Growth of *Pinus sylvestris* 6-11 years after inverted site preparation

Comparison of inverted site preparation and disc trenching's effect on tree growth and pre-commercial thinning needs

Anton Granström

Growth of *Pinus sylvestris* 6-11 years after inverted site preparation. Comparison of inverted site preparation and disc trenching's effect on tree growth and pre-commercial thinning needs.

Tillväxten av Pinus sylvestris *6–11 år efter inversmarkberedning. En jämförelse av hur inversmarkberedning och harvning påverkar trädtillväxt och röjningsbehov.*

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Abstract

Mechanical site preparation (MSP) is widely used to improve microsite conditions for forest regeneration, with disc trenching being the most utilized method in Swedish forestry. Inverted site preparation has been proposed as an alternative MSP method, as previous studies have shown reduced disturbance of ground vegetation while maintaining or enhancing seedling growth. However, the effects of inverted site preparation have primarily been evaluated under controlled experimental conditions, and its performance under operational forestry practises remains insufficiently documented.

This thesis evaluates regeneration outcomes following inverted site preparation carried out using the continuously advancing towed unit Kicken, in comparison with disc trenching. Regeneration was inventoried at 30 operational forest sites regenerated with Scots pine (*Pinus sylvestris* L.) in Västerbotten County, with site age ranging from 6-11 years. The study included 15 sites prepared using inverted site preparation and 15 sites prepared using disc-trenching, which were selected based on comparable site characteristics observed in the field. Seedling growth and natural regeneration were inventoried using 10 systematically placed sampling plots per site. Statistical analyses were conducted using a two-way ANOVA, with site preparation method and site index (SI) included as fixed factors.

No statistically significant differences were detected in seedling height, diameter or leader shoot length between site preparation methods, and similar results were obtained for mean annual height and diameter growth. In contrast, disc-trenched sites exhibited significantly higher densities of naturally regenerated birch *(Betula pubescens* Ehrh. and *Betula pendula* Roth), while total natural regeneration did not differ significantly between methods, although mean regeneration densities were higher following disc trenching.

These results suggest that inverted site preparation using Kicken provides regeneration outcomes comparable to disc trenching under operational conditions, while potentially reducing the need for pre-commercial thinning due to lower birch regeneration.

Keywords: Artificial regeneration, growth responses, Kicken, mean annual growth, mechanical site preparation and natural regeneration.

Sammanfattning:

Mekanisk markberedning (MSP) används i stor utsträckning för att förbättra markförhållanden vid skoglig föryngring, där harvning är den vanligast förekommande metoden inom svenskt skogsbruk. Inversmarkberedning har föreslagits som en alternativ metod till traditionell markberedning, då tidigare studier visat på minskad störning av markvegetationen samtidigt som planttillväxten bibehålls eller förbättras. Effekterna av inversmarkberedning har dock huvudsakligen utvärderats under kontrollerade försöksförhållanden, och dess funktion under operativa skogsbruksåtgärder är fortfarande otillräckligt utforskat.

Denna studie utvärderar föryngringsresultat efter inversmarkberedning utförd med den kontinuerligt framryckande enheten Kicken, i jämförelse med harvning. Föryngringen inventerades på 30 operativa skogliga objekt föryngrade med tall (*Pinus sylvestris* L.) i Västerbottens län, med en beståndsålder mellan 6–11 år. Studien omfattade 15 objekt med inversmarkberedning och 15 med harvning, vilka valdes ut baserat på jämförbara ståndortsegenskaper observerade i fält. Planttillväxt och naturlig föryngring inventerades med hjälp av tio systematiskt utlagda provytor per objekt. Den statistiska analysen utfördes med en tvåvägs ANOVA, med markberedningsmetod och ståndorts index (SI) som fasta faktorer.

Inga statistiskt signifikanta skillnader påvisades i plantornas höjd, diameter eller toppskottslängd mellan markberedningsmetoderna, och motsvarande resultat erhölls för den genomsnittliga årliga höjd- och diameter tillväxten. Däremot uppvisade harvade objekt signifikant högre täthet av naturligt föryngrad björk (*Betula pubescens* Ehrh. och *Betula pendula* Roth). Den totala naturliga föryngringen skilde sig inte signifikant mellan metoderna, även om medelantalet naturligt föryngrade plantor var högre efter harvning.

Resultatet indikerar att inversmarkberedning med Kicken ger föryngringsresultat som är jämförbara med harvning under operativa förhållanden, samtidigt som behovet av framtida röjning potentiellt kan minska till följd av lägre björkföryngring.

Nyckelord: Artificiell föryngring, tillväxtrespons, Kicken, genomsnittlig årlig tillväxt, mekanisk markberedning och naturlig föryngring.

Acknowledgements

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Abbreviations

Abbreviation	Description
GNSS	Global Navigation Satellite System
MSP	Mechanical site preparation
RTK	Real Time Kinematic
SI	Site index
SLU	Swedish University of Agricultural Sciences

1. Introduction

1.1 Background

1.1.1 Historical context of Swedish forest regeneration

The forest management system used in Sweden today has its origins in the late 1800s. Clearcutting was introduced as an intensive forest management strategy to meet the increasing demand for timber during the industrial revolution (Lundmark et al. 2013). This shift from selective cutting to clearcutting enabled higher timber yields and supported Sweden's expanding export-oriented forest industry (Lindahl et al. 2017). During this period, concerns about deforestation spread across Europe as former forestland had been cleared for agriculture, while industrialization created a renewed demand for forest resources. These developments reshaped forest policy and motivated management systems that emphasized continuous regeneration and even-aged stand management (Lundmark et al. 2013).

The first modern forestry law was introduced in 1903 with the primary aim of ensuring continuous reforestation on privately owned forest land (Jansson 2011; Lindahl et al. 2017). It was followed by the Forestry act of 1923, which required forest owners to ensure adequate regeneration on stands left in an unsatisfactory condition after logging (Nylund 2009). For most of the 20th century, legislation strongly prioritized timber production, with the central goal of improving regeneration success and yield. This changed with the 1993 Forestry Act, which established that production and environmental objectives were to be regarded as equal. The updated legislation allowed for a broader range of silvicultural practices as long as regeneration success was achieved (Nylund 2009).

1.1.2 Regeneration practices used today

The main regeneration methods used in Sweden today are planting, sowing and intended natural regeneration. According to the 2022 regeneration statistics from the Swedish Forest Agency, 87% of clearcut areas were planted, while sowing and intended natural regeneration accounted for 4% and 7%, respectively (Skogsstyrelsen 2022). Artificial regeneration uses seedlings (planting) or seeds (sowing) at a higher cost but generally results in more reliable regeneration outcomes. Although planting is the most expensive regeneration method, it may be the most cost-effective when uncertainties and regeneration risks are taken into account (Ahtikoski et al. 2010). Artificial regeneration enables the use of genetically improved material through selection of seed sources, breeding or cloning which can enhance seedling performance and improve establishment in

competition with surrounding vegetation (Ackzell 1993). Intended natural regeneration, by contrast, is primarily conducted using seed-trees for Scots pine (*Pinus sylvestris* L.) or shelterwood for Norway spruce (*Picea* abies (L.) H. Karst), where the remaining trees provide seed material. Although this method involves the lowest regeneration cost, it limits the regeneration material to what is available on site and the regeneration result is dependent on the quality of the seed year (Miina & Saksa 2008)

Site preparation is another key practice to improve regeneration results and increase reforestation rates. In 2022, 87% of regenerated sites had undergone some form of site preparation prior to planting, sowing or natural regeneration (Skogsstyrelsen 2022). Site preparation reduces competition from vegetation and improves resources availability for seedlings (Hjelm et al. 2019). It has been shown to increase conifer seedling survival by 15-20% and height growth by 10-25% after 10-15 years (Sikström et al. 2020). In Northern Europe, site preparation is typically performed mechanically using various mechanical site preparation (MSP) methods, with disc trenching being the most common in Sweden. Other forms of mechanical site preparation are patch scarification, mounding and inverted site preparation. All methods are primarily used to enhance seedling survival and growth, with varying impact on soil disturbance (Krekula et al. 2018).

Disc trenching is the most used MSP method in Sweden. It creates three primary types of microsites: berms consisting of mixed mineral soil and organic material, furrows where the organic layer is removed and mineral soil is exposed, and the undisturbed areas between these (Hansson et al. 2018). The berms provide elevated planting spots composed of mineral soil on top of humus, creating favourable conditions for seedling establishment (Sikström et al. 2020). Removal of the organic layer also enables planting directly in the mineral soil, which reduces the risk of pine weevil damage and increases soil temperature, both contributing to higher survival rates (Sikström et al. 2020). Site preparation in general has also been shown to enhance overall seedling growth (Örlander et al. 1990).

1.1.3 Inverted site preparation

Inverted site preparation has gained increasing attention due to its reduced level of soil disturbance. Instead of creating continuous trenches, the method prepares discreate patches. Each patch of soil is scooped up, inverted, and placed back in the same spot, exposing loose mineral soil above the humus layer. This creates planting spots with improved water supply, nutrient availability, and increased

soil temperature, while minimizing disturbance to ground vegetation (Örlander et al. 1998)

Örlander et al. (1998) conducted a study comparing the establishment of *Pinus contorta* Douglas ex Loudon and *Picea abies* (L.) karst across several site preparation methods, including inverting, ploughing, mounding and disc trenching in northern Sweden. Inverting resulted in higher seedling survival rate and height growth over a 10-year period. These results reflect the favourable growing conditions created by inverting: good water availability, improved mineral nutrient supply, and higher soil temperatures, while limiting the overall site disturbance (Örlander et al. 1998).

1.1.4 Practical implication

Between 2015 and 2020, Kicken was the only continuously advancing, towed site preparation unit in operational use in Sweden capable of performing inverted site preparation. Other technical solutions, such as Karl-Oskar and other excavator-mounted implements (e.g. Bracke P11) were also able to create inverted planting spots, but differed in working method and were not continuously advancing towed units. Kicken was developed by Bracke in collaboration with SCA, Holmen, Sveaskog and a local entrepreneur in Östersund (Skyttmos Skogsentreprenad AB). It was specifically designed for use in reindeer herding areas, where an inverted scoop could be used to minimize disturbance to ground lichen (Skogsaktuellt 2014). Despite its relevance and intended environmental benefits, no studies have evaluated the long-term regeneration outcomes from sites prepared using this technical solution.

1.2 Problem statement

Mechanical site preparation aims to reduce competition from vegetation and improve seedling establishment by exposing mineral soil and modifying microsite conditions (Örlander et al. 1998). While disc trenching is effective, it can cause extensive and long-lasting disturbances to ground vegetation (Hjelm et al. 2025), with the estimated disturbed surface area being approximately 52% (33-70%) (Sikström et al. 2020). This is particularly a problem in reindeer herding areas where conventional mechanical site preparation restricts the reestablishment rate of ground vegetation (Roturier et al. 2011). This may have long-term consequences for reindeer grazing as, ground lichens recover slowly (Eriksson & Raunistola 1990).

Utilizing other site preparation methods in reindeer herding areas can limit the disturbance of ground lichen as well as enhance the reestablishment rate after disturbance. Finding suitable site preparation methods for reindeer herding areas

is of great interest, to find measures that ensures sufficient supply of ground lichen as well as enhance seedling establishment (Roturier et al. 2007).

Inverted site preparation offers a potentially less disruptive alternative, but existing studies have not evaluated the technique as implemented by the Kicken unit. Kicken produces inverted patches of approximately 0.25 m^2, which in theory would result in about 5% of the surface area being disturbed, assuming a planting density of 2 000 plants per hectare. Understanding whether inverting provides comparable or improved regeneration results and whether it sufficiently reduces soil disturbance under operational conditions, is essential for balancing forestry productivity with ecological and cultural values.

1.3 Aim and research questions

The primary objective of this thesis is to evaluate the regeneration outcome of inverted site preparation using Kicken. The evaluation will be based on comparison of seedling growth performance between inverted site preparation (performed using Kicken) and conventional disc trenching.

Regeneration results will be assessed based on three growth parameters:

1. Total seedling height
2. Leader shoot length
3. Stem diameter

In addition, the study examines whether the two site preparation methods differ in their influence on natural regeneration density and thus the potential need for pre-commercial thinning.

The regeneration outcome is evaluated through the following research questions:

- How does the site preparation method influence the height, diameter and leader shoot length of *Pinus sylvestris* (Scots pine) during the first 6-11 years of regeneration?
- How does the site preparation method influence the need for pre-commercial thinning due to natural regeneration during the first 6-11 years of regeneration?

1.4 Scope and Limitations

Field data were collected over a six-week period at 30 sites in Västerbotten: 15 sites with inverted site preparation using Kicken method and 15 with disc trenching. Kicken has mainly been used in reindeer herding areas, which has influenced the site selection toward inland regions such as Lycksele.

Control sites were selected based on similarity to inverted sites regarding soil type, moisture, vegetation, dominant tree species, slash removal, clear cutting year (±2 years), and absence of pre-commercial thinning. The study focused exclusively on sites regenerated with Scots pine on sandy soils with dry soil moisture conditions dominated by ground lichen, heather or lingonberry.

2. Materials and Methods

2.1 Study Area

The study was conducted in Västerbotten, Sweden, primarily within reindeer herding areas. Data was collected in three regions: Lycksele (majority of sites), Nordmaling, and Umeå. Soils at inverted sites consisted of medium-grained sediments and medium- to coarse-grained glacial till soils with dry moisture conditions. Ground vegetation was dominated by ground lichens, heather and/or lingonberry. All sites were planted or sown with Scots pine, within the period 2014-2019 (Table 1). All inverted- and control (disc trenched) sites are plotted out in figure 1.
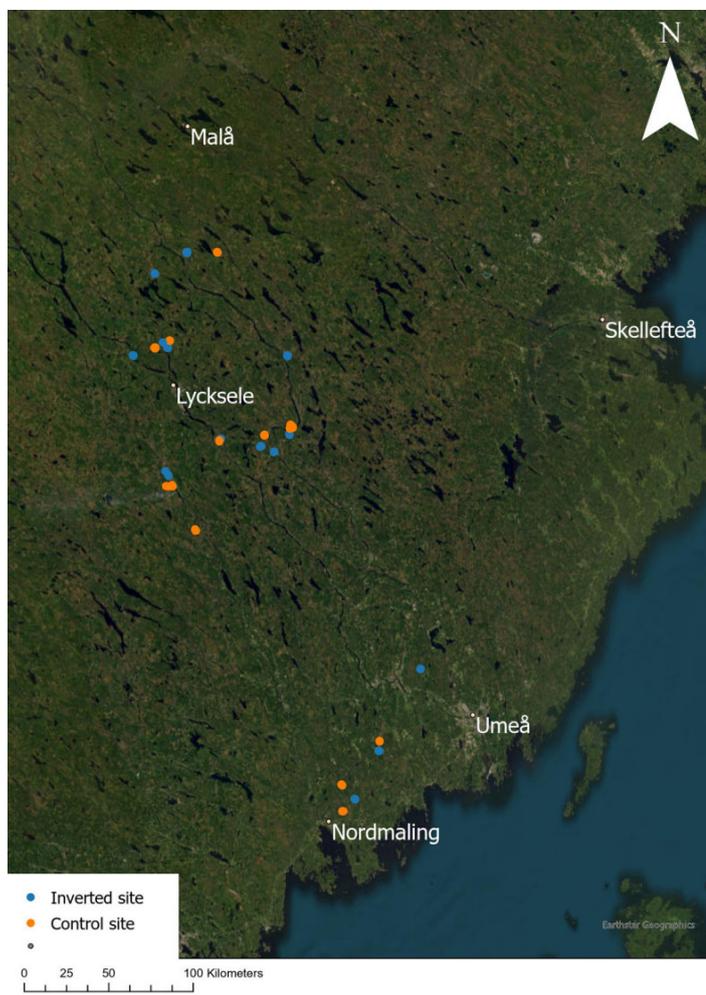
Figure 1: All inventoried disc trenched control sites (red) and all inventoried sites with inverted site preparation using Kicken method (blue).

2.2 Selection of sample sites

Sites prepared using inverted site preparation were identified through the contractor database ForestLink, where site preparation methods are documented. For each inverted site, a corresponding control site prepared using disc trenching was selected, primarily within a 5km radius. When no suitable control site was available within this distance, the search radius was gradually expanded.

Ten control sites were located within 10 km of their corresponding inverted sites. The remaining control sites were located at distances of 13, 18, 22, 35 and 66km, respectively. This resulted in an average distance of 13 km and a median distance of 6,7 km between paired inverted and control sites.

Control sites were selected to match inverted sites as closely as possible based on site characteristics assessed in the field. The criteria used to determine site similarity included:

- Soil type
- Soil moisture
- Ground vegetation
- Tree species
- Pre-commercial thinning
- Removal of slash
- Clear-cutting year (±2 years)

Soil type, ground vegetation and clear-cutting year were site characteristics that were allowed to vary between sites (Table 1), with field assessments conducted to limit these variations. The remaining site characteristics were fixed: soil moisture conditions had to be dry, the regenerated tree species had to be Scots pine, no pre-commercial thinning could have occurred, and slash had to be removed.

In total, thirty sites were selected, consisting of:
- 15 sites prepared using inverted site preparation (inverted)
- 15 sites prepared using disc trenching (Control)

Table 1: All sites included, with the varying site characteristics: MSP method, Planting year, Ground vegetation, Soil classification, Regeneration method, Harvesting year and Area (HA).

MSP method	Regeneration year	Ground vegetation	Soil classification	Regeneration method	Harvesting year	Area (Ha)
Inverted	2016	Lingonberry	Medium-grained sediment	Planted	2015	3.3
Inverted	2016	Lichen	Medium-grained sediment	Planted	2014	9.6
Inverted	2016	Lingonberry	Medium-grained sediment	Planted	2013	3.9
Inverted	2016	Lichen	Medium-grained glacial till	Planted	2014	6.5
Inverted	2016	Lichen	Medium-grained glacial till	Planted	2014	0.7
Inverted	2016	Lichen	Coarse-grained glacial till	Planted	2013	11.5
Inverted	2017	Lichen	Coarse-grained glacial till	Planted	2014	2.9
Inverted	2017	Lingonberry	Coarse-grained glacial till	Planted	2015	10
Inverted	2017	Lichen	Medium-grained glacial till	Planted	2015	6
Inverted	2018	Lichen	Medium-grained glacial till	Planted	2015	2.4
Inverted	2018	Heather	Medium-grained glacial till	Planted	2015	3.3
Inverted	2018	Lichen	Medium-grained glacial till	Planted	2015	4.1
Inverted	2018	Heather	Medium-grained glacial till	Planted	2015	1.1
Inverted	2019	Lichen	Medium-grained glacial till	Planted	2017	2
Inverted	2019	Lichen	Medium-grained glacial till	Planted	2017	5.8
Disc trenched	2014	Lingonberry	Coarse-grained glacial till	Planted	2013	9
Disc trenched	2014	Lichen	Coarse-grained glacial till	Sown	2014	13.1
Disc trenched	2015	Heather	Medium-grained sediment	Sown	2014	2.3
Disc trenched	2015	Heather	Medium-grained sediment	Planted	2013	6.9
Disc trenched	2015	Lingonberry	Coarse-grained glacial till	Planted	2014	3.2
Disc trenched	2016	Heather	Coarse-grained glacial till	Planted	2014	3.6
Disc trenched	2016	Lichen	Coarse-grained glacial till	Planted	2015	7.8
Disc trenched	2017	Lichen	Coarse-grained glacial till	Sown	2016	12.3
Disc trenched	2017	Heather	Medium-grained glacial till	Planted	2016	9.3
Disc trenched	2017	Lichen	Medium-grained glacial till	Planted	2016	14.1
Disc trenched	2017	Lichen	Coarse-grained glacial till	Planted	2015	28
Disc trenched	2017	Heather	Medium-grained glacial till	Sown	2015	8.7
Disc trenched	2018	Lichen	Medium-grained glacial till	Planted	2017	2.5
Disc trenched	2018	Lichen	Medium-grained glacial till	Planted	2017	2.1
Disc trenched	2018	Lichen	Coarse-grained glacial till	Planted	2017	3.8

2.3 Field work

Field work was conducted over a five-week period, from September 16th to October 17th. Data were collected from 30 sample sites in Västerbotten County. Six sites were inventoried in the Umeå-Nordmaling area in September, representing three inverted and three control sites. The remaining 24 sites were located in Lycksele, where data collection was carried out in October, representing twelve inverted and twelve control sites.

Each site was inventoried using ten circular sampling plots established with a centre pole and a 2.52 m string radius, resulting in plots with an area of approximately 20 m^2. Plot locations were systematically predefined in Envisim and imported to Esri field maps prior to fieldwork. An RTK-GNSS receiver (Real Time kinematic Global Navigation Satellite System) with a positional accuracy of approximately 1.4 cm, was used to locate pre-generated sampling plots in the field.

2.4 Data collection

2.4.1 Stem selection

Main stems were defined as Scots pine seedlings located within prepared microsites. In cases where multiple seedlings where present within a microsite, stem selection followed different criteria depending on site treatment. In inverted plots, the largest stem by height within the inverted patch was selected. In disc trenched plots, the largest stem by height within a 2 m planting interval was selected, corresponding to the average planting interval across inventoried sites. Stems not meeting these criteria were regarded as naturally regenerated and as stems to be removed during pre-commercial thinning. The naturally regenerated stems were counted for each species but excluded from growth measurements.

2.4.2 Growth measurements

The following measurements were collected for each main stem:
- Total height, measured using a measuring pole with 5cm increments
- Leader shoot length, measured using the same measuring pole
- Stem diameter was measured at breast height (DBH), using a caliper at 1.3 m height for stems taller than 1.4 m.

Each main stem was georeferenced using RTK-GNSS receiver in Esri Field Maps, where all associated measurements were recorded for each individual stem. Example for field measurement and spatial registration are shown in figure 2.

Figure 2: Left: measurement of leader shoot using measuring pole. Right: plotted out main stems (red dots) and furrows (brown lines) in Esri Field Maps

2.4.3 Assessment of damage

Seedling damage caused by browsing or fungal infection was assessed in the field in order to exclude stem damage as a confounding factor in growth analyses. Seedlings damaged by browsing and/or fungal infections were categorized according to the observed severity of damage. Browsing of the leader shoot affects the growth potential of the current year; therefore, seedlings with damaged leader shoots were regarded as strongly affected by browsing. Seedlings with browsing limited to lateral shoots were regarded as weakly affected, as this does not directly affect the growth potential of the damaged seedling (Palmer & Truscott 2003).

Several fungal infections can be visually observed on Scots pine, including *Diplodia sapinea* (Fr.) Fuckel *(Diplodia tip blight)*, *Gremmeniella abietina* (Lagerb.) Morelet (Scleroderris canker), *Gremmenia infestans* (P.Karst.) Morelet (Snow blight) and *Cronartium pini* (Wild,) Jørst (Scots pine blister rust) (*Svampskador på träd* n.d.). These fungal infections have been shown to reduce growth by affecting shoots and/or needles of Scots pine (Martinsson & Nilsson 1987; Ranta & Saloniemi 2005; Brodde et al. 2023).

Fungal infections were assessed visually in the field and categorized based on the severity. Infections were not classified by species, but rather by degree of infection. Seedlings were categorized as strongly affected when leader shoot damage was present and/or when more than 30% of the green biomass was

affected. Seedlings without leader shoot damage and with less than 30% of the green biomass affected were categorized as weakly affected.

A summary of criteria used to define main stems, diameter, browsing severity and degree of fungal infection is presented in Table 2.

Table 2: Criteria for determining main stems, diameter, browsing severity and degree of fungal infection

Criteria	Level	Inverted	Disc trenched control
Main stem		Largest stem in the inverted patch	Largest stem within a 2 m planting interval
Diameter		Seedling height >1,4m	Seedling height >1,4m
Browsing	Strong	Leader shoot browsing	Leader shoot browsing
	Weak	Lateral Browsing	Lateral Browsing
Fungal infection	Strong	Leader shoot damage and/or >30% of green mass being affected	Leader shoot damage and/or >30% of green mass being affected
	Weak	No Leader shoot damage and <30% of green mass being affected	No Leader shoot damage and <30% of green mass being affected

2.5 Data Analysis and source of errors

This thesis compares growth performance and the natural regeneration density between two site preparation methods. Growth parameters (total height, leader shoot length and stem diameter), mean annual growth (mean annual height and diameter growth) and natural regeneration (total natural regeneration and birch regeneration) were analysed using a two-way analysis of variance (ANOVA), with site preparation method and site index (SI) class as fixed factors.

Site index was included as a categorical factor to account for variation in site productivity among sample sites. SI was derived for each site using stand height and age data from the Swedish University of Agricultural Sciences (SLU) forest map from 2010 in combination with height development curves provided by the Swedish Forestry Agency (Hägglund & Lundmark 2021). The SLU forest map is based on field inventory data combined with aerial photography and satellite imagery. Mean values of stand height and age were calculated across the ten sample plots within each site and used with the height development curves to derive a single site-level SI. As SI represents an indirect estimate of site conditions, it may not fully capture microsite-level variations, which should be considered when interpreting SI-related effects in the analysis. Differences between site preparation methods and SI class were evaluated at a 95% confidence level ($p < 0.05$), while tendencies were noted at a 90% confidence level ($p < 0.1$).

2.5.1 Adjustment of plant age

To improve comparability between site preparation methods, plant age was adjusted when analysing mean annual growth, based on regeneration method. For planted sites, seedlings were assumed to be one year older than the recorded year of regeneration, reflecting the nursery growth period prior to planting. For sown sites, plant age corresponded directly to the recorded year of regeneration.

This adjustment was applied consistently across all sites and was intended to better represent biological age rather than calendar age. However, this approach introduces uncertainty, as variation in nursery practices, seedling size at planting, and early establishment success were not explicitly accounted for.

2.5.2 Sources of measurement error

Height and leader shoot length were measured in the field using a measuring pole with 5 cm increments. This measurement resolution introduces an uncertainty of ±2.5 cm. In addition, ground structure at the measuring position may affect pole placement, potentially resulting in measurement deviations. To reduce systematic error, calibrations were conducted continuously during the field inventory using a measuring tape to verify both total height and leader shoot length measurements.

Stem diameter was measured at breast height (1.3m) for main stems exceeding 1.4 m in height, using a caliper oriented towards the centre of the sample plot. Measurement uncertainty primarily relates to ground irregularities affecting the exact positioning of the measurement height on the stem. Calibration measurements were conducted throughout the field inventory using a measuring tape to verify diameter measurements at 1.3 m height.

Sampling plot locations and main stem positions were recorded using an RTK-GNSS-receiver. The GNSS-receiver system has a positional accuracy of approximately ±1.4 cm. This uncertainty was considered negligible relative to other sources of spatial error, such as positioning of the GNSS-receiver within the plot. To minimize spatial error, the GNSS-receiver was positioned as centrally as possible within each sampling plot and oriented towards the plot centre when registering individual main stems.

2.5.3 Main stems

A total of 1207 stems were measured as main stems, with 599 from inverting and 608 from disc trenching. Damaged stems were removed, with 278 stems being strongly affected by browsing, 24 strongly affected by fungal infection and 12 affected strongly by both. After removal of damaged stems, 469 inverted stems and 424 disc-trenched stems remained in the dataset used for analyses of height

and leader shoot length. The same removal procedure was applied to the diameter data, with additional removal of stems below 1.4 m in height, resulting in 422 inverted and 341 disc-trenched data points used for the statistical analysis of diameter. Figure 3 presents scatter plots of mean diameter, height and leader shoot length measured at each individual site. A complete table of the data used in the analysis of growth parameters is provided in Appendix 1.

Figure 3: scatter plot showing mean stem diameter (cm), height (m), and leader shoot length (cm) for each adjusted stand age (7-12). Values represent site-level means based on ten sample plots per site. Blue points indicate inverted soil preparation, and red points indicate disc trenching (control)

2.5.4 Naturally regenerated stems

The dataset for naturally regenerated stems consisted of 1433 stems of Scots pine, birch and Norway spruce. Inverted sites consisted of a total of 616 stems, including 519 Scots pine, 80 birch and 17 Norway spruce stems. Disc-trenched control sites consisted of a total of 817 stems, including 627 Scots pine, 181 birch and 9 Norway spruce stems. Figure 4 presents scatter plots visualising the mean number of naturally regenerated stems at each individual site. A complete table for the data used in analysing the natural regeneration can be seen in Appendix 2.
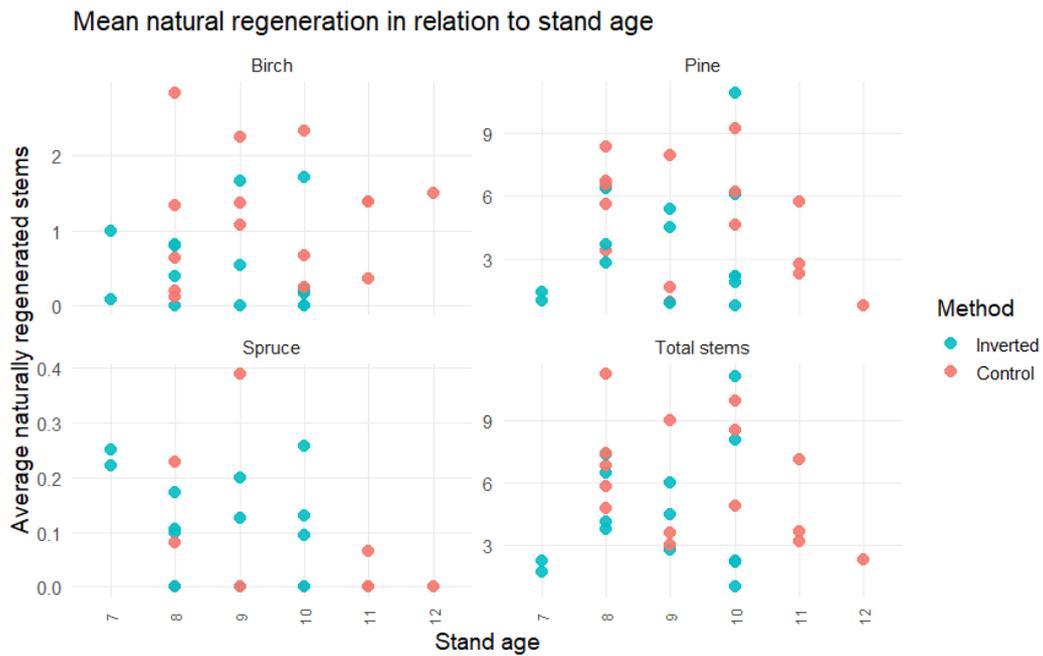
Figure 4: scatter plot showing mean natural regeneration of Scots pine, birch, Norway spruce and total (stems) for each adjusted stand age (7-12) Values represent site-level means based on ten sample plots per site. Blue points indicate inverted soil preparation, and red points indicate disc trenching (control)

3. Results

3.1 Summary table

For growth variables, the mean values were similar between methods within the same SI class, although disc-trenched sites showed slightly higher variation, particularly in lower SI classes (Table 3). Mean annual height and diameter growth of the main stems showed minor differences between methods within the same SI class, with overlapping ranges in all comparisons (Table 3).

Natural regeneration showed larger differences between methods (Table 4). Disc-trenched stands consistently showed higher mean number of stems, for the total natural regeneration and higher mean birch regeneration across SI classes compared to inverted stands, although variability was substantial in both methods. The summary table indicate that early seedling growth parameters are comparable between the two site preparation methods (Table 3), while natural regeneration (especially birch) tends to be more abundant in disc-trenched stands (Table 4).

Table 3: Summary of mean growth variables of main stems for each site index (SI) class and site preparation method. Values are presented as means with standard deviation (SD) in parentheses. Variables include mean height, mean diameter, mean leader shoot length, mean annual height growth and mean annual diameter growth. n represents the number of sites within each SI class, and method refers to inverted site preparation or disc trenching (control).

SI_class	n	Method	Mean height (SD)	Mean diameter (SD)	Mean leader shoot length (SD)	Mean annual height growth (SD)	Mean annual diameter growth (SD)
SI12_14	3	Inverted	2.282 (0.555)	2.560 (0.758)	42.556 (7.253)	0.228 (0.056)	0.256 (0.076)
SI12_14	6	Control	2.037 (1.048)	2.305 (1.445)	41.183 (9.951)	0.215 (0.080)	0.240 (0.115)
SI14_16	5	Inverted	2.23 (0.771)	2.342 (1.129)	43.779 (9.704)	0.241 (0.071)	0.253 (0.111)
SI14_16	3	Control	2.012 (0.778)	2.303 (1.011)	42.379 (3.729)	0.221 (0.068)	0.253 (0.091)
SI16_18	7	Inverted	1.976 (0.743)	2.146 (1.284)	42.575 (9.824)	0.239 (0.060)	0.256 (0.114)
SI16_18	6	Control	2.137 (1.081)	2.466 (1.876)	41.615 (10.870)	0.206 (0.077)	0.233 (0.147)

Table 4: Summary of natural regeneration variables for each site index (SI) class and site preparation method. Values are presented as means with standard deviation (SD) in parentheses. Variables include mean total natural regeneration and mean natural regeneration of birch. n represents the number of sites within each SI class, and method refers to inverted site preparation or disc trenching (control).

SI_class	n	Method	Mean total natural regeneration (SD)	Mean natural regeneration of birch regeneration (SD)

SI12_14	3	Inverted	1.790	0.067
			(0.715)	(0.115)
SI12_14	6	Control	6.107	0.740
			(2.023)	(0.589)
SI14_16	5	Inverted	5.571	0.568
			(3.671)	(0.684)
SI14_16	3	Control	8.028	1.626
			(4.402)	(1.111)
SI16_18	7	Inverted	4.617	0.647
			(2.318)	(0.593)
SI16_18	6	Control	5.045	1.391
			(2.418)	(0.843)

3.2 Growth responses (height, diameter, and leader shoot)

As shown in Table 5, none of the growth variables differed significantly between the inverted and control treatments (all $p > 0.695$). Similarly, SI class had no significant effect on any growth variable (all $p > 0.960$) and no interaction effects between method and SI class were detected. These results indicate that early seedling growth was largely independent of both site preparation method and site index conditions.

Table 5: Results from two-way ANOVA analyses showing the effects of site preparation method (Inverted or Control), site index class (SI 12-14; 14-16; 16-18), and the interaction between method and SI class on height, diameter, and leader shoot length. p < 0.05 indicates statistical significance.

Response variable	Effect	df	F	p-value
Height	Method	1	0.024	0.878
	SI class	2	0.035	0.966
	Method × SI class	2	0.174	0.841
Diameter	Method	1	0.022	0.884
	SI class	2	0.009	0.991
	Method × SI class	2	0.113	0.894
Leader shoot	Method	1	0.157	0.695
	SI class	2	0.041	0.960
	Method × SI class	2	0.002	0.998
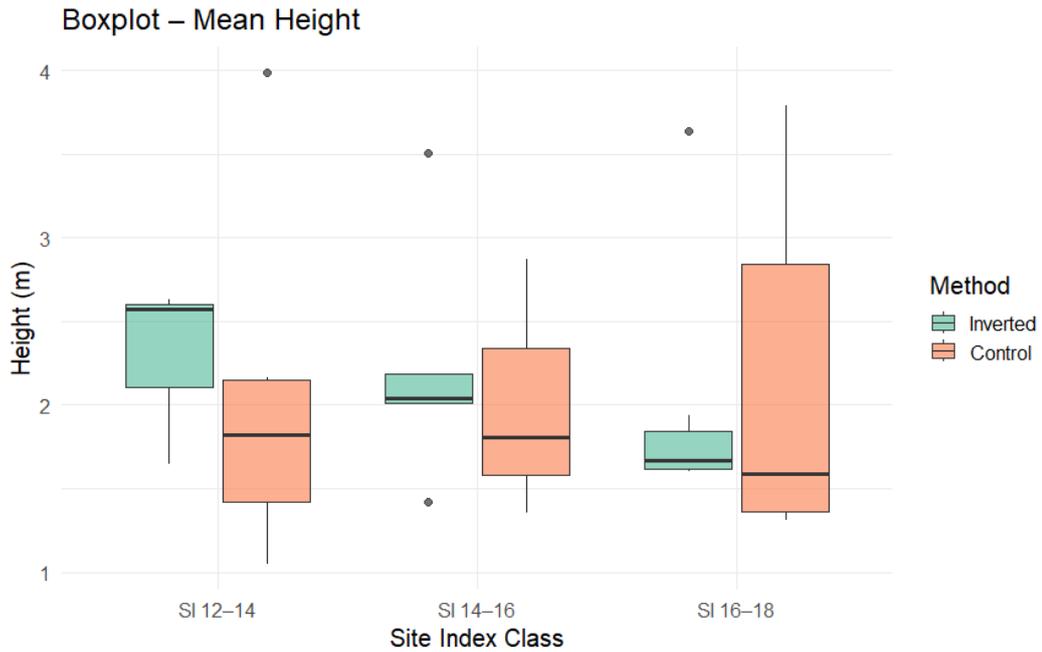
Figure 5. Boxplots showing the distribution of site mean values for height across site index classes (SI 12-14, SI 14-16, SI 16-18) and method (Inverted and disc trenched control). Boxes represent the interquartile range (25th-75th percentiles), with black horizontal line indicating the median. Whiskers extend to values within 1.5 times the interquartile range. Points outside the whiskers represent outliers.
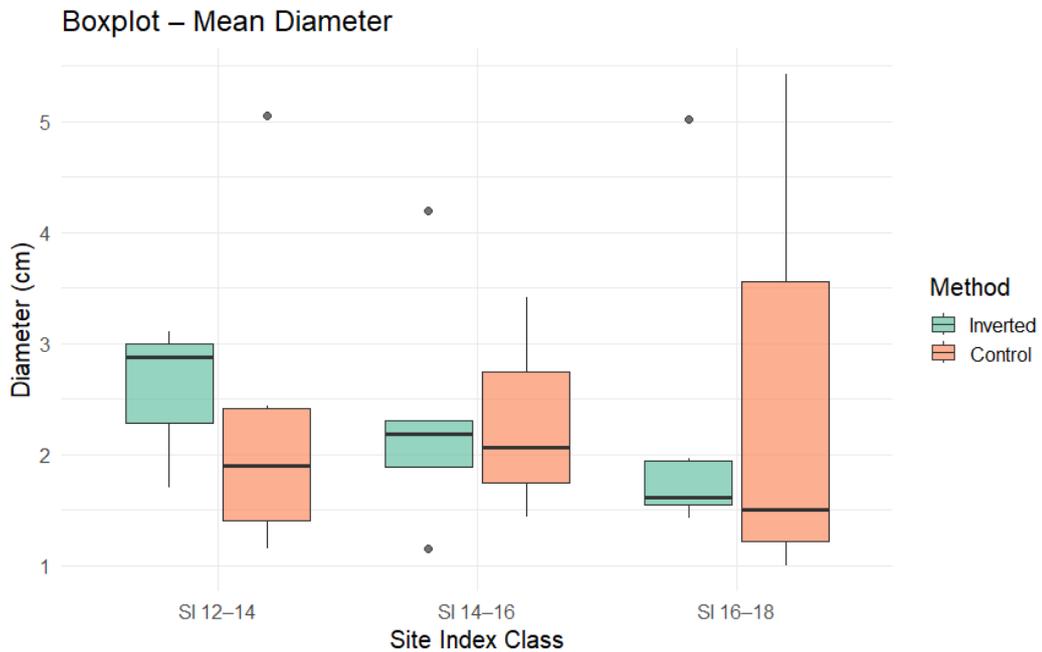
Figure 6. Boxplots showing the distribution of site mean values for diameter across site index classes (SI 12-14, SI 14-16, SI 16-18) and method (Inverted and disc trenched control). Boxes represent the interquartile range (25th-75th percentiles), with black horizontal line indicating the median. Whiskers extend to values within 1.5 times the interquartile range. Points outside the whiskers represent outliers.

Figure 7. Boxplots showing the distribution of site mean values for leader shoot length across site index classes (SI 12-14, SI 14-16, SI 16-18) and method (Inverted and disc trenched control). Boxes represent the interquartile range (25th-75th percentiles), with black horizontal line indicating the median. Whiskers extend to values within 1.5 times the interquartile range. Points outside the whiskers represent outliers.

3.3 Mean annual growth (mean annual height and diameter growth)

As shown in Table 6, none of the response variables differed significantly between the methods. SI class had no significant effect on either response variable (all $p > 0.953$) and no interaction effects between method and SI class were detected (all $p > 0.963$). These results indicate that the mean annual height and diameter growth was largely independent of both site preparation methods and site index conditions.

Table 6: Results from two-way ANOVA analyses showing the effects of site preparation method (Inverted or Control), site index class (SI 12-14; 14-16; 16-18), and the interaction between method and SI class on mean annual height growth and mean annual diameter growth of Scots pine. $p < 0.05$ indicates statistical significance and are shown in bold, and marginally significant values ($0.05 < p < 0.10$) are underlined.

Response variable	Effect	df	F	p-value
Height / age	Method	1	0.946	0.340
	SI class	2	0.031	0.970
	Method × SI class	2	0.053	0.948
Diameter / age	Method	1	0.130	0.723

SI class	2	0.007	0.993
Method × SI class	2	0.023	0.977

Figure 8. Boxplots showing the distribution of site mean values for annual height growth across site index classes (SI 12-14, SI 14-16, SI 16-18) and method (Inverted and disc trenched control). Boxes represent the interquartile range (25th-75th percentiles), with black horizontal line indicating the median. Whiskers extend to values within 1.5 times the interquartile range. Points outside the whiskers represent outliers.

Figure 9. Boxplots showing the distribution of site mean values for annual diameter growth across site index classes (SI 12-14, SI 14-16, SI 16-18) and method (Inverted and disc trenched control). Boxes represent the interquartile range (25th-75th percentiles), with black horizontal line indicating the median. Whiskers extend to values within 1.5 times the interquartile range. Points outside the whiskers represent outliers.

3.4 Natural regeneration (total and birch)

As shown in Table 7, total natural regeneration did not differ significantly between the two site preparation methods (p = 0.113). SI class and the interaction between SI class and method were also non-significant. In contrast, the natural regeneration of birch differed significantly between methods, with control sites showing higher mean birch regeneration than inverted sites (Table 7; p = 0.012). SI class showed a marginal but non-significant trend (Table 7; p = 0.060), suggesting that birch regeneration may increase slightly with higher SI, although the effect was not statistically supported. No interaction effects between method and SI class were observed. These results indicate that the site preparation method had a significant effect on birch regeneration and a limited influence on total natural regeneration.

Table 7: Results from two-way ANOVA analyses showing the effects of site preparation method (Inverted or Control), site index class (SI 12-14; 14-16; 16-18), and the interaction between method and SI class on total natural regeneration and natural regeneration of birch. p < 0.05 indicates statistical significance. Significant values (p <

0.05) are shown in bold, and marginally significant values (0.05 < p < 0,10) are underlined.

Response variable	Effect	df	F	p-value
Total natural regeneration	Method	1	2.701	0.113
	SI class	2	2.220	0.130
	Method × SI class	2	0.975	0.392
Birch natural regeneration	Method	1	7.295	**0.012**
	SI class	2	3.172	<u>0.060</u>
	Method × SI class	2	0.198	0.822

Figure 10. Boxplots showing the distribution of site mean values for total natural regeneration across site index classes (SI 12-14, SI 14-16, SI 16-18) and method (Inverted and disc trenched control). Boxes represent the interquartile range (25th-75th percentiles), with black horizontal line indicating the median. Whiskers extend to values within 1.5 times the interquartile range.
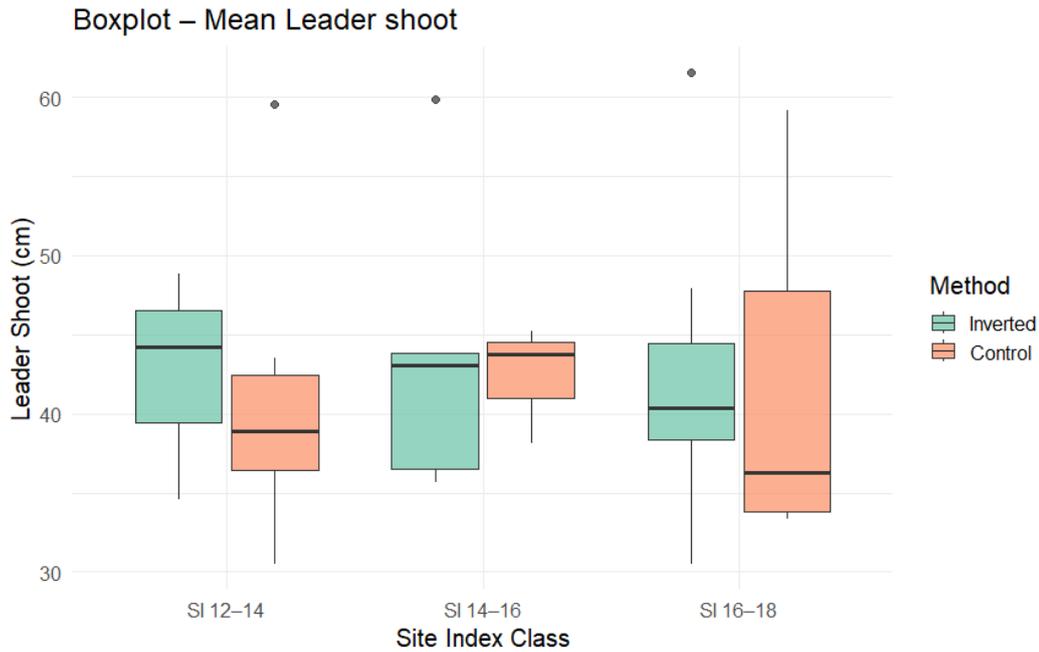
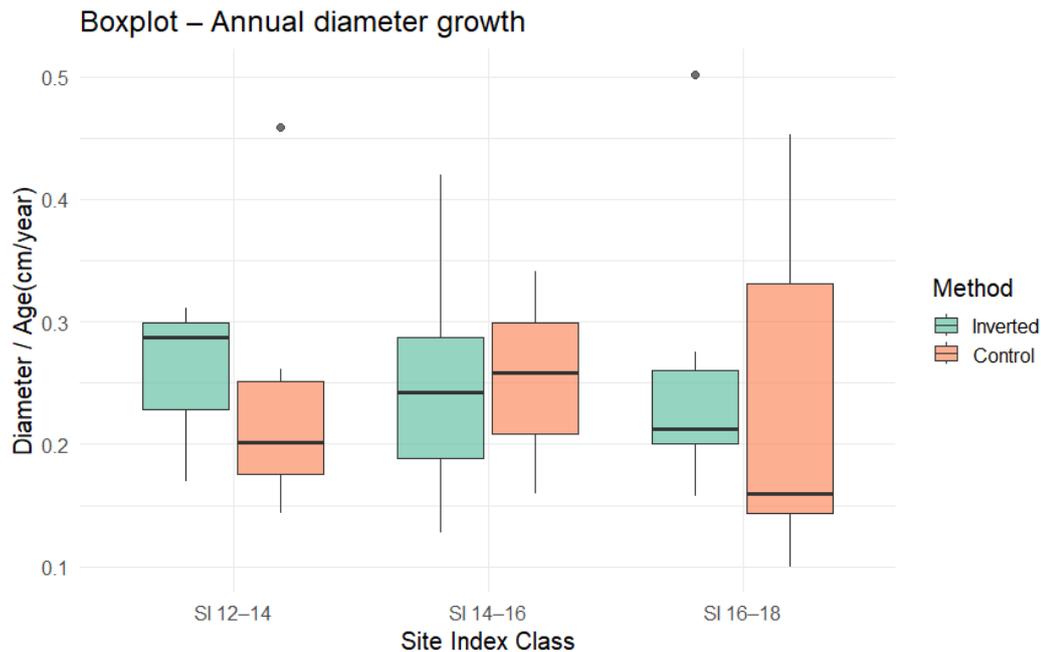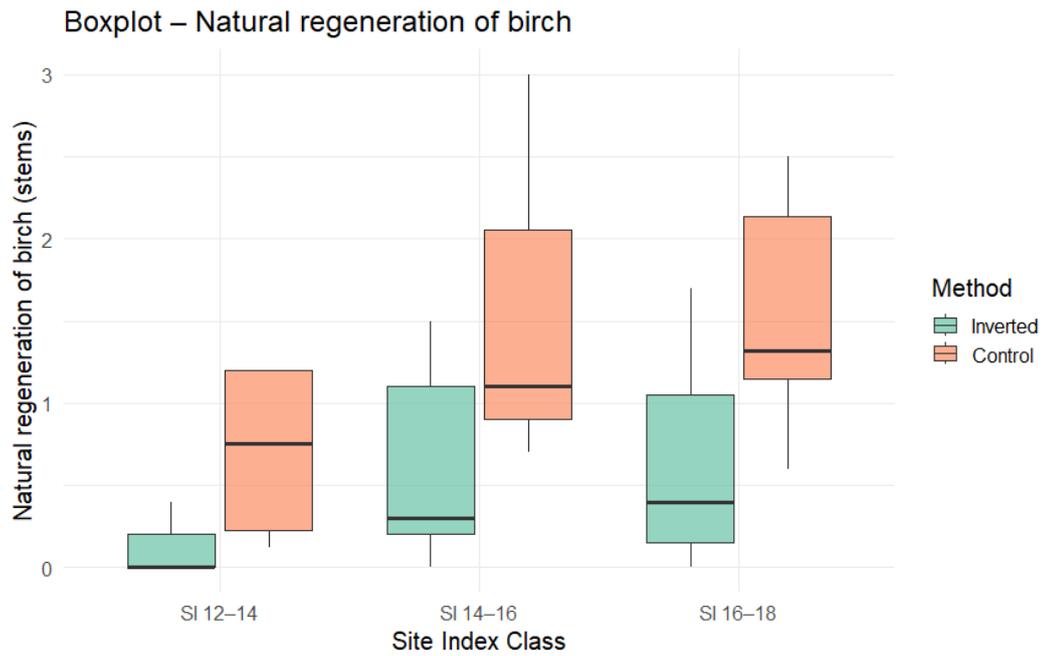*Figure 11. Boxplots showing the distribution of site mean values for natural regeneration of birch across site index classes (SI 12-14, SI 14-16, SI 16-18) and method (Inverted and disc trenched control). Boxes represent the interquartile range (25th-75th percentiles), with black horizontal line indicating the median. Whiskers extend to values within 1.5 times the interquartile range.*

4. Discussion

4.1 Interpretation of Results

4.1.1 Overview of main findings

This thesis investigated regeneration outcomes following inverted site preparation using Kicken in comparison with disc trenching. Overall, no statistically significant differences in growth responses were detected between the two MSP methods when stand age was not considered. Similar results were obtained when accounting for stand age, as neither mean annual height growth nor the mean annual diameter growth differed significantly between the methods. However, significant differences were found in the natural regeneration of birch, with higher regeneration densities on disc-trenched sites, whereas no significant difference were observed in total natural regeneration.

Differences between the results of this thesis and those reported in previous studies may partially be explained by methodological differences. Much of the earlier research has been conducted under controlled experimental conditions, where study sites were selected prior to site preparation and treatments were applied using excavators or specialised machinery not commonly used in large-scale forestry operations (Örlander et al. 1998; Hallsby & Örlander 2004; Laine et al. 2020). In contrast, this study was conducted on operational sites that had already been prepared using Kicken, thereby providing results that more reflect large-scale forestry practices.

4.1.2 Growth responses

No significant difference in growth responses were detected between the two site preparation methods, indicating that the choice of method did not influence seedling height, diameter or leader shoot length of inventoried Scots pine seedlings. These findings deviate from earlier research by Örlander et al. (1998), who reported a significant increase in growth following inverting compared with disc trenching. That study examined the volume development of lodgepole pine and Norway spruce over a 10-year period and demonstrated superior stem volume and height development after inverting.

The deviating result in growth responses in this thesis can be explained by findings from other studies that reported similar outcomes, where no significant differences in growth responses were detected between site preparation methods.

These studies suggested that factors such as insecticide treatment, planting spot and weather conditions during the planting year were more important factors for seedling growth than site preparation method (Wallertz et al. 2018; Nordin et al. 2022).

The observed difference may also be influenced by an overrepresentation of older stands on disc-trenched sites (figure 3), where height and diameter are likely affected by a longer growing period. The lack of significant differences in leader shoot length may further be explained by a decreasing effect of site preparation beyond the early development stage (Johansson et al. 2013). Örlander et al. (1998) collected their first measurements after five years and their final measurements after ten years, calculating growth over five-year intervals. In contrast, this thesis measured the leader shoot growth of the current year in seedlings aged between six and eleven years old. This methodological difference may partly explain the deviating results in leader shoot length.

The analyses also showed that the investigated growth parameters were largely independent of site index conditions. This can primarily be explained by the method used to derive the site index class, as it represents an indirect estimate of site productivity. The site index was obtained using height and age data from the 2010 SLU forest map, together with height development curves from the Swedish Forest Agency (Hägglund & Lundmark 2021). A limitation of this approach is the data quality of both height and age, as these parameters exhibit substantial standard deviations. Height had a standard deviation of 5.8 m, while age had a standard deviation of 38 years, resulting in considerable variability in the dataset and directly affecting the calculated site index.

Another factor that may partially explain why growth parameters were largely independent of site index conditions is that this thesis focused on the regeneration phase. Site index is designed to describe the long-term site productivity based on dominant height at a reference age (Hägglund & Lundmark 2021). Growth of young seedlings is often constrained by physiological establishment processes, such as root development, rather than by the potential long-term productivity potential of the site (Grossnickle 2012). Furthermore, site preparation can create relatively homogenous and favourable microsite conditions, which may reduce variation between SI classes (Örlander et al. 1998).

Together, these factors may explain why site index effects were not statistically significant at this early development stage.

Although no statistically significant difference were found, certain patterns were still observable. Control sites displayed greater variability in mean growth values across all growth parameters, particularly at lower site index levels. This increased variation may partially be explained by the fact that four of the control sites were established through sowing rather than planting. Previous studies have reported greater growth responses in planted Scots pine seedlings compared with sown seedlings (Mäkitalo 1999). This likely contributed to increased variability within the lower site index classes, as two of the six control sites in SI 12 – 14 were sown, compared with one of three in SI 14 -16 and one of six in SI 16 – 18. The uneven distribution of sown stands between SI classes may therefore have amplified the variability observed in the control treatment, especially in SI 12 – 14 and SI 14 – 16.

4.1.3 Mean annual growth

No statistically significant differences in mean annual height growth were detected between the two site preparation methods. This indicates that inverted site preparation did not result in higher mean annual height development compared to disc trenching under the conditions of this study. Although previous studies have reported enhanced early height growth following inverting Örlander et al. (1998) and Johansson et al. (2013), such effects were not detectable in this study.

The absence of a difference in mean annual height growth may be related to the age of the inventoried Scots pine seedlings. Örlander et al. (1998) found increased height growth during the first 10-years, following inverting. Johansson et al. (2013) found no significant difference in height development at the seedling age between 14-18 years old. These studies suggest that height growth is highest during early development stages and decreases as seedling mature, which may reduce detectable differences later in stand development.

Similar patterns have been observed when comparing the seedling growth of Norway spruce during a five-year period following inverting and mounding. Hallsby & Örlander (2004) found that mounding restricted the seedling growth during the first three years after planting, while both treatments resulted in similar growth responses during the final two years. This suggests that inverted site preparation may provide favourable establishment conditions during early development stages, whereas its effect on height growth diminishes as seedlings mature.

Furthermore, a review by Sikström et al. (2020) suggested that growth responses to mechanical site preparation (MSP) are often temporary. This conclusion was based on several long-term studies, including (Johansson et al. 2013), (Fries 1993) and (Hansson & Karlman 1997). Johansson et al. (2013) reported that mounding or inverted site preparation resulted in approximately 20% greater height growth in Norway spruce compared to no site preparation up to 14 years after planting, whereas no significant difference was observed between ages 14-18. Similarly, Hansson & Karlman (1997) found that height growth responses following disc trenching and patch scarification declined over time, with relative differences decreasing after 13-18 years. Together, these findings indicate that MSP primarily enhances early height growth during the first 10-15 years after planting. Beyond this period, height differences may persist, but no additional growth advantage will be contributed from site preparation.

No statistically significant differences in mean annual diameter growth were detected between the site preparation methods, which is consistent with the absence of differences observed for mean annual height growth. Although previous studies have reported increased diameter growth following inverted site preparation associated with enhanced height growth (Hjelm et al. 2019), such patterns were not evident in this study. This may partially be explained by the decreasing effect of site preparation beyond the early development stage (Hallsby & Örlander 2004; Johansson et al. 2013), as well as by a small data set being used for diameter, since diameter was only measured on stems taller than 1.4 m.

4.1.4 Density of naturally regenerated stems

Significant differences were detected in the natural regeneration of birch, with disc-trenched sites exhibiting higher densities of naturally regenerated birch compared to inverted sites. This result is consistent with previous studies reporting increased birch regeneration following site preparation methods that create larger areas of exposed mineral soil, such as spot mounding, compared to inverting (Laine et al. 2020). Site preparation improves microsite conditions not only for planted seedlings but also for the germination of naturally dispersed seeds, thereby promoting regeneration of deciduous species such as birch (Karlsson & Örlander 2000; Lehtosalo et al. 2010).

In theory spot mounding creates soil disturbance patches twice the size of those produced by inverting, as the excavated soil is placed adjacent to the planting spot rather than returned to the same position. This increases the availability of favourable microsites for seed germination (Laine et al. 2020). Although this thesis compared inverting with disc trenching rather than spot mounding, the observed differences in birch regeneration may similarly be explained by disc

trenching creating a larger proportion of exposed mineral soil and thus more favourable germination sites for birch seeds. Consequently, disc-trenched sites may require an increased need for pre-commercial thinning. It should be noted, however, that the density of naturally regenerated birch is strongly influenced by seed year, with lower birch regeneration expected following poor seed years (Karlsson et al. 2002). As the sites representing the different site preparation methods were not located at identical geographical positions and were not prepared in the same year, variation in seed year may have contributed to the observed difference.

Although no statistically significant differences in birch regeneration were found between site index classes ($p = 0.060$), a weak positive trend suggest higher regeneration at higher site indexes. As seedling establishment is often limited by physiological constraints rather than long-term site productivity, this trend may reflect factors correlated with site index rather than site productivity itself. A previous study has reported increased birch regeneration on sites with higher soil moisture (Karlsson et al. 1998), a factor that may also influence site index. Thus, the observed trend may be related to greater water availability at higher site indexes rather than the site index itself.

For total natural regeneration, no significant differences were observed between site preparation methods ($p = 0.113$). This result differs from findings by Laine et al. (2020), who reported significant differences in total natural regeneration between site preparation methods. One possible explanation for the deviating results is variation in Scots pine seed years, which can influence the total regeneration (Karlsson et al. 2002). The observed difference may also be related to differences in regeneration method rather than by site preparation alone. Four of the disc-trenched sites were regenerated by sowing rather than planting. Under favourable conditions, recommended sowing density is approximately 45 000 seeds per hectare (Bergsten & Sahlén 2013), compared to an average planting density of around 2 000 plants per hectare in this thesis. This difference in initial regeneration density may have contributed to higher numbers of Scots pine seedlings on disc-trenched sites, independent on the site preparation method itself.

4.2   Implications for forest management

This thesis was conducted in cooperation with another master's student (Turesson 2026) who investigated soil disturbances generated by the two site preparation methods. That study demonstrated significant differences in soil disturbances, with control sites exhibiting higher levels of disturbance.

Taken together, the results from that study and the findings of this thesis indicate that inverted site preparation creates planting spots of comparable quality to those produced by disc trenching, while resulting in lower requirements for pre-commercial thinning and reduced soil disturbance. These findings suggest that inverted site preparation may represent a suitable site preparation method, particularly in reindeer herding areas where minimising soil disturbances is prioritized.

4.3 Limitations

The method used in this thesis is consistent with previous studies evaluating regeneration outcomes, where growth is assessed using total height, leader shoot length and stem diameter. However, the results differ from several other studies evaluating inverted site preparation, which have reported increased growth compared to other site preparation methods.

While this approach increases practical relevance, it also limited site selection, as inverted sites were predetermined and suitable disc trenched control sites had to be matched based on observed site characteristics. This matching process may have resulted in variation in site conditions between treatment groups, potentially influencing growth parameters independently of site preparation method. Consequently, the selection of control sites led to variation in both site index and regeneration method between groups. Although no significant relationship was observed between site index and the analysed response variables, differences in regeneration method may have influenced growth responses, mean annual growth rates and natural regeneration density.

A total of 30 sites were inventoried, consisting of 15 inverted and 15 disc-trenched sites located in Västerbotten County. The size and geographic extent of the dataset were constrained by the timeframe of the thesis. A larger dataset, covering a broader region would have improved the statistical power and allowed for greater flexibility in excluding divergent sites without substantially affecting the analysis.

4.4 Future research

The results of this thesis support previous research on inverted site preparation, showing a significant difference in the regeneration of birch as well as tendencies toward reduced total natural regeneration compared to disc trenching. Previous studies have, however, also reported significant differences in height and diameter

growth (Hjelm et al. 2019), a pattern that was not observed in this thesis. This suggests that further research is needed to determine whether differences in height and diameter growth are only detectable under more controlled experimental conditions, or if similar trends can be observed when inverted site preparation is performed using Kicken.

Control sites were selected based on field-assessed site characteristics, which resulted in some variation in stand age, soil type, ground vegetation and regeneration method among sites. This variation may have reduced the ability to detect treatment effects, particularly for total natural regeneration. Consequently, future studies should include a larger number of sites to increase statistical power and allow for greater flexibility in site selection. Alternatively, closer cooperation with forest companies during site preparation could facilitate the selection of representative sites for both treatments. Such improvements would help clarify whether the lack of significant differences in total natural regeneration observed in this thesis is a result of limitations in the method or correctly reflects no significant difference between the two methods.

5. Conclusion

This thesis compared two mechanical site preparation methods to evaluate how inverted site preparation using Kicken affects the regeneration outcome of Scots pine.

- The choice of site preparation method did not result in significant differences in growth parameters of Scots pine. Similarly, no significant differences were detected in mean annual height or diameter growth.
- Site preparation method influenced the natural regeneration of birch, with higher birch densities on disc-trenched sites. No significant differences were observed in total natural regeneration, although the mean number of naturally regenerated stems was higher in disc-trenched sites.

Overall, the results suggest that inverted site preparation provides regeneration outcomes comparable to disc trenching, while potentially reducing the need for pre-commercial thinning due to lower birch regeneration.

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Similar regeneration results with less soil disturbance in forest regeneration?

Can similar or even improved regeneration results be achieved while simultaneously reducing soil disturbance in modern forestry? This question formed the basis of my master's thesis, where I compared inverted site preparation with the commonly used method of disc trenching. Previous studies have reported increased growth responses as well as reduced natural regeneration following inverted site preparation, although these studies were largely conducted under controlled experimental conditions. In contrast, this thesis was based on operational forestry, with study sites selected where the site preparation implement Kicken had previously been used.

Kicken was in operational use between 2015-2020, primarily in reindeer herding areas, with the aim of limiting soil disturbances. The Kicken implement performs patch scarification by scooping up a small section of soil, inverting it and placing it back in the same spot, thereby creating small microsite patches for planting seedlings. This method differs from disc trenching, which create continuous furrows across the regeneration area. Inverted site preparation has been shown to result in significantly lees soil disturbances compared to disc trenching.

The results showed that no significant differences in growth parameters could be observed between the two site preparation methods, and similar results were obtained for the mean annual growth. However, a significant difference was observed in the natural regeneration of birch, with disc trenching creating more favourable conditions for birch establishment.

Based on these findings, inverted site preparation does not appear to negatively affect the regeneration of Scots pine compared to disc trenching. Instead, the results suggest that inverted site preparation offers similar regeneration outcomes while simultaneously reducing the establishment of naturally regenerated birch, potentially lowering the future need for pre-commercial thinning.

Overall, the study indicates that comparable or possibly improved regeneration outcomes can be achieved while reducing soil disturbances. These findings challenge the assumption that high productivity requires extensive soil disturbance and suggest that ecological consideration and productive forestry can coexist. I encourage forestry practitioners to view these results as an opportunity to further develop and refine site preparation practises used today.

Appendix 1

Table 8: Data used for ANOVA analysis of growth parameters. The data include mean height, leader shoot length, diameter and standard deviation for each site preparation method. n represents the number of stems included at each site.

Site	Method	Mean height (m)	Sd Height	n	Mean Leader shoot length (cm)	Sd leader shoot length	n	Mean diameter (cm)	Sd diameter	n
1	Inverted	3,505	0,668	31	59,839	12,006	31	4,197	1,271	31
2	Control	2,871	0,450	39	45,228	9,983	39	3,413	1,034	39
3	Inverted	2,633	0,652	32	44,219	10,326	32	2,875	1,245	32
4	Inverted	3,640	0,982	35	61,571	12,472	35	5,020	1,930	35
5	Control	3,990	0,828	31	59,516	10,981	31	5,048	1,312	31
6	Control	3,792	0,861	18	59,167	8,952	18	5,428	1,641	18
7	Inverted	2,572	0,589	30	48,833	8,272	30	3,110	1,182	30
8	Control	1,777	0,489	51	38,529	9,235	51	1,435	0,895	51
9	Inverted	1,622	0,449	32	30,469	8,363	32	1,421	0,656	28
10	Inverted	1,671	0,372	38	40,395	8,251	38	1,594	0,613	33
11	Control	3,197	0,749	29	50,862	10,357	29	4,217	1,457	29
12	Inverted	1,600	0,385	36	40,972	9,623	36	1,490	0,610	29
13	Inverted	1,752	0,369	24	47,917	9,198	24	1,925	0,539	20
14	Inverted	2,187	0,769	39	36,538	9,188	39	1,883	0,581	36
15	Inverted	1,935	0,690	40	38,625	10,621	40	1,959	1,057	34
16	Control	1,045	0,302	19	30,526	7,434	19	1,150	0,129	4
17	Control	1,356	0,464	31	33,710	10,080	31	1,575	0,516	16
18	Control	1,809	0,540	32	43,750	10,701	32	2,064	0,801	25
19	Control	1,557	0,414	37	38,649	7,036	37	1,393	0,689	30
20	Control	1,372	0,403	27	35,741	10,067	27	1,450	0,453	16
21	Inverted	1,613	0,413	26	38,077	10,870	26	1,616	0,422	19
22	Control	2,092	0,514	30	43,500	9,391	30	2,354	0,915	28
23	Inverted	1,417	0,345	15	35,667	8,837	15	1,150	0,554	12
24	Control	1,390	0,263	21	33,333	7,130	21	0,993	0,315	14
25	Inverted	1,642	0,393	26	34,615	6,917	26	1,695	0,656	20
26	Inverted	2,007	0,456	36	43,056	7,863	36	2,179	0,953	34
27	Inverted	2,036	0,471	29	43,793	7,752	29	2,300	1,104	29
28	Control	1,355	0,299	19	38,158	5,326	19	1,433	0,566	9
29	Control	1,309	0,298	22	34,091	5,698	22	1,150	0,415	14
30	Control	2,164	0,438	18	39,167	9,115	18	2,435	0,780	17

Appendix 2

Table 9: Data used for ANOVA analysis of natural regeneration. The data include mean number of naturally regenerated stems for each species (Scots pine, birch and Norway spruce) and standard deviation for each site preparation method. n represents the number of stems included at each site.

Site	Method	Mean of naturally generated pine	Sd pine	Mean of naturally generated birch	Sd birch	Mean of naturally generated Spruce	Sd spruce	Mean of total natural regeneration	Sd total
1	Inverted	1,800	1,619	0,300	0,483	0,200	0,422	2,300	1,337
2	Control	8,900	3,725	0,700	0,823	0,000	0,000	9,600	3,565
3	Inverted	2,000	1,886	0,000	0,000	0,100	0,316	2,100	1,792
4	Inverted	6,100	4,122	1,700	1,947	0,300	0,675	8,100	4,149
5	Control	2,700	2,263	0,300	0,675	0,100	0,316	3,100	2,183
6	Control	0,778	0,972	1,333	1,225	0,000	0,000	2,111	1,833
7	Inverted	0,800	1,135	0,400	0,966	0,000	0,000	1,200	1,874
8	Control	6,000	3,266	2,500	0,972	0,000	0,000	8,500	3,408
9	Inverted	4,200	3,120	0,400	0,966	0,200	0,632	4,800	2,974
10	Inverted	2,300	2,983	1,000	1,886	0,100	0,316	3,400	2,716
11	Control	2,200	3,011	1,300	2,111	0,000	0,000	3,500	3,689
12	Inverted	1,600	1,506	0,100	0,316	0,200	0,422	1,900	1,524
13	Inverted	1,000	1,563	1,100	0,994	0,200	0,632	2,300	1,494
14	Inverted	9,900	4,095	0,200	0,632	0,000	0,000	10,100	4,202
15	Inverted	5,200	6,143	0,000	0,000	0,100	0,316	5,300	6,056
16	Control	6,000	2,928	0,125	0,354	0,000	0,000	6,125	2,748
17	Control	1,100	1,287	2,400	2,757	0,400	0,699	3,900	3,348
18	Control	6,700	6,667	3,000	5,099	0,000	0,000	9,700	7,439
19	Control	5,200	2,860	0,200	0,422	0,100	0,316	5,500	2,915
20	Control	3,400	0,843	1,200	1,619	0,000	0,000	4,600	1,776
21	Inverted	3,600	2,271	0,200	0,632	0,000	0,000	3,800	2,573
22	Control	5,600	8,809	1,200	2,394	0,000	0,000	6,800	8,587
23	Inverted	0,800	0,789	1,500	1,354	0,200	0,422	2,500	2,014
24	Control	4,200	3,120	0,600	0,843	0,000	0,000	4,800	3,011
25	Inverted	2,000	1,700	0,000	0,000	0,000	0,000	2,000	1,700
26	Inverted	4,800	3,084	0,000	0,000	0,000	0,000	4,800	3,084
27	Inverted	5,800	3,011	1,100	1,524	0,100	0,316	7,000	3,651
28	Control	1,500	2,173	1,100	1,853	0,000	0,000	2,600	3,806
29	Control	4,800	3,190	1,100	1,449	0,300	0,483	6,200	3,293
30	Control	4,900	4,630	1,200	2,440	0,000	0,000	6,100	6,773

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En utvärdering av en naturbaserad intervention i cancervården.

2025:02   Författare: Oscar Andersson
Warming alters root trait strategies and enchances overyielding in boreal tree seedling mixtures

2025:03   Författare: Julian Säflund
Forest edge effect on seedling growth, C/N allocation and fungal associations. A closer look at 3-year-old seedling growth patterns above- and belowground and their mycorrhizal symbionts according to their distance to a forest edge.

2025:04   Författare: Jelle van Zanten
Large herbivores and fire shape divergent woody assemblages in temperate wood-pasture. Experimental effects of large herbivores and fire on the survival of ten temperate woody species in southern Sweden.

2025:05   Författare: Adrien Lamodière
Diverse Paths to Restoration: Assessing biodiversity responses to enrichment planting in Sabah's tropical forests. A 27-year comparison of line and gap-cluster planting in the INIKEA restoration project

2025:06   Författare: Stijn Qualm
Ancient Silver Sentinels. Kelo Tree Dynamics in a Boreal Old-Growth Forest in Northern Sweden

2025:07   Författare: Ted Pettersson
Three decades of change in the character and charge density of dissolved organic matter in Swedish surface waters

2025:08   Författare: Erik Dahlin
Årsringsutvecklingen hos tall i relation till graden av kronskada vid brand - Undersökning på naturvårdsbrända områden i Västerbotten

2025:09   Författare: Isak Haglund
Abundance of Invertebrates in Forests near Ditches and Streams

2025:10   Författare: Viktor Boström
Planteringsförbandets inverkan på produktion och kvalitet i ett 29-årigt bestånd av contortatall (Pinus contorta var. latifolia) i norra Sverige

2026:01   Författare: Sebas De Smedt
Quantifying tree diversity along a gradient of structural complexity.
An integrated approach using a variety of aggregation and weighting techniques

2026:02   Författare: Anton Granström
Growth of Pinus sylvestris 6-11 years after inverted site preparation
Comparison of inverted site preparation and disc trenching's effect on tree growth and pre-commercial thinning needs