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The effect of site preparation on vegetation restoration in young hemiboreal mixed stands

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Abstract

Tree logging significantly impacts environmental conditions, increases soil and air temperature, and changes the microclimate and soil hydrology. This contributes to the changes in bryophyte and vascular plant cover and species composition. Site preparation positively affects the growth of planted trees in young stands but also causes forest understorey disturbance. During site preparation in young stands by spot mounding and disc trenching methods, new microtopographies, e.g. soil tumps and hollows are made in young stands. Site preparation generally increases vascular plant diversity, but there is a lack of information about the vegetation differences between microtopography depending on different site preparation methods and soil types.

The aim of this study was to investigate how the microtopography formed during site preparation by spot mounding or disc trenching affects bryophyte and vascular plant communities in hemiboreal young stands two to three years after tree logging. Spot mounding altered vegetation composition more than disc trenching. Bryophyte species cover decreased in prepared soil, but Ellenberg's moisture value increased; therefore, site preparation before planting contributes to the conservation of typical forest bryophyte species in young stands. Hollows lead to better typical forest habitat species preservation, but soil tumps diversify environmental conditions by providing new patches for the development of grassland habitat species that are not typical in this ecosystem, but temporally provide new ecosystem services.

Keywords: bryophytes, spot mounding, disc trenching, vascular plants, plant growth forms, Ellenberg's indicator values

Introduction

Understorey vegetation plays an important role in the stability and productivity of the forest ecosystem; it improves growth conditions by regulating soil fertility and stabilising moisture (Deluca et al. 2002, Nilsson and Wardle 2005, Petersson et al. 2019, Siwach et al. 2021). Vascular plant and moss species make a major contribution to forest biodiversity through interactions with other taxa, including insects, birds and mammals (Storch 1993, Bokhorst et al. 2014, Felton et al. 2017, Zhang et al. 2018). Vegetation in forests is primarily determined by soil type and the dominant tree species, which determine the light intensity, its variability during the growth period, and the chemical composition of the litter (Chipman and Johnson 2002, Sorenson et al. 2011, Li et al. 2012, Petersson et al. 2019). In boreal forests, vegetation is relatively stable in terms of species composition and has a small variation between similar stands in different locations, but the cover of individual species can change significantly depending on succession or management (Nieppola 1992, Chipman and Johnson 2002). Large-scale site factors such as light intensity had less influence on species diversity and abundance than small-scale site variation of geogenic parameters: moisture and nutrient availability (Bridge and Johanson 2000, Chipman and Johnson 2002). Nevertheless, bryophyte species composition is a complex system: species diversity at large scale affects species diversity at a small scale concurrently with the factors affecting them and vice versa (Mills and Macdonald 2005).

The vegetation composition of hemiboreal forests is significantly altered by natural (fire, insect outbreaks, wind) and anthropogenic (thinning, logging, site preparation) disturbances (Decocq et al. 2004, Mayer et al. 2004, Crispo et al. 2021). Clearcutting is a common logging practice in hemiboreal forests but has been criticised for its negative effects on the environment due to the altered microclimate and soil hydrology (McDermott et al. 2010, Tonteri et al. 2016). After clearcut the total cover of bryophytes decreases and vascular species composition changes (Jalonen and Vanha-Majamaa 2000, Uotila and Kouki 2005, Boudreault et al. 2018). Major vascular plant successional change occurs a few years later after a clearcut, while bryophyte species composition experiences large shifts in the earliest years following a clearcut (Niemela 1999, Schmalholz and Hylander 2009). Due to increased numbers of ruderal and light-demanding species, the number of plant species is the highest in the first ten years after felling but decreases with stand age (Zobel et al. 2007, Gustienė et al. 2019, Tullus et al. 2022). Non-typical forest vascular plants, drought-tolerant, light-demanding and pioneer species such as *Rubus idaeus* (L.) dominate in the first few years after logging, but with further succession, bryophytes and dwarf shrub species typical of old boreal forests reoccupy the area (Hannerz and Hånell 1997, Engelmark and Hytteborn 1999, Uotila and Kouki 2005, Bergstedt et al. 2008). Species diversity value may be temporally increased after clearcut, but in terms of succession, species composition and the presence of old forest-specific species are more important (Gustafsson et al. 2021).

Site preparation after logging and before tree planting in young stands creates soil upper layer disturbance, therefore it has an impact on further vegetation development (Peltzer et al. 2000, Jasinski and Angelstam 2002, Tonteri et al. 2016). Site preparation is a valuable and widespread practice, because it improves the availability of nutrients, raises soil temperature and changes soil moisture, as well as reduces damage caused by *Hylobius abietis* (L.) and competition between planted trees and vegetation, resulting in better growth of planted seedlings and survival rate (Örlander et al. 1990, Johansson 1994, Bilodeau-Gauthier et al. 2011, Luoranen and Rikala 2013). The most appropriate site preparation method depends on forest type and soil type, water table level and target species for seedling (Sutton 1993, Uotila et al. 2010). In Latvia, the most widespread site preparation method is disc trenching, in which the humus layer is removed and pushed to one side, creating a berm (Luoranen and Rikala 2013). Other applied methods include spot mounding, which is done by excavating soil and turning it over next to the newly made pit, thereby making a place, where mineral soil is exposed and tree seedlings can be planted (Celma et al. 2019). Spot mounding is more appropriate in the areas with heavy precipitation and high water table, because newly made pits collect excess water and prevent tree seedlings from being drowned under the conditions of high water table, as well as provide water reserves for the drier periods (Gemmel et al. 1996, Nieminen et al. 2012, Heiskanen et al. 2013). These two methods differ in that disc trenching makes long lines with continuous forest upper layer disturbance but impacts shallower soil layers, while spot mounding makes randomly-patched forest soil upper layer disturbance, impacting soil layers deeper. During site preparation, soil tumps and hollows are made; compared to other microhabitat soil depressions in old boreal forests are places, where a higher number of typical old-forest species can be found (Schmalholz and Hylander 2009, Boudreault et al. 2018). This suggests that pits and trenches made during site preparation create a microhabitats with a suitable microclimate for typical forest vegetation, especially bryophyte species. It is significant to understand that the impact of microtopography formed during site preparation on vegetation may be beneficial for the preservation of typical forest vascular and bryophyte species in dry or drained hemiboreal forest types, except that it undoubtedly disturbs forest understorey cover and the upper layer of soil.

This study aimed to determine how the microtopography of selected site preparation methods affected the composition of vascular plants and epigeic bryophyte species in hemiboreal forests on different soil types. Our fundamental questions were: (1) do different site preparation methods and microtopography alter species cover and richness; (2) do site preparation methods and microtopography interact to affect the abundance of forest and grassland habitat species; (3) do patterns of vegetation development differ depending on the soil type. We hypothesise that vegetation composition within the same soil type will be affected by the type of site preparation method since the trench made during disc trenching and the pit made during spot mounding are of different depths, thus having different effects on soil moisture and microtopograpic microclimate (Celma et al. 2019). We also hypothesise that microclimate in the pit and trench will have a positive effect on some typical old forest species that could not be found on unprepared soil. Finally, we also hypothesise that the most appropriate site preparation method for vegetation succession will differ among different hemiboreal forest soil types.

Methods

Study area and design

The study areas were located in the western and central regions of Latvia (the centroid of stands in western Latvia is 57.528285, 22.568904, and in central Latvia is 56.755280, 24.201740), in the hemiboreal forest zone (halfway between the temperate and boreal zones) (Casalegno et al. 2011) (Figure 1). Total precipitation from April 2017 to June 2019 had an annual mean of 1,268 mm and 1,355 mm in the western and central region of Latvia, respectively. We studied 14 one- to two-year-old mixed forest stands in four hemiboreal forest types on three soil types: wet mineral soil, drained mineral soil and drained peat soil (Table 1). Latvian forest classification primary assesses the forest productivity, soil type and water table level having major effect on forests productivity in this area (Zālītis and Jansons 2013). Hemiboreal forest type *Myrtilloso-sphagnosa* grows on wet mineral soil, in which *Pinus sylvestris* L., *Picea abies* L. and *Betula pendula* Roth dominated the overstorey (Zālītis and Jansons 2013). Forest types *Vacciniosa mel.* and *Myrtillosa mel.*

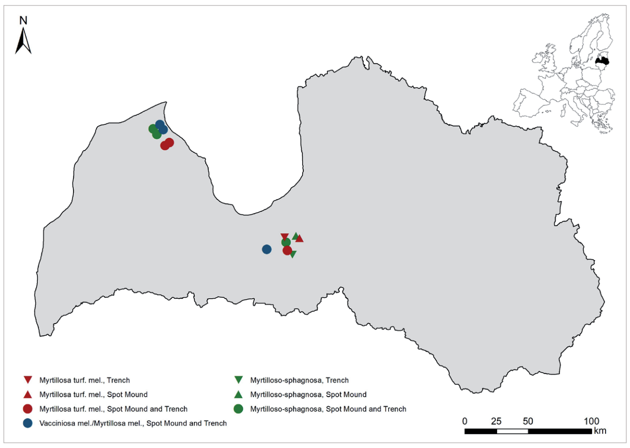

Figure 1. Locations of the forest stands studied and the site preparation method applied

grow on drained mineral soil. In *Vacciniosa mel.* forest *P. sylvestris* dominated in the overstorey, but in *Myrtillosa mel.* forest type *P. sylvestris*, *P. abies* and *B. pendula* dominated in the overstorey. We analysed *Vacciniosa mel.* and *Myrtillosa mel.* forest types together because they grow on the same type of soil. The fourth type of forest is *Myrtillosa turf. mel.* that grows on drained peat soil, where *P. sylvestris*, *B. pendula* and *P. abies* dominated in the overstorey.

We conducted site preparation by spot mounding and disc trenching in the spring before planting (one year after felling) in 2017 and 2018. The requirements for site preparation quality which is set by Latvian State Forests assumes that mound is at least 0.50 m wide, 0.60 m long and 0.15 m high, whilst the trench is 0.50–0.70 m wide and 0.15–0.30 m deep (Celma et al. 2019). In all stands four economically significant tree species seedlings were planted: Scots pine (*P. sylvestris*), Norway spruce (*P. abies*), silver birch (*B. pendula*) and black alder (*Alnus glutinosa* L.). The sites were cleaned by removing the natural

Table 1. Description of the studied young hemiboreal forest stands in Latvia

No.	Region	Soil type	Forest type	Year of planting and soil preparation	Site preparation method	Area (ha)	Sampling plots (n)
1	Western Latvia	Wet mineral soil	*Myrtilloso-sphagnosa*	2017	DM	1.50	48
2					DM	1.50	48
3		Drained mineral soil	*Vacciniosa mel.*	2017	DM	1.70	48
4					DM	1.70	48
5		Drained peat soil	*Myrtillosa turf. mel.*	2018	DM	2.13	48
6					DM	1.70	48
7	Central Latvia	Wet mineral soil	*Myrtilloso-sphagnosa*	2018	DM	1.80	48
8					M	1.10	24
9					D	0.85	24
10		Drained mineral soil	*Myrtillosa mel.*	2017	M	1.10	24
11					D	1.60	24
12		Drained peat soil	*Myrtillosa turf. mel.*	2018	DM	1.80	48
13					M	1.84	24
14					D	1.00	24

Note: Site preparation methods: D – disc trenching; M – spot mounding; DM – both methods.

vegetation mechanically at least once a year. The access of forest animals to the stands was not limited, and therefore, could not exclude herbivorous feeding on the vegetation in the stands as an external factor.

To evaluate vegetation, we established a total of 24 sampling plots in each stand where the site was prepared either with disc trenching or spot mounding and 48 sampling plots in each forest stand, where the site was made ready by both methods, adding 264 sampling plots established as a result of both site preparation methods, totally of 528 sampling plots in all study areas (Table 1, Figure 2).

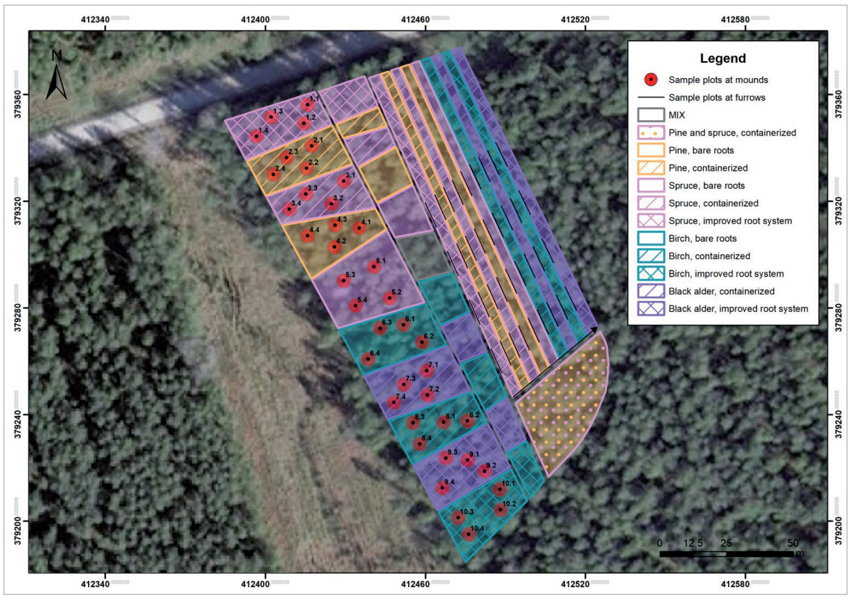

Figure 2. Study area design in *Myrtilloso-sphagnosa* forest type on wet mineral soil where site preparation by both methods – spot mounding and disc trenching – was carried out. Vegetation observation was conducted in each group sampling plots 1–3

As the distribution pattern of planted trees depended on the site preparation method employed, we used the same sized sampling plots with different sampling plot designs in each site preparation method. In the stands, where soil was prepared by spot mounding, we established 24 randomly distributed circular sampling plots. The radius of the sample plot was 2.8 m (S = 25 m^2). The area included several (~3) mounds and pits, as well as unprepared soil. In stands, where soil was prepared with disc trenching, we set up eight transects, two trenches for each planted species. We established three 2.5 m × 10 m (25 m^2) sampling plots which were allocated at equal distances from one another (10 m) along the transect. Each one included two berms, two trenches and unprepared soil. We allocated rectangle-shaped sampling plots in the stands where soil was prepared with disc trenching to reflect the same microtopography ratio in the sampling plot as within the entire forest stand. We established sampling plot size as described in the Cabinet of Ministry Regulations for Forest Inventory planter trees up to 3 m in height (Ministru kabinets 2016). We did this so that data collected in this study could be compared with data sets obtained in other studies of young stands in Latvia. The average planting rate in Latvia in stands where soil is prepared with disc trenching is 2,000–2,100 trees per hectare, and 1,600–1,800 trees per hectare in the stands where soil is worked by mounding, therefore, the shade effect may differ between different site preparation methods in stands.

Data observation

We observed understorey vegetation (vascular and bryophyte species) in all stands in June 2019 – one to two years after site preparation and planting and two to three years after logging. We identified 190 species of vascular plants and 33 species of epigeic bryophytes in all areas combined: this included tree species up to 0.5 m in height. We recorded species coverage to the nearest 5% once during the growing season (from the beginning to the end of July). Data were collected by the same observer in all study sites to avoid subjective errors. We calculated weighted average cover and species richness for vascular and bryophyte species. We divided vascular plant species into forest and grassland species based on the European Union (EU) habitat directives (typical forest habitat species-habitat codes of Natura 2000: 9020, 9060, 9180, 9080, 91E0, 91D0 and typical grassland habitat species-habitat codes of Natura 2000: 6120, 6210, 6230, 6270, 6410, 6430, 6450, 6510, as well as growth forms: annual species, perennial species, dwarf shrub species, shrub species, and tree species (Auniņa 2013). We calculated wheighted average Ellenberg's bryophyte indicator values for moisture and nitrogen (nutrients) by summing each species (i) indicator value (F_i) and weight (W_i), calculated for species based on its percentage cover ($C_i : W_i = f(C_i)$), for all species (n) in each sampling plot (Equation 1). Ellenberg's indicator values are designed to characterise plant growth conditions throughout the seasons and can be used to assess the ecological conditions of the habitat (Ellenberg 2001).

$$Wheighted\ average\ values = \frac{\sum_i \sum_n F_i W_i}{\sum \sum_n W_i} \quad (1)$$

Data analyses

We used R-Studio software package and Microsoft Excel speadsheet for data analyses and visualisation (R Core Team 2019, Posit 2020). Since the data were parametric, we performed a Shapiro-Wilk test for normal distribution prior to the analysis. The data did not significantly differ from the normal distribution. We built a linear mixed effect model to determine which of the factors had the most significant impact on vegetation parameters. The model included the forest stand as a random factor and the region, type of soil, type of site preparation, year of reforestation and microtopography as fixed factors (Equation 2).

$$Analysed\ vegetation\ parameter \sim region + soil\ type + site\ preparation\ method + microtopography + year\ of\ reforestation + \frac{1}{forest\ stand} \quad (2)$$

We performed further analysis for factors that had a significant impact on the vegetation parameter (soil type, site preparation method and microtopography). We used two-way ANOVA analyses and post hoc Tukey's HSD test to assess interaction significance between variables between different soil types and between site preparation methods and microtopography within each soil type.

Results

Vascular plants

The most common vascular plant species were *Rubus idaeus*, *Calamagrostis epigeios* L. and *Calluna vulgaris* L. Hull, which were observed in all microtopographies, although higher proportions were found on prepared soil. Three *Vaccinium* species – *V. myrtillus* L., *V. uliginosum* L. and *V. vitis-idaea* L. – were also commonly observed. *Vaccinium myrtillus* had higher cover on unprepared soil, while *V. uliginosum* was more common on prepared soil and *V. vitis-idaea* on mounds. Vascular plant cover, the proportion of forest and grassland habitat species, and growth forms did not differ by the region or the year of reforestation (Table S1). Mean vascular plant cover was 64.4% (*SE* 0.75) and it was higher on unprepared soil regardless of soil type and site preparation method (Figure 3). We observed differences related to site preparation method only on drained mineral soil, where the cover was significantly higher on the soil prepared with disc trenching rather than spot mounding (ANOVA test results $P = 0.006$; $df = 1$; $F = 7.838$). Higher species richness was observed on drained peat soil (Tukey's HSD test results drained mineral soil $P > 0.001$; wet mineral soil $P > 0.001$) (Figure 4).

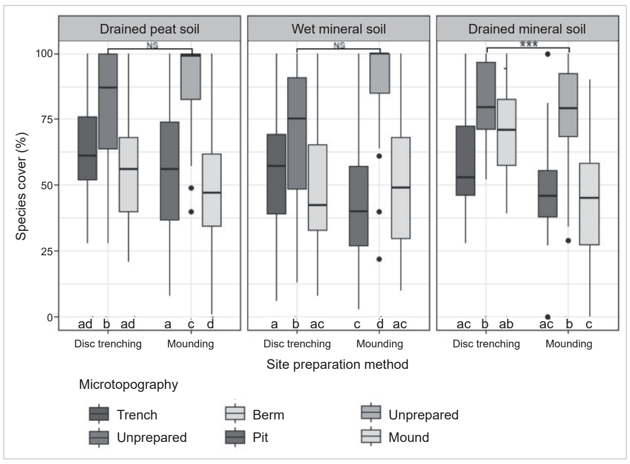

Figure 3. Vascular plant species cover on different soil types depending on site preparation method and microtopography. Significance level *** (< 0.001), ** (0.001–0.01), * (0.01–0.05), NS (Not Significant) shows the results of the ANOVA test between site preparation method and letters (a) Tukey's HSD test significant differences between microtopographies ($P > 0.05$)

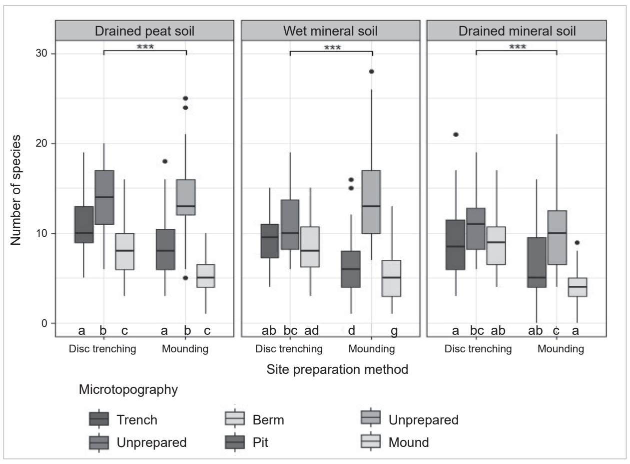

Figure 4. Vascular plant species richness on different soil types depending on site preparation method and microtopography. Significance level *** (< 0.001), ** (0.001–0.01), * (0.01–0.05), NS (Not Significant) shows the results of the ANOVA test between site preparation method and letters (a) Tukey's HSD test significant differences between microtopographies ($P > 0.05$)

In most groups, typical forest species contributed most of the vegetation, regardless of the soil type, site preparation or microtopography (Figure 5). The average proportion of typical forest habitat species did not differ between unprepared and prepared soil (ANOVA test results $P = 0.131$; $df = 4$; $F = 1.778$, Tukey's HSD test results unprepared: berm; mound; pit; trench $P = 0.999$; 0.965; 0.543; 0.974), but it was lower when the site was prepared by spot mounding rather than disc trenching on wet mineral soil and drained peat soil (ANOVA test results: wet mineral soil $P < 0.001$; $df = 1$; $F = 19.78$; drained peat soil $P < 0.001$; $df = 1$; $F = 15.03$) (Table S2). The typical grassland habitat species showed an opposite tendency, therefore significantly larger proportion of grassland species were in areas where the soil was prepared with spot mounding rather than disc trenching (ANOVA test results: wet mineral soil $P < 0.001$; $df = 1$; $F = 11.89$, drained peat soil $P < 0.001$; $df = 1$; $F = 16.41$) (Table S2).

The proportion of different plant growth forms differed depending on soil type, site preparation method and microtopography (Figure 6). Annual plants did not occupy a substantial proportion on any of the soil types, however on drained peat soil, the cover was higher where the site had been prepared by spot mounding (ANOVA test results: $P = 0.004$, $df = 1$, $F = 8.583$). Perennial vascular plants had a higher proportion in the sites, where the soil had been prepared by spot mounding rather than disc trenching on wet and drained mineral soils.

On drained peat soil perennial vascular plants were more commonly found in pits than on mounds. Dwarf

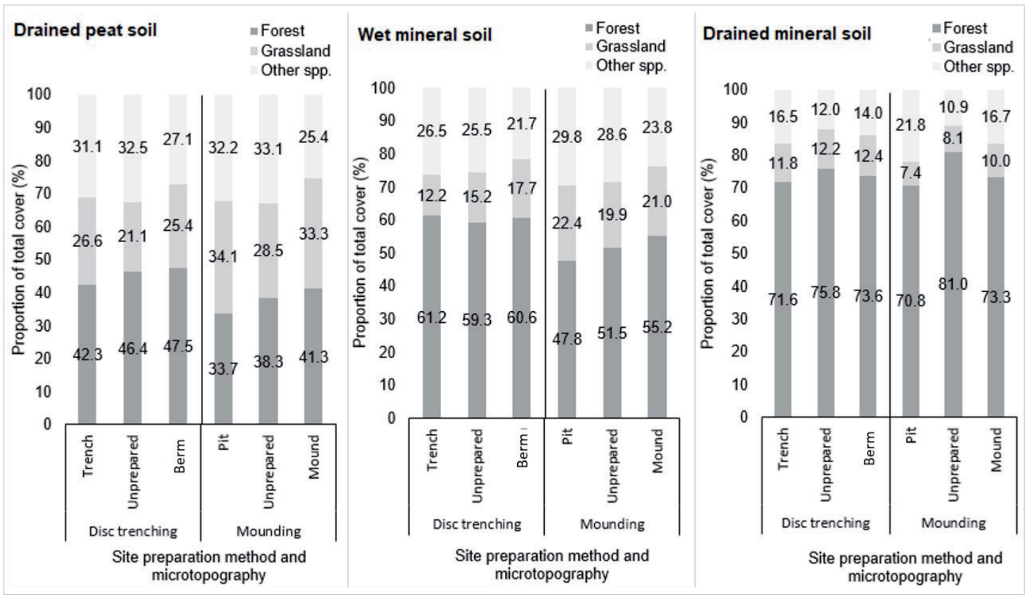

Figure 5. Relative cover (Proportion of total cover) of typical EU habitat directive forest and grassland habitats species in Latvia from total observed vascular plant cover on different soil types depending on site preparation method and microtopography

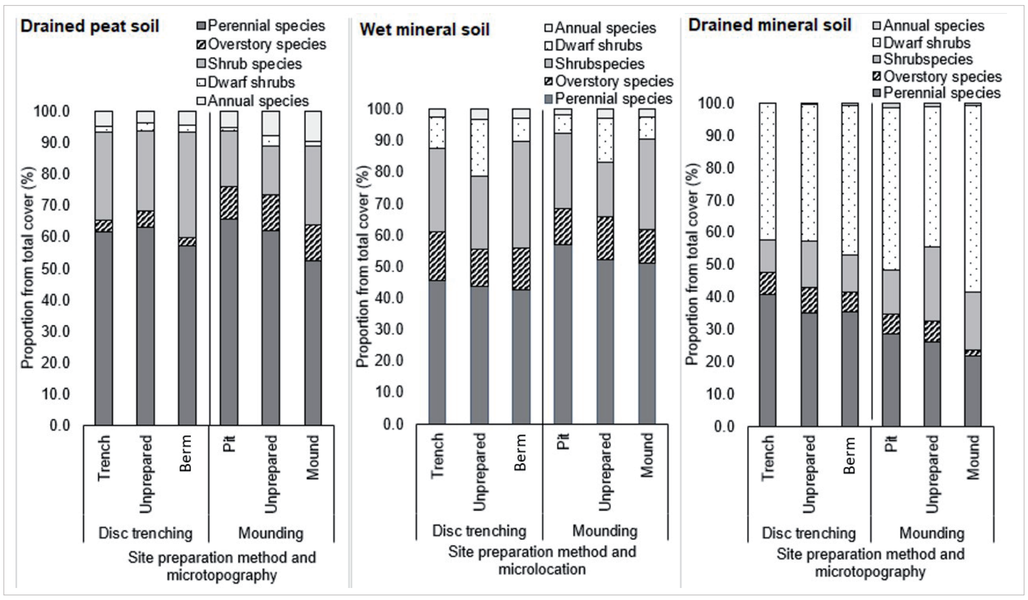

Figure 6. Relative cover (Proportion of total cover) of plant growth forms from total observed vascular plant cover on different soil types depending on site preparation method and microtopography

shrubs cover mostly differed by soil type; on drained mineral soil they were the most dominant plant growth form, but on drained peat soil and on wet mineral soils their mean cover was below 5%. In the stands with disc trenched wet mineral soil dwarf shrub mean cover was higher on disturbed soil layer (berms) than on unprepared soil (Tukey's HSD test results: $P = 0.002$, $diff = 11.159$). The cover of tree and shrub species was higher in the stands prepared with disc trenching (ANOVA test results: trees drained peat soil $P < 0.001$, $df = 1$, $F = 35.260$, drained mineral soil $P = 0.003$, $df = 1$, $F = 4.645$; shrubs drained peat soil $P < 0.001$, $df = 1$, $F = 27.965$, wet mineral soil $P = 0.018$, $df = 1$, $F = 5.681$, drained mineral soil $P = 0.035$, $df = 1$, $F = 4.486$).

Bryophytes

Bryophyte cover and weighted Ellenberg's indicator values did not differ by the region or year of reforestation and the mean bryophyte cover was only 18.4% (*SE* 0.90) (Table S3). The most common bryophyte species differed depending on the soil type. On drained peat soil the most common were *Sphagnum girgensohnii* Russow, *Eurynchium angustirete* Koponen and *Pleurozium schreberi* (Brid.) Mitt. while *S. girgensohnii* and *E. angustirete* were common on all microtopographies, *P. schreberi* was found mostly on unprepared soil and soil tumps (berms and mounds). Such species as *Sphagnum cuspidatum* Ehrh. ex Hoffm., *Sphagnum squarrosum* Crome and *Plagiomnium undulatum* Koponen were more present in hollows (trenches and pits). On wet mineral soil the most common bryophyte species on unprepared soil were *P. schreberi* and *Hylocomium splendens* (Hedw.) Schimp., and the most common species on prepared soil were *Polytrichum commune* Hedw., *S. cuspidatum*, *Polytrichum juniperinum* Hedw. and *S. girgensohnii*. On drained mineral soil the most common bryophyte species were *S. girgensohnii* and *Atrichum undulatum* (Hedw.) P. Beauv.; *Dicranum polysetum* Swartz, *H. splendens* and *P. schreberi* were most common on the unprepared soil and soil tumps, while *S. squarosum*, *S. cuspidatum* and *T. pellucida* were most common in the hollows. Species richness was higher on unprepared soil, followed by those in pits and trenches, but lower species richness occurred on mounds and berms (Figure 7). The highest bryophyte species richness was on unprepared drained mineral soil (Figure 7). This parameter also did not differ among site preparation methods. Similar to species richness, bryophyte cover was higher on unprepared soil (Tukey's HSD test results: unprepared : trench $P = 0.001$; unprepared : berm $P = 0.001$, unprepared : mound $P = 0.001$, unprepared : pit $P = 0.004$) (Figure 8).

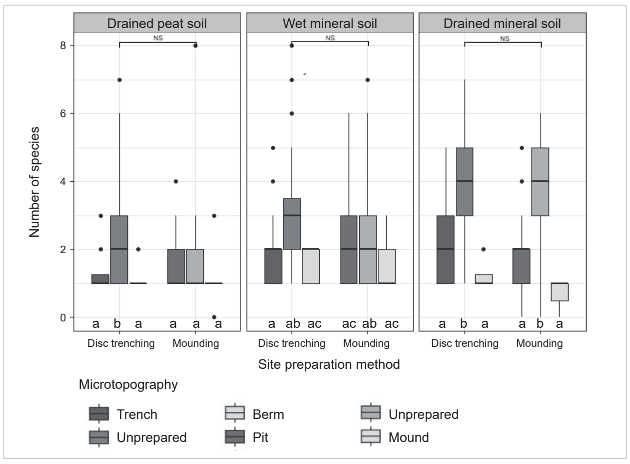

Figure 7. Bryophyte species richness on different soil types depending on site preparation method and microtopography. Significance level *** (< 0.001), ** (0.001–0.01), * (0.01–0.05), NS (Not Significant) shows the results of the ANOVA test between site preparation method and letters (a) Tukey's HSD test significant differences between microtopographies ($P > 0.05$)

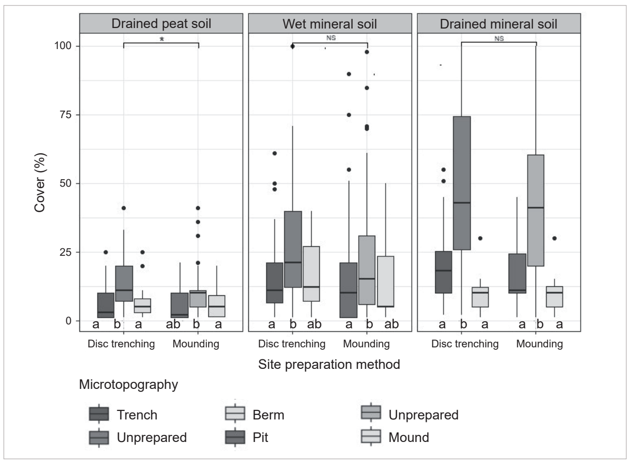

Figure 8. Bryophyte species cover on different soil types depending on site preparation method and microtopography. Significance level *** (<0.001), ** (0.001–0.01), * (0.01–0.05), NS (Not Significant) shows the results of the ANOVA test between site preparation method and letters (a) Tukey's HSD test significant differences between microtopographies ($P > 0.05$)

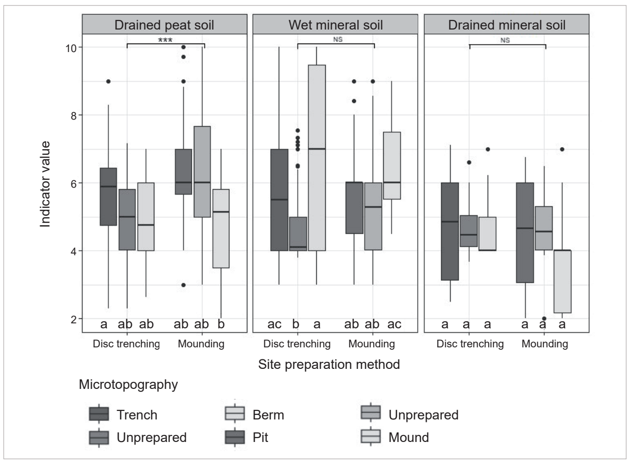

Figure 9. Ellenberg's indicator moisture value for bryophytes on different soil types depending on site preparation method and microtopography. Significance level *** (<0.001), ** (0.001– 0.01), * (0.01–0.05), NS (Not Significant) shows the results of the ANOVA test between site preparation method and letters (a) Tukey's HSD test significant differences between microtopographies ($P > 0.05$)

The bryophyte indicator values are different to that used in vascular plant (Urmi 2010, Simmel et al. 2020). Similar to vascular plant parameters, Ellenberg's bryophyte indicator values, species richness and cover did not differ by region or year of felling and tree planting (Table S3). Ellenberg's bryophyte value for moisture was most sensitive to microtopography and the soil type. Moisture indicator value was lower on drained mineral soil than on the other two soil types and differed between site preparation method, being higher in the sites, where spot mounding had been performed (ANOVA test results: $P = 0.001$, $df = 2$, $F = 21.257$; Tukey's HSD test results on drained peat soil $P < 0.001$, wet mineral soil $P < 0.001$; site preparation method ANOVA test results: $P = 0.001$, $df = 1$, $F = 23.83$) (Figure 9). Moisture indicator value was higher on lower microtopographies (in disc trenched stands; Tukey's HSD test results: unprepared soil : trench $P = 0.027$) but lower on higher microtopographies: on mounds and berms, as well as in the forests on drained peat and mineral soils. On wet mineral soil, moisture value was higher in berms than on unprepared soil (Tukey's HSD test results: $P = 0.001$).

Nitrogen indicator value did not differ between microtopographies, but rather between the site preparation methods and soil types (ANOVA test results for soil types: $P = 0.001$, $df = 14.759$, $F = 2$). Greater differences in Ellenberg's bryophyte value for nitrogen were observed on wet mineral soil in which Ellenberg's nitrogen indicator value in the disc trenched sites was lower in trenches than on unprepared soil (ANOVA test results: $P = 0.002$, $df = 4$, $F = 4.381$) (Figure 10). Although no significant differences were observed on other soil types, mean Ellenberg's indicator nitrogen values on drained mineral soil were higher in mounds and berms than on unprepared soil, and in pits and trenches. On drained peat soil, mean Ellenberg's indicator nitrogen value was higher on prepared soil.

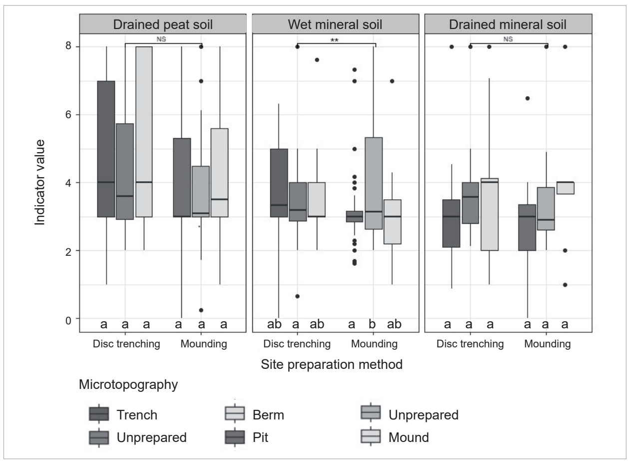

Figure 10. Ellenberg's indicator nitrogen value for bryophytes on different soil types depending on site preparation method and microtopography. Significance level *** (<0.001), ** (0.001–0.01), * (0.01–0.05), NS (Not Significant) shows the results of the ANOVA test between site preparation method and letters (a) Tukey's HSD test significant differences between microtopographies ($P > 0.05$)

Discussion

Although the vegetation compositions and their developments following the establishment of the young stands did not differ by the region, differences were apparent among the soil types of hemiboreal forest, the method used for site preparation, and the microtopography formed during site preparation. The highest species richness was observed on drained peat soil, the same as given in literature (according to Bušs (1981): drained peat soil: 140 species; wet mineral soil: 100 species; drained mineral soil:

mean from both types = 80 species) (Bušs 1981). Increased vascular plant richness on unprepared soil suggested that vegetation succession was still ongoing and that vascular vegetation had not yet emerged in all sites with soil scarification (Gustienė et al. 2019). Vascular plant cover was greater in the stands, where soil was prepared by disc trenching rather than spot mounding, suggesting that disc trenching might have contributed to less affected vegetation during site preparation, therefore enabling faster natural revegetation after it (Niemela 1999). Either way, up to three years after tree planting in the young stands, most species were typical forest habitat species, regardless of the hemiboreal forest soil type, site preparation method or microtopography, therefore the proportion of typical forest species had not changed significantly on revegetated soil.

In the sites where the soil was prepared using disc trenching, a higher proportion of typical forest habitat species and a lower one of grassland habitat species were present, suggesting that the disc trenching method had a lesser effect on altering understorey vegetation composition (Bergstedt et al. 2008). Incoming grassland habitat and tree species may contribute negative effects not only to seedling growth in the young stands but also to typical forest vegetation by making shading and competition (Tonteri et al. 2016). Cleaning by mechanically removing vegetation once in a growing season reduces the competition driven by naturally incoming tree and grass species and may be the driving factor that could help to preserve typical forest species (Man et al. 2008). Many grasslands and ruderal species that ingrow in the stand after logging are higher than typical forest species. Performing cleaning in height that removes ruderal species, but it did not notably mechanically affect lower growing forest vegetation (~ 20 cm), which may be the way to profit forest vegetation. Overall, it can be concluded that spot mounding is more likely to alter typical forest understorey vegetation compared to disc trenching, but simultaneously increases vascular species diversity of the area (Gustienė et al. 2019).

Those species that typically grow in forests on wet organic soil were more present in trenches and pits, which indicates that site preparation in forest stands provides a suitable micro-habitat where typical species from wetter habitats are better preserved. But elevated soil, as on berms and mounds, provided a place where dry forest habitat species and grassland species could occur (Table S2). At this stage of forest development, grassland species may provide additional ecological interactions with different organism groups, including pollinators; similar increased pollinator diversity is notable after cutting the woody vegetation and keeping flowering plant species under power lines (Steinert et al. 2020). As typical forest and grassland habitat species differ in their phenological dynamics, the flowering period could be extended in the area containing plant species from both of these habitats (Kütt et al. 2018). Microtopographies made during site preparation also increase dwarf shrub species diversity, a notable ectomycorrhizal plant group in the forest, because species such as *V. uliginosum* and *V. vitis-idaea* were more common on prepared soil (Storch 1993, Hobbie et al. 2009).

Previous studies have stated that both felling and site preparation may negatively influence bryophyte species richness (Palviainen et al. 2005, Vanha-Majamaa et al. 2017). In this study species richness was higher on the unprepared sites, but total area species richness was higher in the prepared sites; this may be because species that cannot grow in unprepared soil can grow in patches, where the soil is prepared (Anderson et al. 2007). Previous studies have shown that natural microtopographies in the forest ecosystem, such as stones and dead wood, are important in providing the necessary conditions for the conservation of bryophyte indicator species (Schmalholz and Hylander 2011). In most cases, temperature increases, and moisture decreases in the upper part of soil after logging (Tonteri et al. 2016). However, pits and trenches can diversify the microclimate elements in the first years of succession and provide a suitable environment for species that are more dependent on microclimate and cannot survive in harsh conditions that are usually observed after felling. On drained peat and mineral soil, the moisture indicator values in pits and trenches were higher than those on unprepared soil, which confirms the results of a previous study that found temperature is higher and moisture is lower on soil tumps, berms and mounds than on unprepared soil (Kubin and Kemppainen 1994). But on wet mineral soil the mean moisture value is higher in all prepared soil microtopographies such as pits, mounds, berms and trenches. This may have been due to differences in soil moisture and dominant bryophyte and vascular plant compositions on different soil types. On wet mineral soil, one of the dominant bryophytes was *Sphagnum* genus species, which were present in all microtopographies, also on the mounds and berms. The distribution may be positively affected by hydraulic connections of the microtopographies, due to the presence of *Sphagnum* on undisturbed forest soil and high groundwater level (Macrae et al. 2013).

Conclusions

The composition of vegetation does not differ between one- and two-year-old young stands two and three years after logging, and to observe successional changes in the young stands, data should also be observed over a longer time interval. Forest soil type and hydrology had more impact on vegetation than the site preparation method and microtopography in most cases. Spot mounding alters young stand vegetation more than disc trenching, but overall site preparation provides habitat for typical forest species preservation by diversifying the abiotic environment of the stand. Typical forest species preservation in young stands is problematical because, during the first years after logging, understorey vegetation is primarily determined by species with light, temperature, and drought tolerance, and expansions of ruderal and stress-tolerant species may occur. However, a notable cover of typical forest species underneath the canopy of ruderal species ensures that as the stand ages, the forest understorey vegetation may restore faster than if the cover of typical forest species had decreased drastically. Therefore, we presume that vegetation cleaning at least once in a season at a height that removes non-typical forest species but did not affect typical forest species may lead to faster forest vegetation development after site preparation. The soil depressions generated by disc trenching and spot mounding – pits and trenches – are crucial microtopography elements that collect and maintain soil moisture beneficial for a wider range of typical forest vascular species as well as bryophyte species which are important for the succession of the forest ecosystem.

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References

Auniņa, A. (Ed.) 2013. Eiropas Savienības aizsargājamie biotopi Latvijā. Noteikšanas rokasgrāmata [Biotopes protected by the European Union in Latvia. Determination Guide]. 2nd ed., updated. Riga: LDF, VARAM, 320 pp. (in Latvian).

Anderson, H.M., Gale, M.R., Jurgensen, M.F. and Trettin, C.C. 2007. Vascular and non-vascular plant community response to silvicultural practices and resultant microtopography creation in a forested wetland. *Wetlands* 27: 68–79; https://doi.org/10.1672/0277-5212(2007)27[68:VANPCR]2.0.CO;2.

Bergstedt, J., Hagner, M. and Milberg, P. 2008. Effects on vegetation composition of a modified forest harvesting and propagation method compared with clear-cutting, scarification and planting. *Applied Vegetation Science* 11(2): 159–168; https://doi.org/10.3170/2007-7-18343.

Bilodeau-Gauthier, S., Paré, D., Messier, C. and Bélanger, N. 2011. Juvenile growth of hybrid poplars on acidic boreal soil determined by environmental effects of soil preparation, vegetation control, and fertilization. *Forest Ecology and Management* 261(3): 620–629; https://doi.org/10.1016/j.foreco.2010.11.016.

Bokhorst, S., Wardle, D.A., Nilsson, M.C. and Gundale, M.J. 2014. Impact of understory mosses and dwarf shrubs on soil micro-arthropods in a boreal forest chronosequence. *Plant and Soil* 379(1/2): 121–133; https://doi.org/10.1007/s11104-014-2055-3.

Boudreault, C., Paquette, M., Fenton, N.J., Pothier, D. and Bergeron, Y. 2018. Changes in bryophytes assemblages along a chronosequence in eastern boreal forest of Québec. *Canadian Journal of Forest Research* 48(7): 1–14; https://doi.org/10.1139/cjfr-2017-0352.

Bridge, S.R.J. and Johanson, E.A. 2000. Geomorphic principles of terrain organization and vegetation gradients. *Journal of Vegetation Science* 111(1): 57–70; https://doi.org/10.2307/3236776.

Bušs, K. 1981. Meža ekoloģija un tipoloģiju [Ecology and Typology of the Forest]. Rīga: Zinātne, 64 pp. (in Latvian).

Casalegno, S., Amatulli, G., Bastrup-Birk, A., Durrant, T.H. and Pekkarinen, A. 2011. Modelling and mapping the suitability of European forest formations at 1-km resolution. *European Journal of Forest Research* 130(6): 971–981; https://doi.org/10.1007/s10342-011-0480-x.

Celma, S., Blate, K., Lazdiņa, D. and Dūmiņš, K. 2019. Effect of soil preparation method on root development of *P. sylvestris* and *P. abies* saplings in commercial forest stands. *New Forests* 501(1): 283–290; https://doi.org/10.1007/s11056-018-9654-4.

Chipman, S.J. and Johnson, E.A. 2002. Understory Vascular Plant Species Diversity in the Mixedwood Boreal Forest of Western Canada SFM Network Project: Understanding how Fire Behavior Characteristics Shape Tree Population Dynamics, Diversity and Forest Patterns. *Ecological Applications* 12(2): 588–601; https://doi.org/10.1890/1051-0761(2002)012[0588:UVPSDI]2.0.CO;2.

Crispo, M., Jean, M., Fenton, N.J., Leduc, A. and Bergeron, Y. 2021. Factors explaining the composition and diversity of vascular plant understories along a transcontinental gradient in the Canadian boreal forest. *Journal of Vegetation Science* 32(4): e13058; https://doi.org/10.1111/jvs.13058.

Decocq, G., Aubert, M., Dupont, F., Alard, D., Saguez, R., Wattes-Franger, A., de Foucault, B., Delelis-Dusollier, A. and Bardt, J. (2004). Plant diversity in a managed temperate deciduous forest: Understorey response to two silvicultural systems. *Journal of Applied Ecology* 41(6): 1065–1079; https://doi.org/10.1111/j.0021-8901.2004.00960.x.

Deluca, T.H., Zackrisson, O., Nilsson, M.C. and Sellstedt, A. 2002. Quantifying nitrogen-fixation in feather moss carpets of boreal forests. *Nature* 419(6910): 917–920; https://doi.org/10.1038/nature01051.

Ellenberg, H. 2001. Zeigerwerte der Gefäßpflanzen (ohne Rubus). In: Ellenberg, H., Weber, H.E., Düll, R., Wirth, V. and Werner, W. (Eds.) Zeigerwerte von Pflanzen in Mitteleuropa. Ed. 3. Göttingen: Erich Goltze, Scripta Geobotanica 18, p. 9–166.

Engelmark, O. and Hytteborn, H. 1999. Coniferous forests. *Acta Phytogeographica Suecica* 84: 55–74.

Felton, A.M., Felton, A., Cromsigt, J.P.G.M., Edenius, L., Malmsten, J. and Warm, H.K. 2017. Interactions between ungulates, forests, and supplementary feeding: The role of nutritional balancing in determining outcomes. *Mammal Research* 62: 1–7; https://doi.org/10.1007/s13364-016-0301-1.

Gemmel, P., Nilsson, U. and Welander, T. 1996. Development of oak and beech seedlings planted under varying shelterwood densities and with different site preparation methods in southern Sweden. *New Forests* 12: 141–161; https://doi.org/10.1007/BF00036626.

Gustafsson, L., Johansson, V., Leverkus, A.B., Strengbom, J., Wikberg, S. and Granath, G. 2021. Disturbance interval modulates the starting point for vegetation succession. *Ecology* 102(9): e03439; https://doi.org/10.1002/ecy.3439.

Gustienė, D., Varnagirytė-Kabašinskienė, I. and Stakėnas, V. 2019. Ground vegetation, forest floor and mineral topsoil in a clear-cutting and reforested Scots pine stands of different ages. *Plants* 11(19): 2651; https://doi.org/10.3390/plants11192651.

Hannerz, M. and Hånell, B. 1997. Effects on the flora in Norway spruce forests following clearcutting and shelterwood cutting. *Forest Ecology and Management* 90(1): 29–49; https://doi.org/10.1016/S0378-1127(96)03858-3.

Heiskanen, J., Saksa, T. and Luoranen, J. 2013. Soil preparation method affects outplanting success of Norway spruce container seedlings on till soils susceptible to frost heave. *Silva Fennica* 47(1): 1–17; https://doi.org/10.14214/sf.893.

Hobbie, J.E., Hobbie, E.A., Drossman, H., Conte, M., Weber, J.C., Shamhart, J. and Weinrobe, M. 2009. Mycorrhizal fungi supply nitrogen to host plants in Arctic tundra and boreal forests: 15N is the key signal. *Canadian Journal of Microbiology* 55(1); https://doi.org/10.1139/W08-127.

Jalonen, J. and Vanha-Majamaa, I. 2001. Immediate effects of four different felling methods on mature boreal spruce forest understorey vegetation in southern Finland. *Forest Ecology and Management* 146(1): 25–34; https://doi.org/10.1016/S0378-1127(00)00446-1.

Jasinski, K. and Angelstam, P. 2002. Long-term differences in the dynamics within a natural forest landscape – Consequences for management. *Forest Ecology and Management* 161(1/3): 1–11; https://doi.org/10.1016/S0378-1127(01)00486-8.

Johansson, M.B. 1994. The influence of soil scarification on the turn-over rate of slash needles and nutrient release. *Scandinavian Journal of Forest Research* 9(1/4): 170–179; https://doi.org/10.1080/02827589409382828.

Kubin, E. and Kemppainen, L. 1994. Effect of soil preparation of boreal spruce forest on air and soil temperature conditions in forest regeneration areas. *Silva Fennica* 244: 7506; https://doi.org/10.14214/aff.7506.

Kütt, L., Paal, T., Lõhmus, K., Rammi, I.J., Zobel, K. and Liira, J. 2018. Multi-user quality of floral services along a gradient of margin habitats between semi-natural grasslands and forests. *Applied Vegetation Science* 21(3): 363–372; https://doi.org/10.1111/avsc.12376.

Li, J., Shi, J., Luo, Y. and Heliövaara, K. 2012. Plant and insect diversity along an experimental gradient of larch-birch mixtures in Chinese boreal forests. *Turkish Journal of Agriculture and Forestry* 36(2): 247–255; https://doi.org/10.3906/tar-1011-1470.

Luoranen, J. and Rikala, R. 2013. Field performance of Scots pine (*Pinus sylvestris* L.) seedlings planted in disc trenched or mounded sites over an extended planting season. *New Forests* 44(2): 147–162; https://doi.org/10.1007/s11056-012-9307-y.

Macrae, M.L., Devito, K.J., Strack, M. and Waddington, J.M. 2013. Effect of water table drawdown on peatland nutrient dynamics: implications for climate change. *Biogeochemistry* 112: 661–676; https://doi.org/10.1007/s10533-012-9730-3.

Man, C.D., Comeau, P.G. and Pitt, D.G. 2008. Competitive effects of woody and herbaceous vegetation in a young boreal mixedwood stand. *Canadian Journal of Forest Research* 38(7): 1817–1828; https://doi.org/10.1139/X08-032.

Mayer, P., Abs, C. and Fischer, A. 2004. Colonisation by vascular plants after soil disturbance in the Bavarian Forest – Key factors and relevance for forest dynamics. *Forest Ecology and Management* 188(1/3): 279–289; https://doi.org/10.1016/j.foreco.2003.07.027.

McDermott, C.L., Cashore, B. and Kanowski, P.J. 2010. Global environmental policies. An international comparison. London (UK): Earthscan, 392 pp.; https://doi.org/10.4324/9781849774925.

Ministru kabinets. 2016. Meža inventarizācijas un Meža valsts reģistra informācijas aprites noteikumi [Regulations regarding the circulation of Forest Inventory and information of the State Forest Register]. Ministru kabineta noteikumi Nr. 384. *Latvijas Vēstnesis* 122, 28.06.2016 (in Latvian).

Mills, S.E. and Macdonald, S.E. 2005. Factors Influencing Bryophyte Assemblage at Different Scales in the Western Canadian Boreal Forest. *The Bryologist* 108(1): 86–100; https://doi.org/10.1639/0007-2745(2005)108[86:FIBAAD]2.0.CO;2.

Niemela, J. 1999. Management in relation to disturbance in the boreal forest. *Forest Ecology and Management* 115(2/3): 127–134; https://doi.org/10.1016/S0378-1127(98)00393-4.

Nieminen, J.K., Räisänen, M. and Haimi, J. 2012. Spot mounding and granulated wood ash increase inorganic N availability and alter key components of the soil food web in clearcut Norway spruce forests. *Forest Ecology and Management* 263: 24–30; https://doi.org/10.1016/j.foreco.2011.09.023.

Nieppola, J. 1992. Long-Term Vegetation Changes in Stands of Pinus sylvestris in Southern Finland. *Journal of Vegetation Science* 3(4): 475–484; https://doi.org/10.2307/3235804.

Nilsson, M.C. and Wardle, D.A. 2005. Understory vegetation as a forest ecosystem driver: Evidence from the northern Swedish boreal forest. *Frontiers in Ecology and the Environment* 3(8): 421–428; https://doi.org/10.1890/1540-9295(2005)003[0421:UVAAFE]2.0.CO;2.

Örlander, G., Gemmel, P. and Hunt, J. 1990. Site preparation: A Swedish overview. Victoria B.C., Canada: Forestry Canada and British Columbia Ministry of Forests, 67 pp. Available online at: https://www.for.gov.bc.ca/hfd/pubs/Docs/Frr/FRR105.pdf.

Palviainen, M., Finér, L., Mannerkoski, H. and Piirainen, S. 2005. Responses of ground vegetation species to clear-cutting in a boreal forest: Aboveground biomass and nutrient contents during the first 7 years. *Ecological Research* 20(6): 652–660; https://doi.org/10.1007/s11284-005-0078-1.

Peltzer, D.A., Bast, M.L., Wilson, S.D. and Gerry, A.K. 2000. Plant diversity and tree responses following contrasting disturbances in boreal forest. *Forest Ecology and Management* 127(1/3): 191–203; https://doi.org/10.1016/S0378-1127(99)00130-9.

Petersson, L., Holmström, E., Lindbladh, M. and Felton, A. 2019. Tree species impact on understory vegetation: Vascular plant communities of Scots pine and Norway spruce managed stands in northern Europe. *Forest Ecology and Management* 448(3): 330–345; https://doi.org/10.1016/j.foreco.2019.06.011.

Posit. 2020. RStudio IDE [Computer software]. Posit, PBS, 250 Northern Ave., Boston, MA 02210, USA. URL: https://posit.co/products/open-source/rstudio/.

R Core Team. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: https://www.R-project.org/.

Schmalholz, M. and Hylander, K. 2009. Succession of bryophyte assemblages following clear-cut logging in boreal spruce-dominated forests in south-central Sweden – Does retrogressive succession occur? *Canadian Journal of Forest Research* 39(10): 1871–1881; https://doi.org/10.1139/X09-113.

Schmalholz, M. and Hylander, K. 2011. Microtopography creates small-scale refugia for boreal forest floor bryophytes during clear-cut logging. *Ecography* 34(4): 637–648; https://doi.org/10.1111/j.1600-0587.2010.06652.x.

Siwach, A., Kaushal, S. and Baishya, R. 2021. Effect of Mosses on physical and chemical properties of soil in temperate forests of Garhwal Himalayas. *Journal of Tropical Ecology* 37(3): 126–135; https://doi.org/10.1017/S0266467421000249.

Sorenson, P.T., Quideau, S., Mackenzie, M.D. and Landhäusser, S.M. 2011. Forest floor development and biochemical properties in reconstructed boreal forest soils. *Applied Soil Ecology* 49: 139–147; https://doi.org/10.1016/j.apsoil.2011.06.006.

Steinert, M., Eldegard, K., Sydenham, M. and Moe, S. 2020. Bumble bee communities in power-line clearings: Effects of experimental management practices. *Insect Conservation and Diversity* 14(3): 377–392; https://doi.org/10.1111/icad.12463.

Storch, I. 1993. Habitat selection by capercaillie in summer and autumn: Is bilberry important? *Oecologia* 95(2): 257–265; https://doi.org/10.1007/BF00323498.

Sutton, R. 1993. Mounding site preparation: A review of European and North American experience. *New Forests* 7(2): 151–192; https://doi.org/10.1007/BF00034198.

Tonteri, T., Salemaa, M., Rautio, P., Hallikalnen, V., Korpela, L. and Merilä, P. 2016. Forest management regulates temporal change in the cover of boreal plant species. *Forest Ecology and Management* 381: 151–124; https://doi.org/10.1016/j.foreco.2016.09.015.

Tullus, T., Lutter, R., Randlare, T., Saag, A., Tullus, A., Oja, E., Degtjarenko, P., Pärtel, M. and Tullus, H. 2022.

The effect of stand age on biodiversity in a 130-year chronosequence of *Populus tremula* stands. *Forest Ecology and Management* 504(2): 119833; https://doi.org/10.1016/j.foreco.2021.119833.

Uotila, A. and Kouki, J. 2005. Understorey vegetation in spruce-dominated forests in eastern Finland and Russian Karelia: Successional patterns after anthropogenic and natural disturbances. *Forest Ecology and Management* 215(1/3): 113–137; https://doi.org/10.1016/j.foreco.2005.05.008.

Uotila, K., Rantala, J., Saksa, T. and Harstela, P. 2010. Effect of Soil Preparation Method on Economic Result of Norway Spruce Regeneration Chain. *Silva Fennica* 44(3): 511–524; https://doi.org/10.14214/sf.146. **Vanha-Majamaa, I., Shorohova, E., Kushnevskaya, H. and Jalonen, J.** 2017. Resilience of understory vegetation after variable retention felling in boreal Norway spruce forests – A ten-year perspective. *Forest Ecology and Management* 393: 12–28; https://doi.org/10.1016/j.foreco.2017.02.040.

Zālītis, P. and Jansons, J. 2013. Latvijas meža tipoloģija un tās nākotne [Latvian forest typology and its future]. Daugavpils: DU AA "Saule", 168 pp. (in Latvian).

Zhang, J., Qian, H., Girardello, M., Pellissier, V., Nielsen, S.E. and Svenning, J.C. 2018. Trophic interactions among vertebrate guilds and plants shape global patterns in species diversity. *Proceedings of the Royal Society B* 285(1883): 20180949; https://doi.org/10.1098/rspb.2018.0949.

Zobel, M., Kalamees, R., Püssa, K., Roosaluste, E. and Moora, M. 2007. Soil seed bank and vegetation in mixed coniferous forest stands with different disturbance regimes. *Forest Ecology and Management* 250(1): 71–76; https://doi.org/10.1016/j.foreco.2007.03.011.

Supplementary

Table S1. Linear mixed effects model results for vascular plant parameters

Response variable	Fixed effects	Estimated coefficient	*SE*	*df*	*t* value	*p* value
Cover	(intercept)	885.02	2,3197.99	8.92	0.04	**0.9704**
	Site preparation Mounding	27.69	2.06	1,177.97	13.44	**< 0.001 *****
	Microtopography Mound	–40.93	1.78	1,168.92	–22.75	**< 0.001 *****
	Microtopography Pit	–38.54	1.78	1,168.92	–21.42	**< 0.001 *****
	Microtopography Trench	3.86	1.96	1,168.92	1.97	**0.049 ***
	Microtopography Unprepared	19.75	1.96	1,168.92	10.07	**< 0.001 *****
	Region Central Latvia	–7.46	8.66	8.9	–0.86	0.412
	Soil type Drained Mineral Soil	–3.44	8.82	8.78	–0.39	0.706
	Soil type Wet Mineral Soil	–0.82	11.39	8.95	–0.07	0.945
	Year	–0.41	11.50	8.92	–0.04	0.973
	Random effect	Variance	Std. Dev.			
	Forest stand	138	11.75			
	Residual	348	18.65			
Perennial species	Fixed effects	Estimated coefficient	*SE*	*df*	*t* value	*p* value
	(intercept)	15,268.02	47,880.15	8.12	0.32	0.758
	Site preparation Mounding	–2.70	2.39	1174.00	–1.13	0.259
	Microtopography Mound	–6.51	2.08	1168.97	–3.13	**0.002 ****
	Microtopography Pit	3.76	2.08	1168.97	1.81	0.071
	Microtopography Trench	4.06	2.27	1168.97	1.79	0.073
	Microtopography Unprepared	3.63	2.27	1168.97	1.60	0.110
	Region Central Latvia	16.07	17.94	8.58	0.90	0.395
	Soil type Drained Mineral Soil	–13.22	18.32	8.69	–0.72	0.489
	Soil type Wet Mineral Soil	–19.72	23.56	8.55	–0.84	0.426
	Year	–7.54	23.73	8.12	–0.32	0.759
	Random effect	Variance	Std. Dev.			
	Forest stand	609.4	24.69			
	Residual	466.0	21.49			
Shrub species	Fixed effects	Estimated coefficient	*SE*	*df*	*t* value	*p* value
	(intercept)	–23,860	24,290	9.66	–0.98	0.350
	Site preparation Mounding	–5.43	1.92	1178	–2.83	**0.005 ****
	Microtopography Mound	8.13	1.68	1169	4.85	**< 0.001 *****
	Microtopography Pit	1.66	1.68	1169	0.99	0.323
	Microtopography Trench	–5.32	1.83	1169	–2.911	**0.004 ****
	Microtopography Unprepared	–7.07	1.83	1.17	–3.87	**< 0.001 *****
	Region Central Latvia	–2.97	9.08	9.25	–0.33	0.751
	Soil type Drained Mineral Soil	3.89	9.25	9.04	0.42	0.684
	Soil type Wet Mineral Soil	–0.42	11.94	9.33	–0.04	0.973
	Year	11.84	12.04	9.66	0.98	0.349
	Random effect	Variance	Std. Dev.			
	Forest stand	56.153	12.37			
	Residual	302.40	17.39			
Dwarf shrub species	Fixed effects	Estimated coefficient	*SE*	*df*	*t* value	*p* value
	(intercept)	–4,653	35,350	10.74	–0.13	0.898
	Site preparation Mounding	5.38	1.65	1,173	3.25	**0.001 ****
	Microtopography Mound	–1.97	1.44	1,169	–1.37	0.172
	Microtopography Pit	–3.65	1.44	1,169	–2.53	**0.011 ***

Table S1 (continued)

Response variable	Fixed effects	Estimated coefficient	*SE*	*df*	*t* value	*p* value
Dwarf shrub species	Microtopography Trench	–0.01	1.57	1,169	–0.01	0.993
	Microtopography Unprepared	3.45	1.57	1,169	2.20	**0.028 ***
	Region Central Latvia	–20.09	13.25	9.67	–1.52	0.161
	Soil type Drained Mineral Soil	9.76	13.53	9.35	0.72	0.488
	Soil type Wet Mineral Soil	31.52	17.40	9.79	1.81	0.100
	Year	2.31	17.52	10.74	0.13	0.897
	Random effect	Variance	Std. Dev.			
	Forest stand	332.80	18.24			
	Residual	223.00	14.93			
Annual species	Fixed effects	Estimated coefficient	*SE*	*df*	*t* value	*p* value
	(intercept)	–3,614	6,068	10.85	–0.60	0.564
	Site preparation Mounding	2.99	1.11	1,088	2.70	**0.007 ****
	Microtopography Mound	0.83	0.98	1,170	0.85	0.397
	Microtopography Pit	–1.82	0.98	1,170	–1.85	0.064
	Microtopography Trench	–0.05	1.07	1,170	–0.04	0.965
	Microtopography Unprepared	–0.08	1.07	1,170	–0.07	0.942
	Region Central Latvia	–0.25	2.23	10.09	–0.11	0.914
	Soil type Drained Mineral Soil	–2.39	2.23	9.381	–1.07	0.311
	Soil type Wet Mineral Soil	–3.38	2.96	10.55	–1.14	0.278
	Year	1.79	3.01	10.85	0.60	0.563
	Random effect	Variance	Std. Dev.			
	Forest stand	7.85	2.80			
	Residual	103.54	10.17			
Typical forest habitat species	Fixed effects	Estimated coefficient	*SE*	*df*	*t* value	*p* value
	(intercept)	–31,820	37,690	9.84	–0.84	0.419
	Site preparation Mounding	1.52	2.29	1,170	0.66	0.507
	Microtopography Mound	2.87	2.00	1,163	1.43	0.152
	Microtopography Pit	–3.93	2.00	1,163	–1.97	**0.049 ***
	Microtopography Trench	–2.33	2.17	1,163	–1.07	0.285
	Microtopography Unprepared	–0.56	2.17	1,163	–0.26	0.797
	Region Central Latvia	–19.66	14.11	9.31	–1.39	0.196
	Soil type Drained Mineral Soil	17.42	14.40	9.10	1.21	0.257
	Soil type Wet Mineral Soil	35.28	18.54	9.39	1.90	0.088
	Year	15.80	18.68	9.84	0.85	0.418
	Random effect	Variance	Std. Dev.			
	Forest stand	374.60	19.35			
	Residual	103.54	10.17			
Typical grassland habitat species	Fixed effects	Estimated coefficient	*SE*	*df*	*t* value	*p* value
	(intercept)	23,594.27	24,641.61	9.11	0.96	0.363
	Site preparation Mounding	–4.35	1.874	1,171.53	–2.32	**0.020 ***
	Microtopography Mound	3.01	1.64	1,162.99	1.83	0.067
	Microtopography Pit	3.53	1.64	1,162.99	2.15	**0.032 ***
	Microtopography Trench	–1.72	1.78	1,162.98	–0.97	0.334
	Microtopography Unprepared	–2.80	1.78	1,162.98	–1.57	0.117
	Region Central Latvia	6.99	9.22	9.02	0.76	0.467
	Soil type Drained Mineral Soil	–10.39	9.39	8.90	–1.106	0.298
	Soil type Wet Mineral Soil	–20.40	12.11	9.07	–1.68	0.126
	Year	–11.68	12.21	9.11	–0.96	0.364
	Random effect	Variance	Std. Dev.			
	Forest stand	157.9	12.57			
	Residual	287.4	16.95			

Note: Number of observations: 1182, groups: 14.

Table S2. Mean typical EU forest habitat species cover (%) depending on site preparation method and microtopography

Soil type	Forest habitats	Disc trenching			Spot mounding		
		Trench	Unprepared	Berm	Pit	Unprepared	Mound
Drained peat soil	Dry forest habitats on mineral soils	34.6 [a]	35.0 [a]	41.2 [a]	22.6 [b]	24.1 [ab]	31.7 [bc]
	Wet forest habitats on mineral soils	6.1 [ab]	8.9 [a]	5.5 [b]	5.5 [a]	8.8 [b]	4.5 [a]
	Wet forest habitats on organic soils	1.6 [ab]	2.5 [a]	0.8 [b]	5.6 [a]	5.4 [a]	5.1 [a]
Wet mineral soil	Dry forest habitats on mineral soils	41.6 [a]	32.1 [b]	43.6 [a]	32.9 [a]	29.3 [a]	39.6 [a]
	Wet forest habitats on mineral soils	6.6 [a]	17.1 [b]	5.8 [a]	9.8 [a]	15.6 [a]	11.0 [a]
	Wet forest habitats on organic soils	13.1 [a]	10.1 [a]	11.2 [a]	5.1 [a]	6.0 [a]	4.5 [a]
Drained mineral soil	Dry forest habitats on mineral soils	31.7 [a]	35.3 [a]	37.1 [a]	30.0 [a]	38.2 [ab]	43.3 [b]
	Wet forest habitats on mineral soils	6.8 [a]	11.3 [a]	9.6 [a]	6.8 [a]	11.8 [a]	6.0 [a]
	Wet forest habitats on organic soils	33.1 [a]	29.2 [a]	27.0 [a]	33.9 [a]	30.9 [a]	24.0 [a]

Note: Forest habitats on dry mineral soils: 9010; 9020; 9060; 9180. Forest habitats on wet mineral soils: 9080; 91E0. Forest habitats on wet organic soils: 91D0. Different letter denotations (a, b, c) indicate Tukey's HSD test significant differences between microtopographies in one site preparation method.

Table S3. Linear mixed effects model results for bryophyte cover, species richness and weighted average Ellenberg's indicator values

Response variable	Fixed effects	Estimated coefficient	*SE*	*df*	*t* value	*p* value
Cover	(intercept)	39,556.65	12,924.13	7.96	3.06	**0.016 ***
	Site preparation Mounding	13.64	2.54	581.79	5.37	**< 0.001 *****
	Microtopography Mound	–19.20	3.14	579.34	–6.11	**< 0.001 *****
	Microtopography Pit	–8.92	1.85	578.39	–4.81	**< 0.001 *****
	Microtopography Trench	5.25	2.53	578.38	2.08	**0.038 ***
	Microtopography Unprepared	19.39	2.47	579.15	7.85	**< 0.001 *****
	Region Central Latvia	–7.39	3.98	9.34	–1.86	0.095
	Soil type Drained Mineral Soil	4.41	4.34	7.50	1.02	0.341
	Soil type Wet Mineral Soil	–2.58	7.10	7.31	–0.36	0.727
	Year	–19.60	6.41	7.96	–3.06	**0.016 ***
	Random effect	Variance	Std. Dev.			
	Forest stand	25.66	5.065			
	Residual	214.73	14.65			
	Fixed effects	Estimated coefficient	*SE*	*df*	*t* value	*p* value
Species richness	(intercept)	2,241.62	1,346.31	8.57	1.67	0.132
	Site preparation Mounding	1.25	0.19	581.07	6.42	**< 0.001 *****
	Microtopography Mound	–1.60	0.24	577.21	6.68	**< 0.001 *****
	Microtopography Pit	–0.40	0.14	576.38	2.84	**0.005 ****
	Microtopography Trench	0.64	0.19	576.17	3.34	**< 0.001 *****
	Microtopography Unprepared	1.91	0.19	576.90	10.16	**< 0.001 *****
	Region Central Latvia	–0.28	0.41	9.39	–0.68	0.514
	Soil type Drained Mineral Soil	0.30	0.45	8.32	0.67	0.521
	Soil type Wet Mineral Soil	–0.14	0.75	8.19	–0.19	0.855
	Year	–1.11	0.67	8.57	–1.66	0.132
	Random effect	Variance	Std. Dev.			
	Forest stand	0.31	0.56			
	Residual	1.24	1.11			
	Fixed effects	Estimated coefficient	*SE*	*df*	*t* value	*p* value
Ellenberg's Moisture indicator value	(intercept)	1,975.92	1,407.97	8.27	1.40	0.197
	Site preparation Mounding	0.13	0.25	581.99	0.51	0.609
	Microtopography Mound	–0.42	0.31	578.72	–1.38	0.169
	Microtopography Pit	0.37	0.18	577.78	2.02	**0.044 ***
	Microtopography Trench	0.15	0.25	577.68	0.61	0.545
	Microtopography Unprepared	–0.47	0.24	578.46	2.00	0.046 *
	Region Central Latvia	–0.22	0.43	9.59	–0.52	0.616
	Soil type Drained Mineral Soil	–0.41	0.47	8.03	–0.86	0.416
	Soil type Wet Mineral Soil	–2.19	0.78	7.79	–2.82	**0.023 ***
	Year	–0.98	0.70	8.27	–1.40	–0.98
	Random effect	Variance	Std. Dev.			
	Forest stand	0.32	0.56			
	Residual	2.07	1.44			
	Fixed effects	Estimated coefficient	*SE*	*df*	*t* value	*p* value
Ellenberg's Nitrogen indicator value	(intercept)	–997.73	1,555.20	8.14	–0.64	0.539
	Site preparation Mounding	–0.31	0.28	582.00	–1.10	0.271
	Microtopography Mound	–0.06	0.34	578.68	–0.17	0.865
	Microtopography Pit	–0.65	0.20	577.72	–3.19	**0.001 ****
	Microtopography Trench	–0.32	0.28	577.62	–1.16	0.245
	Microtopography Unprepared	–0.47	0.27	578.42	–1.75	0.080
	Region Central Latvia	0.55	0.47	9.38	1.15	0.278
	Soil type Drained Mineral Soil	–0.53	0.52	7.83	–1.02	0.338
	Soil type Wet Mineral Soil	–0.37	0.86	7.62	–0.44	0.674
	Year	0.50	0.77	8.14	0.64	0.537
	Random effect	Variance	Std. Dev.			
	Forest stand	0.39	0.62			
	Residual	2.56	1.60			