Naturally regenerated birch and planted Norway spruce - comparison with soil moisture maps

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Abstract

Nowadays, when Lidar technologies are developing so fast, it is a lot easier and efficient to use information in forest management processes. Such technologies allow forest owners to make more rational and clever decisions in forest management taking into account different factors which in the past where not possible to use.

Firstly, soil moisture maps from Södra were obtained and used to define stands where groundwater level is high and could affect regeneration and soil preparation. Then 30 clear-felled stands, larger than 2 ha, were selected which have been harvested in 2012 and regenerated with Norway spruce, so that seedlings would have overgrown ground vegetation and effects of high groundwater could be seen.

After that a systematic grid with 25 m spacing was created in ArcGIS program. For stands larger than 5 ha, 50 m spacing between sample plots was used. In each selected stand sample plots were created according to the grid, with radius of 1,78 m (10 m^2). Due to systematic grid, sample plots will represent both, areas in the stand where groundwater level is acceptable and areas where groundwater level is estimated to be high. In each sample plot all seedlings were counted and for each group average height was measured. Seedlings were divided by species and their origin, although, only Norway spruce occurred as planted species. In total, 791 sample plots were measured. All plots were grouped by their mean soil moisture values representing wet/mesic (value 0 – 0,9) and mesic (value 0,91 – 1), thus observed scarification was also taken into account.

Results show that birch natural regeneration is very strong and had highest seedling mean density and height in wet/moist plots where soil scarification was not observed. For planted Norway spruce highest density and mean height was observed in mesic plots where soil scarification was carried out.

Key words: soil moisture maps, birch, Norway spruce, natural regeneration

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1. Introduction

1.1 Background

More than 100 years ago, already first relationships between topography and water table were recognized (King, 1899). Topography is the most important factor for soil moisture in boreal forest landscapes. Evaporation and precipitation are homogenous, which can be assumed as minor importance. Usually groundwater level is rather close to the surface, which allows to assume that flow will follow the topography (Zinko et al., 2005). Moisture level is higher in lower positions on slopes, where direct sunlight radiation is minimized (hill shade effect) and in depressions. Also moisture level is higher in soils which can store a large amount of water (Iverson et at., 1997).

In landscapes, groundwater availability is a crucial factor for vegetation composition and tree growth (Zinko et al., 2005; Anenkhonov et al., 2015). Different plant species compositions can be reflected to certain moisture conditions, to which species are exposed during a period of time (Anenkhonov et al., 2015). Anenkhonov (2015) used plant species composition to observe differences among soil moisture in the pine and larch woodlands in forest-steppe in Siberia, Russia. Thus, species composition can be used as indicators for trends in soil moisture conditions, which are affected by global precipitation or other climatic factors. Also, soil moisture factor can be used to examine spatial structures and even vulnerability of vegetation regarding soil moisture factor (Anenkhonov et al., 2015).

Precise measurements of soil moisture content for long periods could be costly and difficult. In the past, topographic indexes acquired from field assessment of terrain topography were used (Parker, 1982; Allen et al., 1991). Nowadays due to technological development topographic indexes are gained from digital elevation models (DEMs) within geographic information systems (GIS) (Moore et al., 1991; Gruber & Peckham, 2008). From digital elevation models (DEM) and other hydrographic data, information about hydrological connectivity of wetlands and surface flow pathways can be derived (Moore et at., 1991).

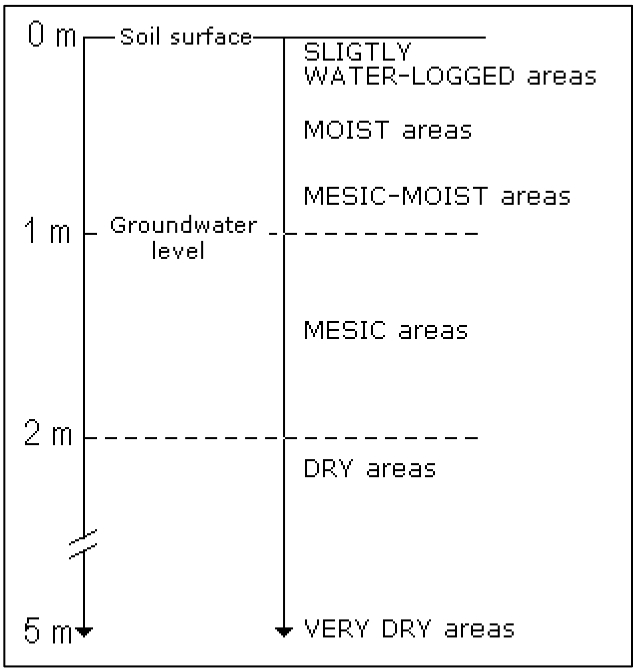


Figure 1. Soil moisture classes by depth down to the average level of groundwater during growing season. (http://www-markinfo.slu.se)

In the landscapes, wetlands are key elements in terms of regulation of watershed hydrology, biodiversity and habitats (Bhatti & Preston, 2006). Precise wetland inventories can be very important source of information for different actors. As a tool of GIS, this data can be combined with other data, allowing for better planning and management (Turner et al., 2000). Since DEMs have been introduced, significant development has been done with affordable options (Dirnböck et al., 2002). DEMs have given an opportunity to create many computer-based models to calculate geomorphological, climatological and hydrological processes over landscapes (Beven & Kirkby, 1979).

Due to GIS development it is possible to create continuous field model where soil properties are represented as pixels with continuous coverage across the landscape. This model can represent gradual change in properties and typically is mapped as raster data in GIS. A common approach has been to create topographic indexes from DEM and relate them to watershed properties, for example, moisture content and soil drainage conditions. One of the most common is a topographically derived soil wetness index (SWI) which has been used in numerous studies (Iverson et al., 1997).

To measure soil moisture content, estimation of the depth to the average level of the groundwater table in the growing season has to be done. Soil moisture maps are created by continuous mapping approach, creating a depth-to-water value for each pixel (Fig. 2). These values are derived from hydrographic data and DEM by using GIS algorithm (Murphy et al., 2007). Higher resolution DEMs allow to make more precise depth-to-water maps and obtain flow-channels or wet-areas. Thus, lower quality DEMs can alter actual ground elevation due to dense vegetation or other factors (Murphy et at., 2008).

Value is approximate indicator of depth-to-water which represents elevation difference between any cell (pixel) within the landscape and already mapped wetlands and any nearest surface water or smallest points in depression (Murphy et at., 2011). All surface waters (rivers, lakes, streams etc.) are assumed as value 0. Smaller depth-to-water values represent wetter soils. Such cells with low value can have water near or at the surface for long period. Thus, values which are further into landscape tend to increase, describing drier soils (Fig. 1). In steeper terrains value increases more rapidly than in flatter terrains (Murphy et al., 2007).

There are many factors which are affecting groundwater level in upland (non-wetland) soils, such as soil hydraulic and sediment properties, climate, vegetation etc. Seasonal factors and longer time scale can have crucial role in water table depth. Therefore, acquiring the depth-to-water index to actual groundwater depth in upland soil, should be verified by the region (Murphy et al., 2007). Murphy et al. (2007) pointed out that deriving depth-to-water values for bogs was not as effective as for other wetlands, due to the fact that bogs can have surface and groundwater raised above surrounding terrain because of organic matter.

Also they concluded that depth-to-water index creates continuous landscape hydrologic system even for very small wetlands (<1 ha) where other methods represent them as isolated units. However, such information about small wetlands or small wet riparian areas are crucial in terms of habitat and watershed protection and land management in agriculture and forestry. Such additional information about wetland connectivity and hydrologic flow can improve planning and management, help land planners and identity other important factors. For example, such information would allow to understand to what extent wetlands can be affected by road construction, ditches etc. (Murphy et al., 2007).

It is important to understand that mapped depth-to-water value is a time-integrated indicator of drainage conditions or soil moisture next to surface water features. In result, depth-to-water index is separate from regional and local groundwater table delineations. Thus, derived flow channels do not represent all possible options by which water flows through and into landscape (Devito et al., 2005).

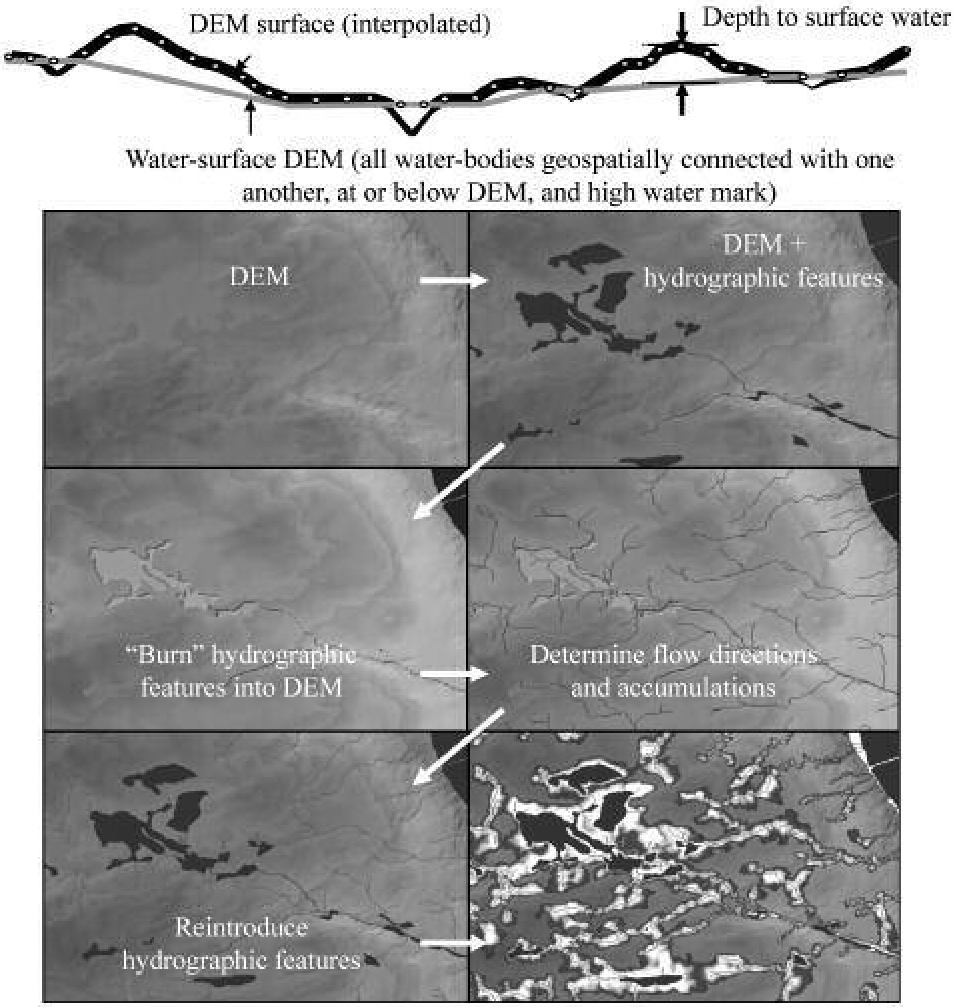


Figure 2. Process to map flow channels and wet areas using a digital elevation model (DEM) and hydrographic data. Bottom right: area which represents the cartographic depth-to-water index <1 from the soil surface. (Murphy et at., 2008)

1.2 Natural regeneration

Nowadays productive forest cover in Sweden is about 57 % of the total land area. In the past decade`s area of forests has increased, mostly with coniferous. 39 % of total volume represents Scots pine (*Pinus sylvestris)*, 42% Norway spruce *(Picea abies)* and only 12% broadleaved tree species (www.skogsstyrelsen.se). Bergquist et al. (2011) concluded that more than 70 % of total regenerated forest area in Sweden is planted with conifer tree species, even though growing conditions could be more suitable for broadleaves. Such trend is due to high demand from forest sector for raw material, annual growth, shorter rotation period, knowledge in management and most relevant, lower regeneration costs due to high browsing pressure (Felton et al., 2010).

Even-aged monocultures are not so common in natural regeneration, only after heavy disturbances such as storms or forest fire. Increasing the amount of even-aged monocultures decreases biodiversity and natural habitats for many species (Felton et al., 2010). Different papers have concluded that even-aged conifer monocultures attract lees species diversity (Carnu et al., 2006; Brockerhoff et al., 2008) than mixed stands e.g. Norway spruce and birch (Felton et al., 2010). In mixed stands of broadleaves and conifers, nutrients are used more efficiently (Brandtberg et al., 2000) and stands are more resistant to storm damages (Schutz et al., 2006).

Nevertheless, a mixed plantation of broadleaved and conifer seedlings is very rare in commercial forestry for several reasons. First of all, high density of browsers is one of the most common issues (Felton et. al., 2010). Secondly, artificial regeneration of broadleaves has higher costs in comparison to Norway spruce (Ezebilo et al., 2012). Forest owners in Sweden do not have confidence that broadleaf timber will be in demand and get a good price at final felling time, and price variations do not increase this confidence (Felton et. al., 2010). Thirdly, natural regeneration with a retained seed tree shelterwood, which could increase the share of broadleaves significantly, is not so common in Sweden, with exceptions for Scots pine and beech (*Fagus [add sp])* (Karlsson & Nilsson, 2005). Negative aspects of natural regeneration are longer rotation period and high number and diversity of tree species which affects pre-commercial thinning and final yield. Holmström et al. (2016) stressed that pre-commercial thinning have a huge role in ensuring certain tree species living conditions and have to be done more often, which increases the costs. Natural regeneration in clear-cut without soil preparation can create diverse species structure which depends on growing conditions, seed bank and weather (Karlsson & Nilsson, 2005).

Even though natural regeneration could reduce the establishment costs, it has still many disadvantages in comparison to artificial regeneration. First of all, there is a quite high risk that preferable species fail to regenerate or the regeneration phase will be prolonged. In good growing conditions, grass and other vegetation will overgrow new seedlings (Mangalis, 2004). Also, for Scots pine, it is almost impossible to regenerate naturally without soil scarification. Secondly, the stand structure could be very diverse and patchy, which would demand earlier and tough pre-commercial thinning. Thus, natural regeneration creates an uneven structure where the dominant trees have large branches and uneven annual rings. With an uncontrolled regeneration the seedling density could be very high and result in more and earlier pre-commercial thinning being required, which will increase costs. Therefore, at the final felling, it is possible that naturally regenerated stands have a smaller yield than planted stands and logs have lower quality (Mangalis, 2004).

For natural regeneration it is very crucial that a seed source is nearby. Amount of seeds are defined by mature trees both in the stand and near the stand. Amount and quality of seeds can vary a lot from years and are affected mostly by weather conditions (Clark et al., 1998). Mangalis (2004) concluded that for Scots pine and Norway spruce, seed dispersal distance is 40 – 50 m, but for birch dispersal is 200 m or more. In Swedish forestry, birch seed dispersal distance is assumed as very far (Karlsson & Nilsson, 2005) although the majority of seeds fall within 100 m from the source.

Birch is the most common naturally regenerated tree species in southern Sweden (Karlsson & Nilsson, 2005). Göotmark et al. (2005) concluded that 80 % of naturally regenerated species in clear-cuts is represented by both birch species *(Betula pendula & Betula pubescens)*. Other species such as aspen *(Populus tremula)*, black alder *(Alnus glutinosa)* and oak *(Quercus robur)* also can regenerate naturally, but in lesser amounts than birch (Holmström et al., 2016). Birch can produce around 5 million seeds ha^{-1}, though, 80 – 90% of seeds are empty and germination is not higher than 50 - 60% (Granström & Fries, 1985).

Birch is a pioneer species and due to fast growing ability, the competition with weeds and grass is only severe within the first two to three years. Birch is more adapted to harsh weather conditions than other broadleaved tree species. Due to high stem density browsing pressure is lower than for other species (Mangalis, 2004). Soil moisture has a relevant role in natural birch regeneration (Sarvas, 1948). High moisture improves germination of birch seeds (Ackzell, 1994).

1.3 Soil preparation

One of the key factors for intensive forest management is to regenerate the stand as soon as possible after the clear-cut with the best and most productive tree species. Soil preparation has a crucial role in intensive forest management. With soil preparation moisture and aeration aspects are improved, soil layers are mixed and competition with weeds and grass is decreased

(Gasiņš, 1975). Thus, scarification of soil decreases damage from pests e.g. pine weevil *(Hylobius abietis)* (Petersson et al., 2005). Soil preparation is also a huge benefit for natural regeneration, especially for species which seeds are spread by wind because opened mineral soil enhance better growing conditions for seeds and competition with weeds is much lower (Clark et al., 2007).

1.4 The aim of this study

The aim of this study was to understand if regeneration and growing of natural and artificial seedlings have correlation between areas which by soil moisture maps have high soil moisture values.

The objectives of this study were:

1) Do the natural birch and planted Norway spruce seedling density and height correlate with soil moisture values from soil moisture maps?
2) Does scarification affect mean density and height of birch and planted Norway spruce seedlings?
3) Is there any risk of limits in my results due to lack of seeds in sample plots too far from seed source?
4) Is it possible to use this information and soil moisture maps to detect areas for high birch regeneration?

2. Materials and methods

2.1 Study site

The study was done in Southern part of Sweden (Skåne), close to Hässleholm and Kristianstad (56^{o}24’ N, 13^{o}94’ E) (Fig. 3). The climate of the study area is considered as warm and temperate, with average temperature 7.5^{o} C. July is the warmest month with an average temperature of 17.0^{o} C and February average temperature is the lowest -0.6^{o} C. The average annual rainfall is about 690 mm (Climate data, 2017).

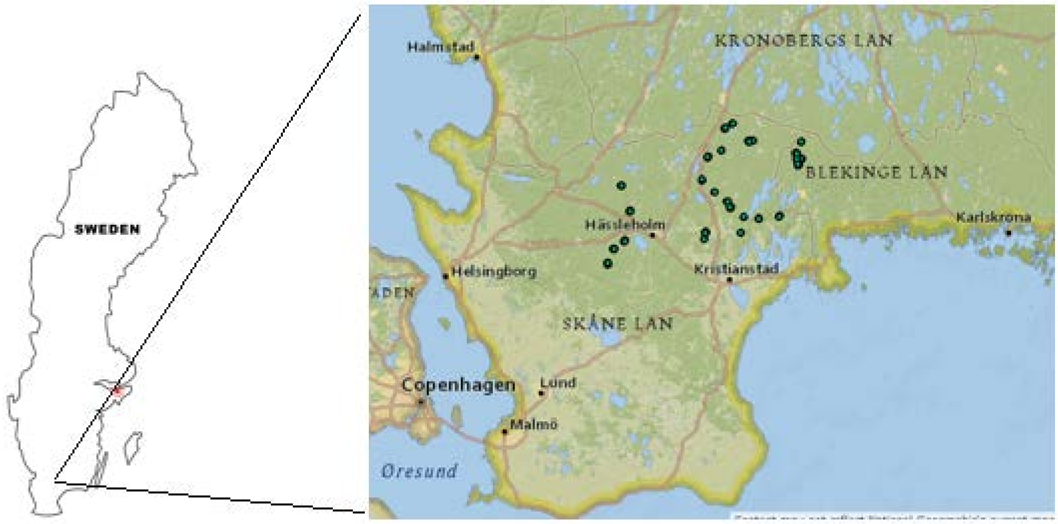


Figure 3. Study area. Available: https://gis-slu.maps.arcgis.com/home/webmap/viewer.html?layers=3e043b8605c94350aaf6b73243f22ca9&useExisting=1 (accessed 09.02.2017.).

2.2 Data selection

In this study soil moisture maps were created using the continuous mapping approach, creating a depth-to-water value for each pixel. These values were derived from hydrographic data and DEM by using GIS algorithm. This value is approximate indicator of depth-to-water which represents elevation difference between any cell (pixel) within the landscape and already mapped wetlands and any nearest surface water or smallest points in depression. All surface waters (rivers, lakes, streams etc.) are assumed as value 0. Smaller depth-to-water values represent wetter soils. Such cells with low value can have water near or at the surface for long periods. Thus, values which are further into landscape tend to increase, describing mesic soils.

The inventory was done on a selection of regenerated clear-cuts, provided by *Södra skogsägarna* in spring of 2016. All forest stands that were harvested during the year 2012, within the district Södra Broby, were delivered in a shapefile along with soil moisture maps (*Foran* company).

Stands smaller than two hectares were excluded from the selection due to possibility to other factors affect seedling growing more particularly than in larger stands, for example edge effect. The regenerations with the biggest proportion of both mesic and moist areas, based on the soil moisture maps, were selected for the field inventory.

2.3 Field inventory

Data was collected from 21st to the 27th of March in 2016. During this period 30 stands were measured and 791 sample plots were created.

The mapping and registrations of the inventory were made with an Ipad and the application Collector (gis-slu.maps.arcgis.com).

The sample plots for the field inventory were based on a systematic grid and designed to cover the whole regeneration area of the clear-cuts (Fig. 4). The grid was laid out with the fishnet tool in ArcGIS, with the spacing between plots adjusted to clear-cut size. On clear-cuts smaller than five hectares, the spacing between the plots was 25×25 m, on larger clear-cuts 50×50 m. Due to the systematic grid, sample plots were distributed evenly covering the whole stand and representing both areas in the stand where groundwater level is acceptable and areas where groundwater level is estimated to be high by soil moisture maps.

In each sample plot of radius 1,78 m (sample plot area 10 m^2) all naturally regenerated and planted tree seedlings were counted. Mean height of the seedlings was estimated for each species. 29 clear-cuts were regenerated with Norway spruce (*Picea abies)*, except for one stand (stand identity 4000) where no artificial regeneration was observed. Common naturally regenerated species were birch (*Betula pendula&pubescens*), Scots pine *(Pinus sylvestris*), aspen (*Populus tremula*), black alder (*Alnus glutinosa*), oak (*Quercus robur*), lime (*Tilia cordata*) and beech (*Fagus sylvatica*).

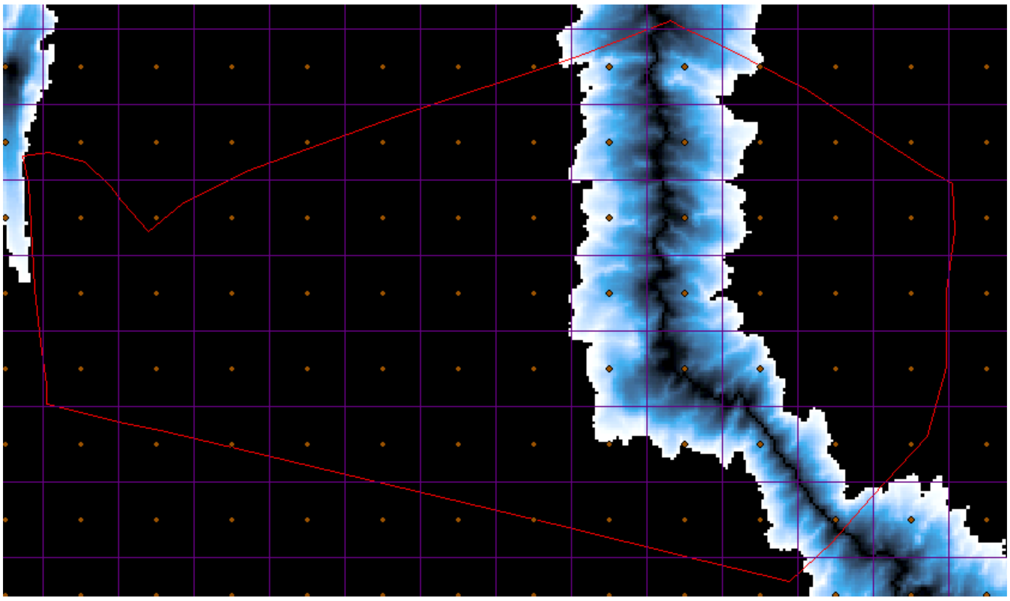


Figure 4. Soil moisture map with stand border, fishnet and locations of sample plots (ArcGIS)

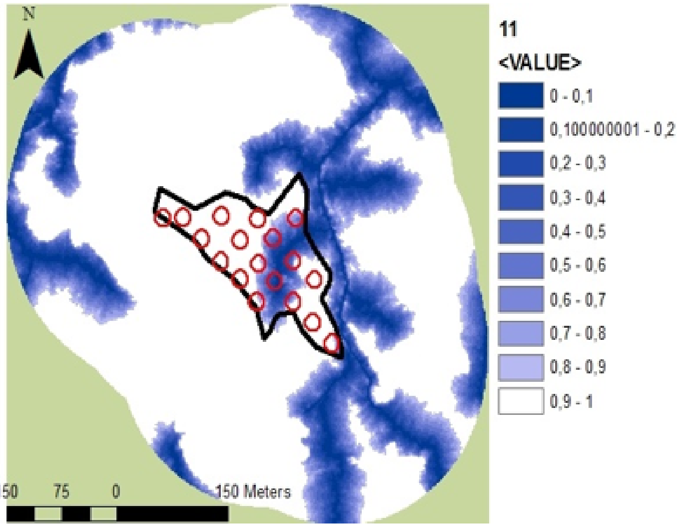
In addition to the information from the soil moisture map, a soil moisture class was estimated for each sample plot in the field inventory, where value 1 represents wet and 0 mesic. Also, any indication of performed soil scarification was registered as was if the sample plot had no planted seedlings.

2.4 Data processing

A moisture value for every sample plot was extracted from the commercial groundwater map used by Södra (reference *Foran*). The value was calculated in two different resolutions, in circular buffer zones with 2 and 10 m radius from the centre of the sample plot. To test the eventual difference between 2 and 10 m buffer of the moisture value *Student`s* t-test was applied.

Moisture values ranged from 0 to 1 (Fig. 5), where 0 – 0,9 is the value which was estimated for areas with high risk of high groundwater level and 0,91 - 1 represents mesic or lower groundwater depth. Values describe the risk of high soil moisture according to company *Foran*.

According to soil moisture values, the sample plots were grouped into wet/moist and mesic plots.



Depth-to-water value	Classification
0-0,1	Surface water
0,11–0,2	Water logged areas
0,21–0,3	
0,31–0,4	
0,41–0,5	
0,51–0,6	
0,61-0,7	
0,71-0,8	
0,81-0,9	Mesic-moist areas
0,91-1	Mesic areas

Figure 5. Stand border with buffers for sample plots in red circles and the range of the soil moisture values in blue and white.

(ArcGIS)

An estimate of potential birch seed supply was made by calculating the distance to nearest possible seed source represented as the distance to the nearest forest edge. The distance was calculated in ArcGIS based on stand boundaries from the clear-cut shapefiles delivered from Södra.

Further data treatment was done in Excel, including statistical analysis. A t-test for samples with uneven variance was applied.

3. Results

3.1 Stand level

In total 791 plots were measured in 30 stands. All stands, except stand 4000, were regenerated by Norway spruce. In stand 4000 no planting was observed, probably due to high moisture conditions, but no information was given from Södra. Mean density for planted Norway spruce was 1600 seedlings per hectare (standard deviation, SD=1400) and mean height 0,4 m (SD=0,4). Some exceptions were found, (stand 1800 and 1900), with a very low density of planted Norway spruce, because of many rocks and steep slopes in the stands (Appendix: Table 4).

Table 1. Naturally regenerated tree species mean density, height, standard deviation and presence in stands.

Tree species	Mean density ha^{-1}	SD	Mean height, m	SD	Presence in stands (30)
Birch	5700	7700	0,6	0,8	30 (100%)
Norway spruce	1800	4400	0,1	0,3	30 (100%)
Scots pine	300	1100	0,1	0,2	19 (63%)
Other	600	2900	0,1	0,4	18 (60%)

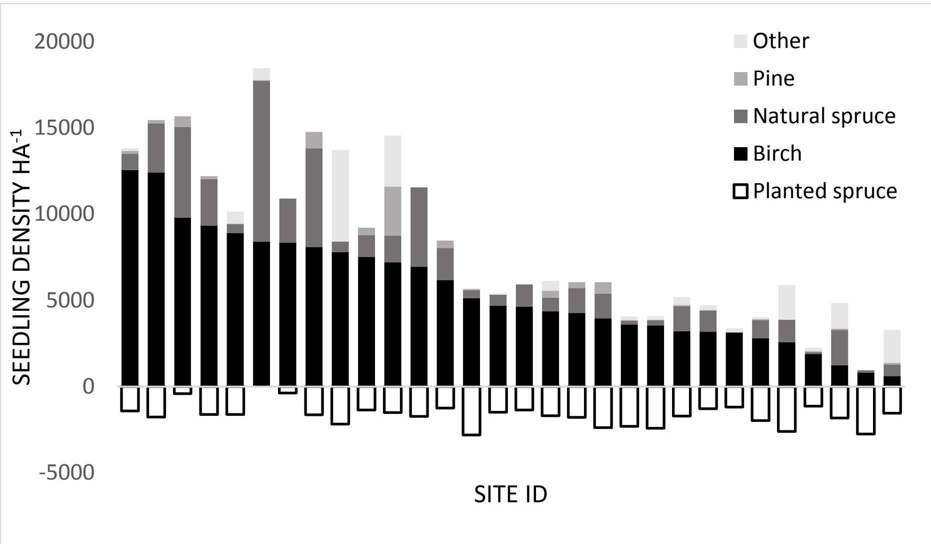


Figure 6. Mean seedling density (seedlings ha^{-1}) for each species for each stand.

Birch and naturally regenerated Norway spruce were present in all regenerations while Scots pine only in 19 (63 %) stands (Table 1). Other tree species, representing oak, black alder, aspen, beech and lime, were observed also in 18 (60 %) stands.

In most of the stands, wet areas represent quite small proportion of the area (Fig. 7). But in some cases, for example, in stands 4000 and 1900 almost all the stand area was represented by high soil moisture values, 89 and 72 % respectively.

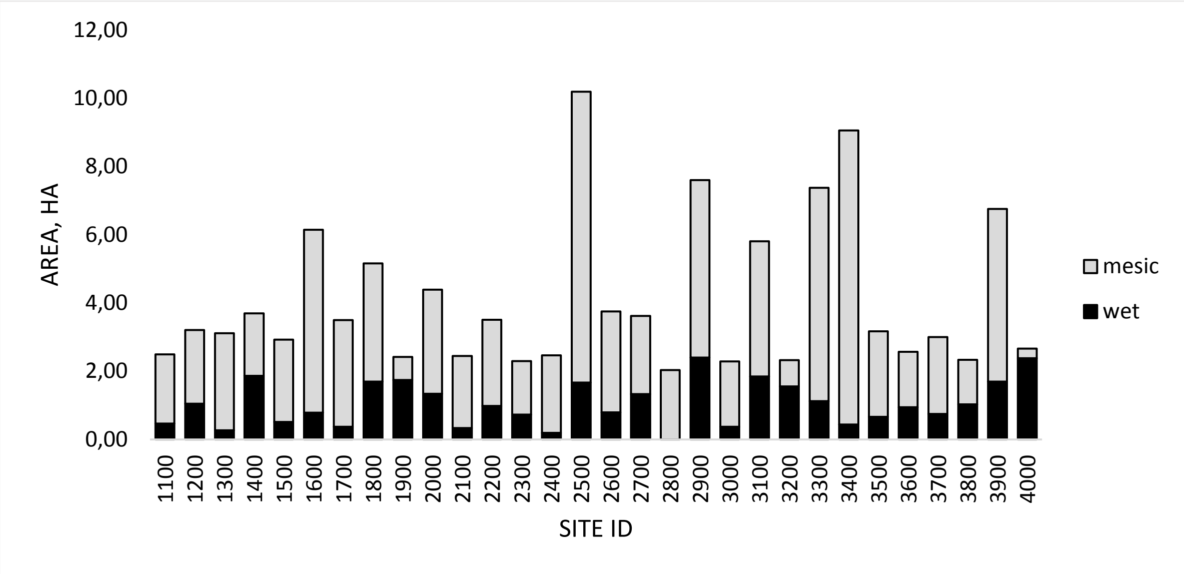


Figure 7. Proportion of mesic and wet area within the stand.

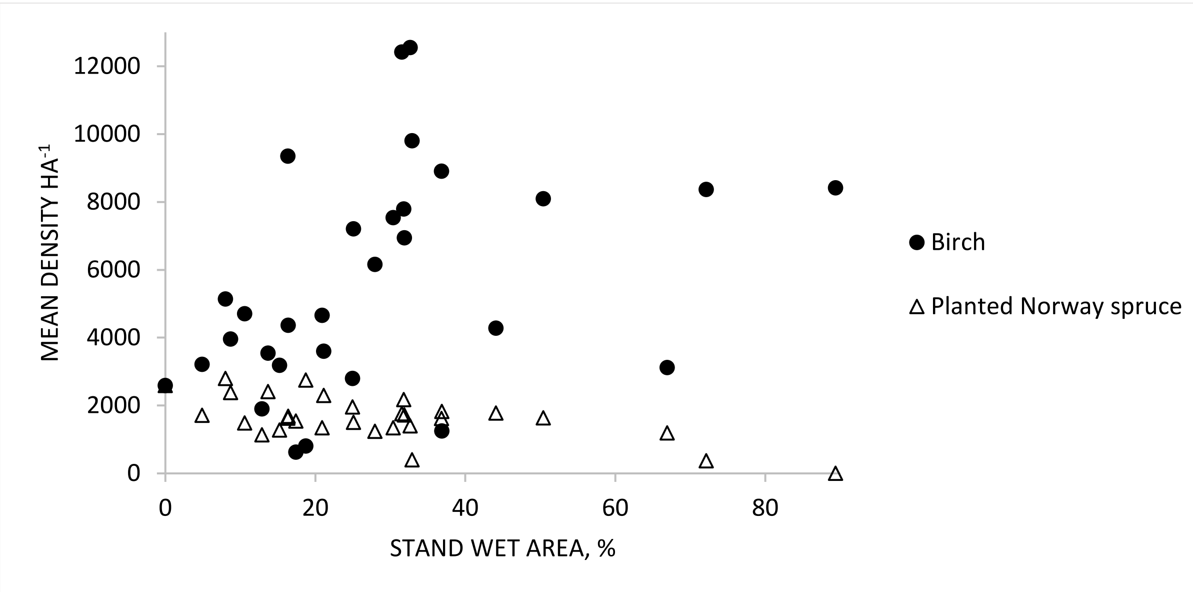


Figure 8. Seedling density in relation to proportions of wet areas in the stands.

There was an increasing tendency in the mean density of birch seedlings with an increase in the proportion of wet areas in the stand. The opposite tendency was detected for the planted Norway spruce seedlings (Fig. 8). The difference between birch and planted Norway spruce seedling mean density is considered to be extremely statistically significant ($p<0.0001$).

The same tendency for birch and planted Norway spruce was observed with mean height correlation with the proportion of wet area in each stand (Fig. 9). The difference here is also considered to be extremely statistically significant (p=0,0006).

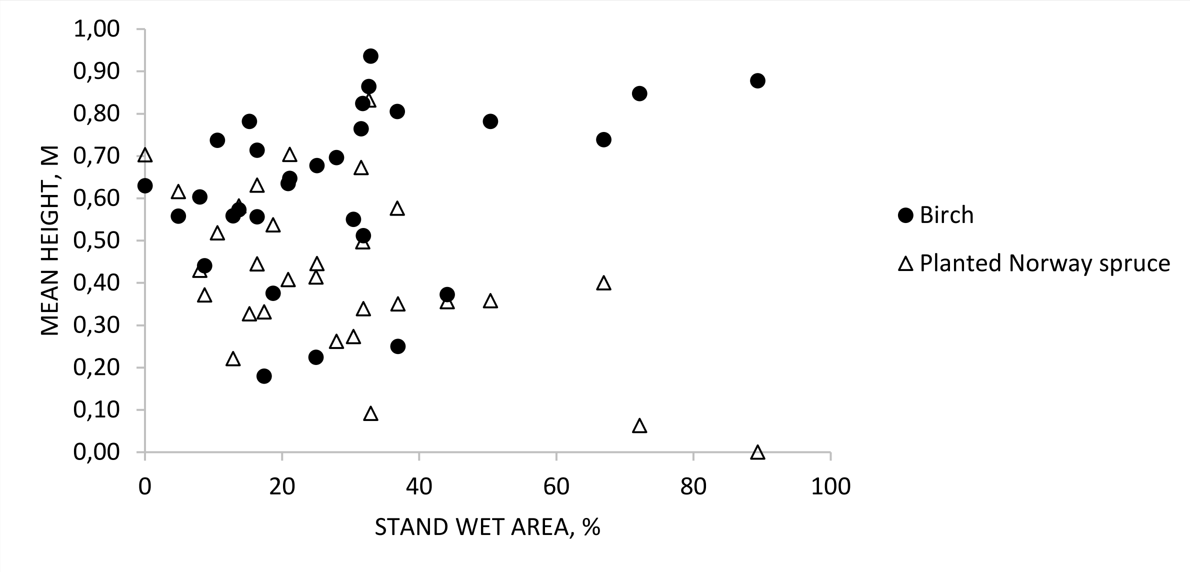


Figure 9. Seedling height in relation to proportions to wet areas in the stands.

3.2 Sample plot level

The two different resolutions of buffer zones for estimating moisture value in the sample plots were not significantly different from each other (p=0.992), therefore the smaller buffer zone of 2 m radius was used for further analysis.

From all plots 509 (64%) plots were calculated as mesic and 282 (36%) as wet (Table 2). Mean value for proportion of calculated wet sample plots per stand was 32 % (SD=22) and mesic 68 % (SD=19).

Of all 791 plots, 478 (60%) were marked as scarified from which 359 (75%) were mesic and 119 (25%) wet. But in 313 (40%) plots no signs of scarification were observed (150 – mesic; 163 – wet) (Table 2.).

In stands that still had signs of soil scarification, there were also 171 (26%) plots that had no sign of soil scarification and were therefore classified as not scarified. Six stands with steep slopes, high soil moisture or with many boulders and rocks, were not scarified (stand 1600, 1900, 2200, 3500, 3600 and 4000). In some plots with big piles of harvest residues, small streams, ditches or strip roads no sign of soil scarification was found. Almost, in all stands, soil preparation was done by disc trenching in continuous rows, but in one case mounding in intermittent patches was used.

Table 2. Plot distribution by soil moisture values and observed scarification.

Scarified	Mesic plots	Wet plots	Total
No	150	163	**313 (40%)**
Yes	359	119	**478 (60%)**
Total	**509 (64%)**	**282 (36%)**	**791 (100%)**

Highest mean density and mean height for birch seedlings was found in wet plots without signs of soil scarification (Table 3). The lowest mean density was observed in mesic plots without scarification, but the lowest mean height was in mesic plots where scarification was done. However, the difference in mean heights between mesic plots is only 0,01 m.

For planted Norway spruce highest seedling density and seedling height was observed in mesic plots with scarification. Lowest density (464 seedlings ha^{-1}) and smallest (0,12 m) seedlings were observed in wet, not scarified plots.

Table 3. Birch and planted Norway spruce mean densities (seedlings ha^{-1}) and mean height (m) in sample plot categories.

		Birch		Planted spruce	
		Density	Height	Density	Height
All plots		5700	0,6	1600	0,4
Wet/Moist					
	Scarified	7800	0,7	1600	0,4
	Not scarified	8300	0,9	500	0,1
Mesic					
	Scarified	5000	0,6	2100	0,6
	Not scarified	3900	0,6	1400	0,4

The difference between birch and planted spruce seedling mean density according to soil moisture values is considered as very statistically significant (p=0,0096). As for mean height the difference is considered to be not quite statistically significant (p=0,089).

The sample plots were distributed between 1 and 99 meters from forest edges of adjacent stands. There was no strong correlation detected with birch seedling density and distance to the nearest forest stand edge (Fig. 10). Although after 80 m density of birch seedling decreased significantly it is not possible to assume that the main reason could be the distance to forest stand edge.

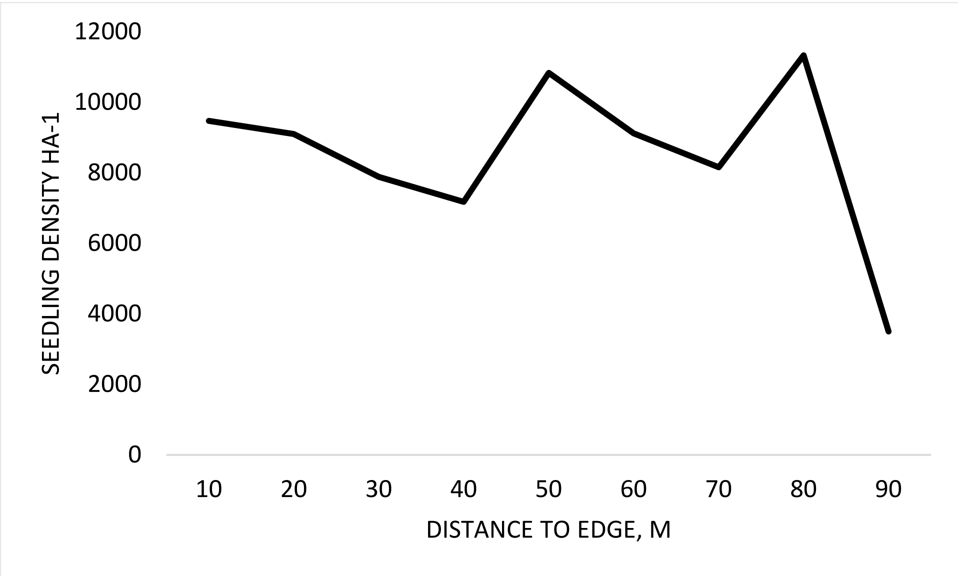


Figure 10. Mean birch seedling density for 10 m classes distance to forest edge.

4. Discussion

Natural birch regeneration is very strong and competitive. In most of the stands, birch regeneration had highest mean density and mean height, in comparison to planted Norway spruce or naturally regenerated other species (Fig. 6). Birch seedlings were widely distributed between very wet and mesic plots. Results show that stands with a higher proportion of wet area had a higher mean density of birch regeneration (Fig. 9).

Soil scarification did not have any significant effect for either birch seedling density or height which can be explained by the fact that birch is a strong pioneer species and therefore, there is likely already a high density of naturally regenerated birch seedlings when soil preparation is done. For the planted Norway spruce, scarification had a significant effect on mean density and height, especially in plots which were classified as wet/moist. In the mesic plots the difference was smaller between scarified and not scarified plots. Thus from all scarified plots 75% were mesic and only 25% wet/moist. There can be a possibility that during soil preparation forest manager or machine operator already adjusted management to avoid wet places.

To improve results and understanding of the effect of soil preparation on new seedling grow both in mesic and wet plots, more precise measurements should be taken because in this research scarification was detected by individual observations and experience. Human factor at planting should also be considered because planters have the possibility to choose the best spot for new seedlings by estimating wet areas which are not so suitable for Norway spruce.

There are many factors that can affect both natural and artificial regeneration. In most of the stands, natural regeneration of Norway spruce, pine and other tree species was present due to surrounding stands or retention trees (personal observations). Natural spruce, pine and other tree species did not have any serious correlation with soil moisture values for each plot or soil preparation (Appendix: Table 5). Due to high variation of mean density and mean height it is possible to assume that there are many factors affecting natural regeneration. Starting with surrounding stands, soil conditions, competition with other species, browsing, etc. In addition natural Norway spruce regeneration in some plots and stands were very high especially in stands with high soil moisture area percentage (Appendix: Table 4 and 5). It could be explained by the fact that in the moist stands seeds can have better growing conditions more nutrients. .

There were no birch seedlings measured further than 99 m from an edge, which could be explained by the fact that, shapes of stands are very different. Even though, the largest stand was more than 10 ha, irregular shape of stands created a situation when it is not possible to have plots further than 100 m from the stand edge. In some cases, there were even two edges which were affecting natural regeneration in certain plots. This cannot be objective data because only the closest stand edge was calculated. Double edge effect can mean more seed bank, higher protection against frost damages, stable weather conditions, but also more shadow and less nutrients. Unfortunately, it was not possible to get surrounding stand data to fully understand what kind of tree species were affecting natural regeneration, but from individual observations, mostly it was Norway spruce.

4.1 Increasing broadleaves

One of the key factors for sustainable forest management is effective forest regeneration. That includes soil preparation, most suitable tree species, artificial or natural regeneration and planning. But sustainable forest management also includes high biodiversity and reduction of risks from pests, storms, fire and snow damages (Mangalis, 2004).

The highest interest for a forest owner is to decrease rotation length, increase the yield at the final felling and decrease establishment costs to a minimum (Mangalis, 2004). To increase the effectiveness of regeneration and to avoid high costs, planning should take an important role before regeneration process. In some cases, due to high moisture level in the stand, successful regeneration is not even possible and there is a need for second regeneration to replace seedlings which have withered. To avoid such situations wet areas in the stands could be left for natural regeneration. Such approach would increase the share of broadleaves and decrease costs because soil preparation and regeneration have to be done for a smaller area.

But due to a high number of naturally regenerated seedlings, pre-commercial thinning will have a more significant role in certain species establishment. Pre-commercial thinning for natural seedlings will be more complicated than for planted seedlings which will take more time and result in higher costs.

4.2 Soil moisture map potential

Soil moisture maps created from Lidar data have huge potential in planning forest management activities. Iverson (1997) in his paper already in 1997 stressed that geographical information system (GIS) technology could be a perfect tool to develop models of moisture level across landscapes. Murphy et al. (2008) stressed that mapping wet areas, depth-to-water index and flow channels is useful in different operations, starting with road and communication construction, estimating risks for soil erosions and especially for forest operations planning and management. For example, the maps can be used for improving harvest block layout to sustain wet areas, ensure better site-species matching, choosing appropriate machines for soil scarification and for selecting right operating season to decrease soil disturbances e.g. rutting.

If we assume that data from maps have a correlation with species composition and growing conditions then such information would allow for a change to the whole management approach. Nowadays, when forest owners have to consider the option to increase the share of broadleaves, such a tool could help to define areas where broadleaves are more suitable than coniferous, regarding natural regeneration and potentially productivity as well. Thus, the advantages of higher species biodiversity can be shown over the benefits of coniferous monoculture.

Additionally, information from soil moisture maps could be very relevant in thinning and final cut operations, especially in stands where soil moisture is very high. Forest owners could use these maps to make right decisions in planning strip roads, landings or even usage of forest machines. For example, special harvesters and forwarders with improvements for working in wet conditions could be used in identified wet areas. Thus, soil moisture maps have even higher usage potential in countries where the ground soil does not have so many rocks as in Sweden, such as in Baltic or Eastern Europe countries.

In general, a more comprehensive analysis should be done, including more precise measurements of scarification, soil properties, surrounding stands etc. It is hard to estimate soil preparation effectiveness in plots with high soil moisture values. Scarification could be done in summer when soil moisture conditions in stands are very different. In order to improve results, observations of scarification should be done right after the action.

Long-term observations (2 times or even more) would allow for more objective data on species composition and growth of seedlings. A comparison should be done right before first pre-commercial thinning, which would improve understanding of which species are dominating and the benefits or negative aspects of high-level groundwater, soil preparation, etc.

Fertility and structure of soil should be included to better understand the effectiveness of natural and artificial regeneration because for some species certain soil structure can benefit more than for other species. Soil structure would allow to understand soil moisture capacity which is an important factor for regeneration and also for soil preparation. Additionally, time of regeneration, the method of planting and experience of planter also could have a relevant role in regeneration factor.

5. Conclusions

The highest birch seedling density and mean height was found in wet plots with no soil scarification (Table 3). Also, in wet plots with scarification mean density is very high. But lowest density and mean height was estimated in mesic plots with no scarification, which allows to assume that birch regeneration is much higher in plots with high soil moisture values.

For planted Norway spruce results were opposite compared to birch regeneration. Highest mean density and mean height were estimated in mesic scarified plots and the lowest in wet plots with no scarification observed. Such trends represent the fact that birch regeneration is stronger and more suitable for areas with high water level, but Norway spruce prefers mesic areas. However, there are different factors which should be included.

There was no correlation observed with the distance to edge and birch seedling density. It can be affected by many factors but most relevant could be that selected stands were quite small and surrounding stands were too close to estimate the effectiveness of natural regeneration due to surrounding stands.

Finally, such results allow to make the assumption that areas in stands with a high moisture values estimated by soil moisture maps, could be left with no scarification and not planted which would increase the proportion of birch or other tree species and decrease establishment costs.

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Appendix

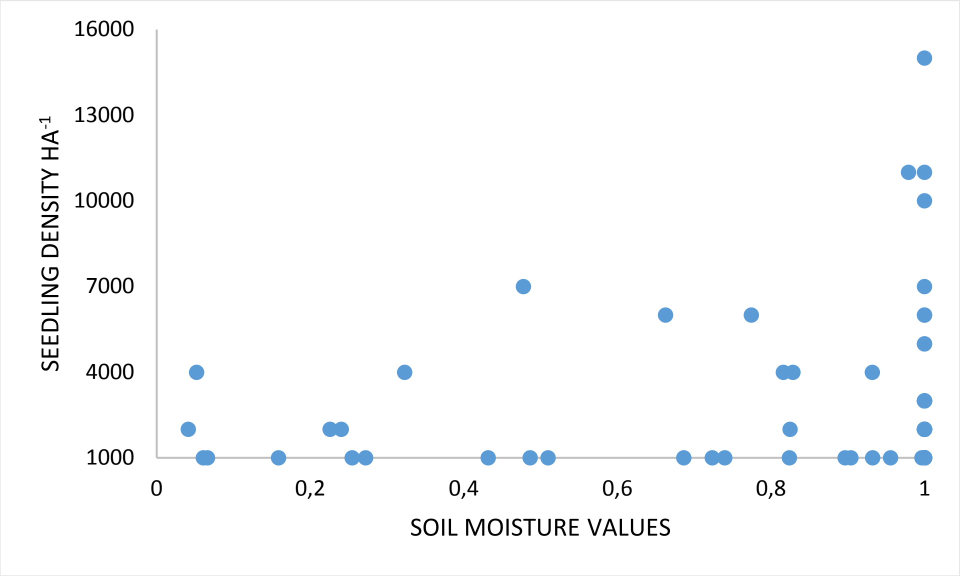

Figure 11. Pine seedling density ha^{-1} relation to moisture values.

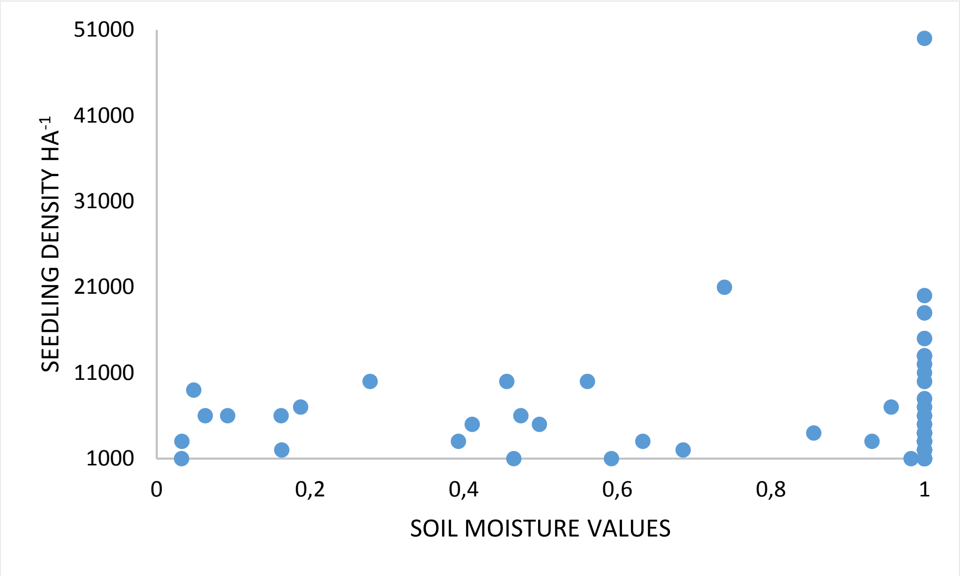

Figure 12. Other species seedling density ha^{-1} relation to moisture values.

Site id	Area, ha	Wet area, %	Scarified	Nr of plots	Planted spruce		Natural spruce		Birch		Pine		Others		Total density
					Density	Mean height	Density	Mean height	Density	Mean height	Density	Mean height	Density	Mean height	
1100	2,5	19	yes	20	2750	0,5	150	0,1	800	0,4	0	0,0	0	0,0	3700
1200	3,2	33	yes	40	1400	0,8	950	0,2	12550	0,9	175	0,0	150	0,0	15225
1300	3,1	9	yes	21	2381	0,4	1429	0,1	3952	0,4	667	0,1	0	0,0	8429
1400	3,7	50	yes	33	1636	0,4	5727	0,3	8091	0,8	939	0,1	0	0,0	16394
1500	2,9	17	yes	24	1542	0,3	667	0,0	625	0,2	83	0,0	1917	0,1	4833
1600	6,1	13	no	29	1138	0,2	103	0,1	1897	0,6	69	0,0	207	0,1	3414
1700	3,5	11	yes	27	1481	0,5	630	0,1	4704	0,7	0	0,0	74	0,1	6889
1800	5,2	33	yes	25	400	0,1	5240	0,4	9800	0,9	640	0,2	0	0,0	16080
1900	2,4	72	no	19	368	0,1	2526	0,2	8368	0,8	0	0,0	0	0,0	11263
2000	4,4	30	yes	32	1344	0,3	1250	0,1	7531	0,6	438	0,1	0	0,0	10563
2100	2,5	14	yes	22	2409	0,6	318	0,1	3545	0,6	0	0,0	227	0,0	6500
2200	3,5	28	no	25	1240	0,3	1880	0,2	6160	0,7	440	0,1	0	0,0	9720
2300	2,3	32	yes	18	1722	0,3	4611	0,1	6944	0,5	0	0,0	0	0,0	13278
2400	2,5	8	yes	15	2800	0,0	467	0,6	5133	0,6	67	0,1	0	0,0	8467
2500	10,2	16	yes	41	1683	0,4	805	0,1	4366	0,6	390	0,1	561	0,2	7805
2600	3,8	21	yes	30	2300	0,7	233	0,0	3600	0,6	33	0,0	200	0,1	6367
2700	3,6	37	yes	28	1821	0,4	2036	0,1	1250	0,3	71	0,0	1500	0,4	6679
2800	2,0	0	yes	17	2588	0,7	1294	0,0	2588	0,6	0	0,0	2000	0,7	8471
2900	7,6	32	yes	29	1759	0,7	2862	0,2	12414	0,8	172	0,1	0	0,0	17207
3000	2,3	16	yes	29	1621	0,6	2690	0,1	9345	0,7	172	0,1	0	0,0	13828
3100	5,8	32	yes	34	2176	0,5	618	0,2	7794	0,8	0	0,0	5294	0,9	15882
3200	2,3	67	yes	26	1192	0,4	38	0,0	3115	0,7	0	0,0	231	0,0	4577
3300	7,4	15	yes	33	1273	0,3	1242	0,1	3182	0,8	0	0,0	303	0,0	6000
3400	9,1	5	yes	38	1711	0,6	1447	0,1	3211	0,6	79	0,0	474	0,0	6921
3500	3,2	21	no	26	1346	0,4	1269	0,1	4654	0,6	0	0,0	38	0,0	7308
3600	2,6	37	no	21	1619	0,6	524	0,1	8905	0,8	0	0,0	714	0,1	11762
3700	3,0	25	yes	25	1960	0,4	1040	0,0	2800	0,2	80	0,0	120	0,0	6000
3800	2,3	44	yes	18	1778	0,4	1444	0,1	4278	0,4	333	0,0	0	0,0	7833
3900	6,8	25	yes	24	1500	0,4	1542	0,3	7208	0,7	2833	0,3	2958	0,1	16042
4000	2,7	89	no	22	0	0,0	9318	0,4	8409	0,9	45	0,0	682	0,1	18455

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Table 4. **Area for each site with observed scarification and mean density and height for each species.**

Table 5. Naturally regenerated Norway spruce, pine and other tree species mean densities (seedlings ha^{-1}) and mean height (m) in sample plot categories.

		Natural spruce		Pine		Others	
		Density	Height	Density	Height	Density	Height
All plots		1800	0,2	300	0,1	600	0,1
Wet/Moist							
	Scarified	1300	0,1	200	0,1	800	0,2
	Not scarified	4200	0,2	200	0,1	300	0,1
Mesic							
	Scarified	1100	0,1	300	0,1	800	0,1
	Not scarified	1500	0,1	200	0,1	400	0,1