.

At autumn two years after planting, i.e. after third growing season, annual height growth was measured, and possible damages were inventoried from planted seedlings. In addition, the regeneration of deciduous tree species was recorded. Stoniness was determined from five points (from the center of sample plot and from 1 meter away from the center in each main cardinal direction) by measuring the occurrence of stone (cm) and it was presented as a mean depth for each sample plot.

Soil samples were taken from each sample plot from the first 15 cm of the soil layer below the humus. Samples from the same subplot were joined before particle size analysis and the proportion of fine-textured soil was determined (particles <0.063 mm). Topographic wetness index (TWI) for subplots was calculated from the digital elevation models (Salmivaara et al. 2017), and it based on the mean TWI value of the 16 m × 16 m squares within the subplot. The TWI ranges between 0 and 34.8 (in Finland) and it describes the tendency of an area to accumulate water (higher index value indicates wetter area). The TWI data are freely available at Paituli spatial data download service (www.csc.fi/paituli). The main characteristics of research stands are presented in Table 1.

2.3 Statistical analyses

The statistical program R was used to analyze differences between the two site preparation methods (R Core Team 2018). The number of naturally regenerated birch seedlings (ha^{-1}), the proportion of exposed mineral soil, i.e. proportion of mound and patch (%), and the height of planted seedlings (cm) were investigated with linear mixed models (LMM), using the lme function in the nlme library (Pinheiro et al. 2018). Logit transformation was applied to exposed mineral soil model and the number of naturally regenerated birch seedlings (n_{birch}) needed logarithmic transformation, i.e. $\ln(n_{birch} + 1)$.

Different stand characteristics (site type, soil type, topographic wetness index (TWI), stoniness, share of soil particles <0.063 mm; Table 1) were tested using manual forward selection and only factors statistically significant at the $p < 0.050$ level were included in the final model. Stump harvesting or site fertility was not included in the analysis since they were confounded. Eventually, only soil preparation method (a factor with two levels: spot mounding and inverting) was as explanatory variable in all three models. Stands and blocks were included as nested random factors in all models as conditions within the same stand and block may be more similar than on a randomly selected stand or a block resulting correlated observations.

Residual plots (fitted values against residuals) were inspected after each model in order to check the normality assumptions of response variables and to identify outliers. Thus, two subplots were excluded from the final analysis as outliers, since they deviated considerably from other observations by the occurrence of birch seedlings. Also, one sample plot was missing at the final inventory. The final data used in the analysis consisted of 42 subplots, 132 sample plots and 1251 planted seedlings (598 planted on spot mounds and 653 to inverted spots). Finally, fit of the models were examined by comparing the variances of the random parts with (full model) and without (empty model) fixed effects at the stand and subplot levels.

3 Results

3.1 Growth of conifers

There were 1898 seedlings planted on spot mounds ha^{-1} and 1893 seedlings ha^{-1} on inverted mounds. Mortality after the first growing season was 11.4% and 9.0% for seedlings planted on spot and inverted mounds, respectively (Fig. 3a). After the third growing season, the corresponding values were 13.5% and 13.3%. Mortality was greatest in stand one, mostly due to pine weevil damage.
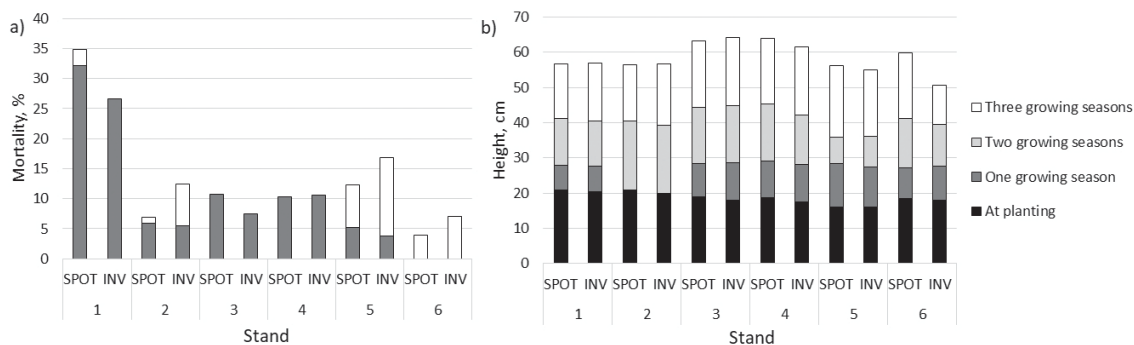

Fig. 3. Cumulative mortality (a) after first and third growing season and height (b) of seedlings at planting and after first, second, and third growing seasons in areas of spot mounding (SPOT) and inverting (INV). In stand two height was not measured one growing season after planting.

Table 2. The effects of the site preparation method (spot mounding vs. inverting) on the number of birches regenerated (seedlings ha^{-1}), the proportion of exposed mineral soil on site preparation (%),and the height of the planted seedlings (cm) three growing seasons after regeneration (linear mixed models). Parameter estimates, standard error (SE), and *p*-values are presented as well as standard deviation of random effects. Statistically significant p-values ($p < 0.050$) for the model coefficients are in bold.

Explanatory variables	Birch regeneration		Exposed mineral soil		The height of the seedling	
	Coeff. ± SE	*p*	Coeff. ± SE	*p*	Coeff. ± SE	*p*
Intercept	4.802±0.288	**<0.001**	−1.040±0.095	**<0.001**	57.301±1.967	**<0.001**
Site prep. [INVERTING]	−0.310±0.094	**0.004**	−0.161±0.099	0.118	0.767±1.698	0.656
Standard deviation of random effects						
Stand level	0.674		0.152		3.755	
Block level	0.236		0.000		0.000	
Residual	0.307		0.326		5.597	

Height development was similar between mounding methods ($p=0.656$) (Fig. 3b; Table 2). After planting, seedlings on spot and inverted mounds were on average 19.1 cm (standard deviation, SD 4.5) and 18.2 cm (SD 4.3) in height, respectively. After the third growing season, the height was 60.0 cm (SD 16.9) and 57.6 cm (SD 15.9) for living seedlings planted on spot and inverted mounds, respectively. Planting depth was on average approximately equal: 5.7 cm (SD 2.1) and 6.1 cm (SD 2.0) for seedlings planted on spot and inverted mounds, respectively.

3.2 Exposed mineral soil

There was only a small difference in the area of the mounds: spot mounds were on average 0.84 m^2 (102 × 82 cm) and inverted mounds 0.90 m^2 (101 × 89 cm). Inverted mounds were 8.9 cm and spot mounds 9.2 cm high. Patches produced in spot mounding were on average 0.40 m^2 and patches in inverting were only 0.04 m^2.

Distribution of soil surface disturbance categories also showed similar results as above (Table 3). There was only a small difference in area covered by mounds (17.6% and 17.8% for spot and inverted mounds of the soil surface, respectively), whereas the difference in the area of patch was notable (9.4% and 5.8% for patches of the soil surface performed in spot and inverting mounding, respectively). This is reflected in the proportion of undisturbed soil, lower in spot mounted areas (48.2%) than inverted areas (53.0%). The proportion of otherwise disturbed soil was quite similar between the methods.

To separate the effect of stump harvesting on soil disturbance, in stands where stumps were not harvested the occurrence of patches was six percentage points higher in spot mounded areas than in inverted areas (Table 3). The corresponding difference between mounding methods in

Table 3. Site preparation effects (spot mounding and inverting) on the occurrence of soil surface disturbance categories (mean ± standard deviation, %).

	Site preparation	Mound	Patch	Otherwise disturbed	Undisturbed	Stone	Stump
Whole data	Spot mounding	17.6±4.6	9.2±5.0	20.9±16.1	46.6±15.5	4.9±4.4	0.8±0.6
	Inverting	17.8±4.1	5.8±4.7	19.0±19.1	53.0±19.3	3.8±4.3	0.7±0.5
Stump harvesting excluded	Spot mounding	17.6±3.8	10.8±4.4	11.8±5.2	55.2±11.9	3.5±4.7	1.0±0.6
	Inverting	17.4±2.8	4.8±4.2	9.6±5.5	64.5±9.6	3.0±4.5	0.7±0.5

Table 4. Influence of fixed and random effects on the total variation of models of the number of birches regenerated (seedlings ha⁻¹), the proportion of exposed mineral soil on site preparation (%), and the height of planted seedlings (cm). Full models refer to Table 2 and empty models to models estimated without fixed predictors. ICC refers to Intra Class Correlation.

Response	Empty model		Full model		Influence of fixed effects, %
	Variance estimate	ICC, %	Variance estimate	ICC, %	
Stand level					
Birch regeneration	0.438	71.5	0.454	75.2	−1.8
Exposed mineral soil	0.022	16.7	0.023	17.9	−2.0
The height of the seedling	13.920	31.2	14.100	31.0	−0.64
Block level					
Birch regeneration	0.039	77.9	0.056	84.4	−19.2
Exposed mineral soil	0.000	16.7	0.000	17.9	−4.2
The height of the seedling	0.000	31.2	0.000	-	15.7

All estimates of random effects converged in the calculations, but some were so small that they round to zero.

undisturbed soil was almost ten percentage points. Based on the average patch size, the difference should be even greater.

Based on linear mixed model, there was no difference in exposed mineral soil, i.e. the area covered by mounds and patches, in spot mounding and inverting ($p = 0.118$) (Table 2). There was 18% variation between stands in exposed mineral soil (Table 4).

3.3 Natural birch regeneration

After the third growing season, the number of naturally regenerated birch seedlings was on average 25 879 ha⁻¹. On spot mounded areas, there were 29 086 birch seedlings ha⁻¹ and on inverted areas 22 951 birch seedlings ha⁻¹. Relatively, the difference in birch regeneration between spot mounding and inverting was fairly consistent across stands (Fig. 4), and the difference was statistically significant ($p = 0.004$) (Table 2). Of the variation in the number of birches, 75% was explained by the stands (Table 4).
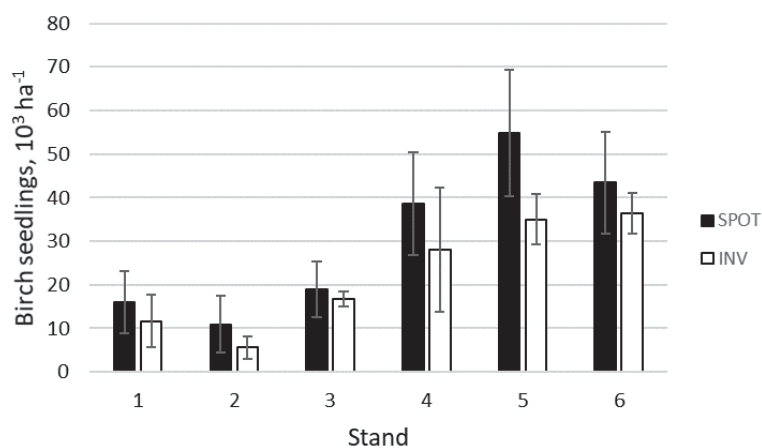

Fig. 4. Number and standard deviation of naturally regenerated birch seedlings (10³ ha⁻¹) in areas of spot mounding (SPOT) and inverting (INV).

4 Discussion

In inverted areas, there were 21% fewer naturally regenerated birches compared to spot mounded ones. Site preparation has been reported to increase the number of naturally regenerated trees compared to controls where no site preparation was done (Karlsson et al. 2002; Johansson et al. 2013; Sikström et al. 2020). Compared to previous studies, our observation of 29 086 ha^{-1} of naturally regenerated birch on spot mounded areas can be considered notable. Using the time consumption model of Kaila et al. (2006), young stand management in spot mounded areas (density of 29 086 saplings ha^{-1}) of the present study would take 1.0 days ha^{-1} if saplings were 0.5 cm stump diameter and 2.6 days ha^{-1} if saplings were 2.5 cm, whereas it would take 0.9 days ha^{-1} and 2.2 days ha^{-1} for inverted areas (density of 22 951 saplings ha^{-1}), respectively. However, it is good to consider that this calculation is a demonstrative example and does not take into account that higher density reduces increment and thus diameter growth.

The difference in the number of naturally regenerated birches was most likely due to the slightly, but not statistically significantly, larger area of mineral soil exposed in spot mounding than in inverting. Theoretically, inverting should expose one half as much mineral soil as spot mounding since the soil is returned to the patch from which it came. The disturbed soil surface could be as small as 50 cm by 50 cm in an area resulting in 5% soil disturbance area with a planting density of 2000 seedlings ha^{-1}. However, there was soil classified as "patch" in inverting as well. The share of mineral soil patch in inverting was about 5% in this study, comparable to Hallsby and Örlander (2004). Thus, with high work quality, skilled operators and improved equipment, inverting could even reduce soil disturbance more than found in our study and restrain natural regeneration of birches. Generally, the proportion of soil surface disturbance in this study was similar to that reported in other studies as mounding has been reported to affect, on average, 37% of the surface area (ranging from 17 to 67%) (Sikström et al. 2020).

The variation in natural regeneration of birches between the stands was typical as all stands in this study represented conventional regeneration stands and usual conditions in Finland. It is well known that the result of natural regeneration of birches varies greatly between the years, geographical locations (between stands and within a stand), but also soil texture, moisture and weather conditions affect the regeneration of birches (Saksa 2013). Findings of the present study can be generalized to other Nordic countries with silvicultural practices similar to Finland. When placing the results in wider context, it is important to consider or account for site and climate difference.

In the present study, there was no difference in seedling mortality or growth between the mounding methods, even after three years post-planting. The effect of soil preparation may occur later because of increased nutrient availability. In their meta-analysis, Sikström et al. (2020) found out that soil preparation increases tree height by 10–25% in 10–15 years after planting. However, there were no statistically significant differences between the mounding methods (Sikström et al. 2020). However, some previous studies have shown better seedling survival and growth for inverting than mounding in the short- and long-term (Örlander et al. 1998; Hallsby and Örlander 2004; Johansson et al. 2013). In addition, in fine-textured soils susceptible to frost heave, spot mounding has been reported to give better results than inverting (Heiskanen et al. 2013). In general, results of survival and height growth were consistent with previous studies of mounding in Nordic forests but the results have varied in the North American studies (Sikström et al. 2020).

There is no previous study of different mounding methods on future development of stands. To conclude the results of the present study, inverting did expose less mineral soil than spot mounding and thus reduced the natural regeneration of birch seedlings. There was no difference in seedling mortality or growth between site preparation methods. Furthermore, even though there was a difference between inverting and spot mounding in natural regeneration of birches, the variation

between regeneration stands was notable. Thus, the inspection of individual stands is recommended for assessing regeneration success. We recommend that inverting should be favored in those areas where the prerequisites are fulfilled.

Acknowledgement

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