Comparison of Soil Inversion and Disc Trenching: Soil Disturbance on Regeneration Sites in Northern Sweden 5-10 Years After Scarification

Gentle Scarification Using the Kicken Implement

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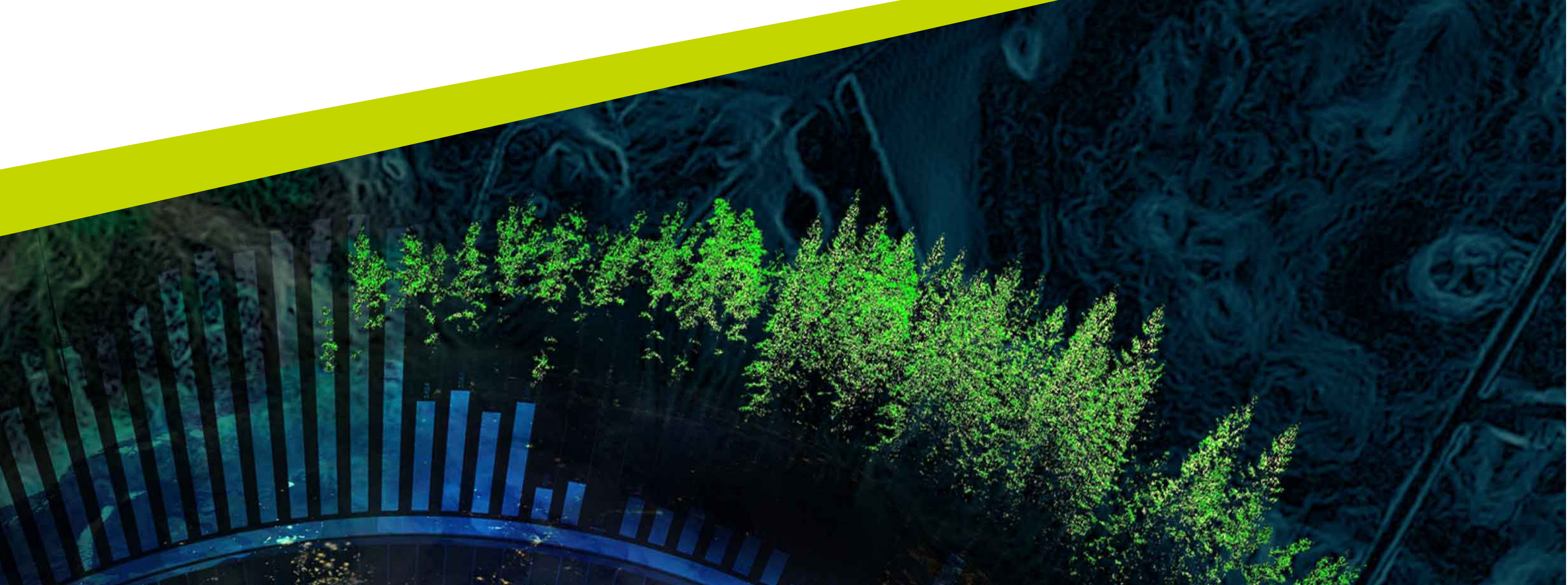

Comparison of Soil Inversion and Disc Trenching: Soil Disturbance on Regeneration Sites in Northern Sweden 5-10 years after scarification. Gentle Scarification Using the Kicken Implement.

Jämförelse av markstörning efter inversmarkberedning och harvning på föryngringsytor i norra Sverige 5–10 år efter markberedning. Skonsam markberedning med Kicken.

Johannes Turesson

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Abstract

Successful forest regeneration is an important component in modern silviculture, ensuring sustainable production of forest ecosystems services. Mechanical site preparation is a widely used method in Northern Europe to create advantageous conditions for planted seedlings, increasing survival rates and growth, thus contributing to sustainable development of future forests. Yet, existing scarification methods often conflict with other values and stakeholders in the forest, including reindeer grazing, biodiversity, and recreation, due to the extensive impact on soil and vegetation cover. The need to minimize soil disturbance, while maintaining sufficient regeneration quality, has consequently led to a development of new scarification methods targeted at minimizing environmental impact.

Soil inversion is often considered a gentle scarification method compared to modern conventional scarification methods due to lower disturbance area by only treating the soil closest to where the seedling is to be planted. Kicken is a gentle scarification implement developed by Bracke Forest AB and uses the concept of soil inversion. Kicken has been used by the forest industry between 2015 and 2020 on sites where gentle scarification methods have been required, primarily on lichen-rich areas used for reindeer grazing. While conventional scarification methods and following soil disturbances have been studied for a long time, no previous long-term assessment on disturbances following soil inversion performed with Kicken has been conducted.

The aim of this study is to evaluate soil disturbances levels and vegetation recovery rates on sites treated with soil inversion using Kicken compared to conventional disc trenching. The study was conducted during 2025 by field inventory of regeneration sites in northern Sweden harvested 8-12 years earlier. Total surface area of soil disturbances caused by scarification was measured using a high precision GPS and classified depending on the severity of disturbance. The collected data were analysed and compared between the two treatment groups using statistical methods.

The results indicated significantly lower levels of disturbance on sites treated with soil inversion using Kicken compared to conventional disc trenching. Sites treated with soil inversion had on average 92% less exposed mineral soil and 83% less disturbed ground and field vegetation compared with disc trenching on sites harvested 8-12 years ago. The findings indicate lower total disturbance levels on sites treated with soil inversion. Proportion of disturbance level had a significant correlation with time when measuring soil disturbance on sites harvested at different years, indicating a vegetation recovery on sites treated with disc trenching. No significant vegetation recovery could be observed for sites treated with soil inversion. Overall, the results suggest that soil inversion, in this case performed with Kicken can reduce environmental impact, making it particularly suitable on lichen-rich sites where soil disturbance levels should be minimized. Soil inversion may therefore be an important tool for future high precision and low impact regeneration systems.

Keywords: scarification, mechanical site preparation, soil inversion, Kicken, disc trenching, soil disturbance, vegetation recovery, lichen, reindeer grazing

Sammanfattning

Framgångsrik skogsföryngring är en grundläggande del i det moderna skogsbruket för att säkerställa hållbart nyttjande av skogens ekosystemtjänster. Mekanisk markberedning är en vanligt förekommande metod i norra Europa för att skapa gynnsamma förhållanden för plantor genom ökad plantöverlevnad och tillväxt, vilket bidrar till en hållbar utveckling av framtidens skogar. Samtidigt står konventionella markberedningsmetoder ofta i konflikt med andra skogliga värden och intressenter, bland annat rennäring, biologisk mångfald och sociala värden, på grund av deras omfattande påverkan på mark och vegetation. Behovet av att minimera markstörningar samtidigt som tillfredsställande föryngringskvalitet upprätthålls har därför lett till en utveckling av nya markberedningsmetoder med syfte att minska miljöpåverkan.

Inversmarkberedning anses ofta som en skonsam markberedningsmetod jämfört med dagens konventionella markberedningsmetoder. Metoden minimerar markstörningsytan genom att endast bearbeta jorden i direkt anslutning till planteringspunkten. Kicken är ett markberedningsaggregat utvecklat av Bracke Forest AB som bygger på principen om inversmarkberedning. Kicken har använts av skogsindustrin mellan 2015 och 2020 i områden där skonsam markberedning har efterfrågats, främst på lavrika marker som nyttjas för renbete. Konventionella markberedningsmetoder och deras efterföljande markstörningar har studerats under lång tid, men tidigare långtidsstudier av markstörningar efter inversmarkberedning utförd med Kicken saknas.

Syftet med denna studie är att utvärdera omfattningen av markstörning samt vegetationens återhämtning på marker behandlade inversmarkberedning med Kicken i jämförelse med konventionell harvning. Studien genomfördes under 2025 genom fältinventering av föryngringsytor i norra Sverige som avverkades för 5–10 år sedan. Den totala markytan med markstörningar mättes med hjälp av högprecisions-GPS och klassificerades utifrån graden av störning på mark och vegetation. Det insamlade datamaterialet analyserades och jämfördes mellan de två behandlingsgrupperna med statistiska metoder.

Resultaten visade signifikant lägre nivåer av markstörning på ytor behandlade med inversmarkberedning med Kicken jämfört med harvning. Inversmarkberedning resulterade i genomsnitt i 92 % mindre blottad mineraljord samt 83 % mindre störd mark- och fältvegetation jämfört med harvning på trakter som avverkades för 8–12 år sedan. Resultaten tyder på en lägre total markpåverkan för ytor behandlade med inversmarkberedning. Störningsgraden hade en signifikant korrelation med trakter avverkade vid olika år, vilket indikerar en återhämtning av fält- och markvegetationen för områden behandlade med harvning. Ingen signifikant återhämtning av mark- och fältvegetationen kunde observeras för ytor behandlade med inversmarkberedning. Sammantaget tyder studien på att inversmarkberedning utförd med Kicken kan minska miljöpåverkan och är särskilt lämplig på lavrika marker där markstörning bör begränsas. Inversmarkberedning kan därmed utgöra ett viktigt verktyg i framtida högprecisionssystem för skonsam skogsföryngring.

Nyckelord: markberedning, mekanisk markberedning, inversmarkberedning, Kicken, harvning, markstörning, vegetationsåterhämtning, lav, renskötsel

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1. Introduction

Forests play a key role in society's transition toward sustainable development, providing a wide range of ecosystem services, including carbon sequestration, biodiversity, recreation, and the production of wood-based materials (Chen et al. 2022). The increasing demand on forest ecosystems, combined with the presence of multiple stakeholders with diverse interests, call for sustainable silvicultural that considers conflicting objectives and balances economic, ecological, and social values (Blattert et al. 2023). Successful forest regeneration is an essential stage in modern silviculture to secure sustainable and functional services from the forest ecosystem over the long term. The importance of forest regeneration has been recognized for a long time and is reflected by the Swedish Forestry Act, established 1903 (5 §), stating that actions must be taken to secure reforestation and promote sustainable land use (*SFS 1979:429*).

Mechanical site preparation (MSP) is a commonly used method during the regeneration stage to create advantageous conditions for seedling establishment. Advantageous conditions are created by exposing mineral soil and removing surrounding vegetation prior to planting new seedlings (Johansson et al. 2013). MSP has proven to reduce the risk of severe pine weevil (*Hylobius abietis* L.) damage to newly planted conifer seedlings, as a consequence of an increased amount of pure mineral soil around the seedlings, leading to higher survival rates (Wallertz et al. 2018). Other effects that have been studied following MSP include increased soil temperature during the growing season (Hansson 2019), and reduced competition from ground and field vegetation. The reduction in competition from surrounding vegetation has indicated improvement of both water availability of and nutrients during establishment of new seedlings (Johansson et al. 2013). These factors also have long term impacts on the planted seedlings, increasing the overall growth and productivity of forest stands due to higher survival rates and improved annual growth (Hjelm et al. 2019; Sikström et al. 2020). The advantageous conditions following MSP makes it an important tool in silviculture and regeneration of today's forests. From 2019 to 2024, MSP covered between 160 000 – 205 000 hectares of Swedish forest land annually, equal to approximately 80% of the regeneration areas (Hansson & Forsmark 2020; Skogsstyrelsen 2024a).

Disc trenching is the most widely used MSP method in Sweden, covering approximately 60% of treated areas (Krekula et al. 2018). Disc trenching is a continuous method where machines equipped with rotating discs cut through the vegetation layer. The discs create furrows where the organic layer is removed, exposing mineral soil, and form ridges parallel to the furrows from the removed soil (Figure 1) (Chaves Cardoso et al. 2020). The continuous furrows created by disc trenching result in a relatively large area of disturbed soil and vegetation and provide many options for planting seedlings. These attributes make disc trenching especially valuable on stony soils, offering a higher number of suitable planting spots compared with other scarification methods (Wallertz et al. 2018).

Mounding is an intermittent MSP method, covering approximately 30% of treated sites (Krekula et al. 2018), which creates elevated planting spots by scraping the top soil layer and placing the mound next to the pit (Figure 1) (Chaves Cardoso et al. 2020). The elevated mound provides well-drained and aerated planting spots which leads to increased survival rates and growth, particularly on wet or fine-textured soils (Uotila et al. 2022). The elevated planting spot provided by mounding also reduced the competition from surrounding ground and field vegetation, making it especially suitable on rich-herb sites (Nilsson & Örlander 1999).

A different MSP method that has been recognized for a long time, but with marginal use, is soil inversion. Soil inversion creates planting spots by inverting the humus and mineral soil layer upside down before placing it back in the original spot (Figure 1) (Johansson et al. 2013). The method is considered a "spot" or "patch-wise" site preparation method and is often referred to as a gentle scarification methods as it affects only the area closest to where the seedling is to be planted (Sundblad & Hajek 2015). Studies have shown that soil inversion can increase seedling survival rate, stem volume production and growth, compared with disc trenching and mounding (Örlander et al. 1998; Johansson et al. 2013).

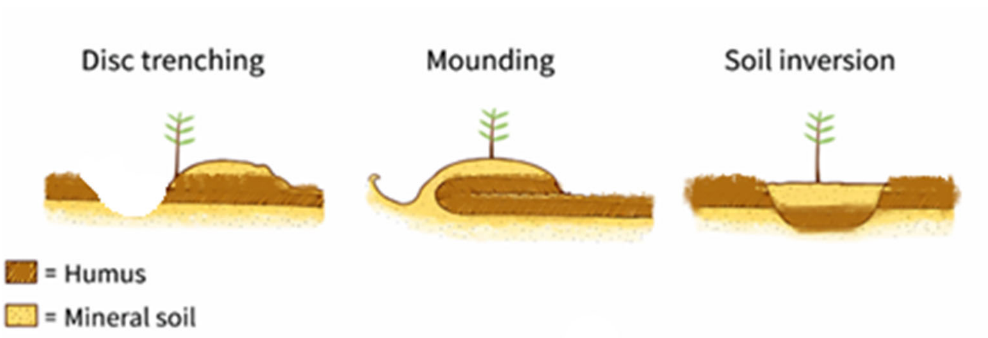

Figure 1. Illustration of site preparation methods and planting spot. Disc trenching (left), mounding (middle), and soil inversion (right). Humus layer in brown and mineral soil in yellow. Adapted from Hansson (2014).

1.1 Environmental consequences of MSP

Although MSP can provide many advantageous effects during the regeneration stage, disturbance of the topsoil layer also leads to undesired outcomes. The extensive use of MSP may override other cultural, recreational and ecological values in the forest. MSP accounts for the largest cause of damage to cultural remains during forest operations (Skogsstyrelsen 2024b), and extensive MSP treatments may reduce accessibility and negatively impact recreational values (Hannerz et al. 2016). Negative ecological impacts of disc trenching and mounding have been studied, including increased risk for erosion, nutrient leaching, and potentially transport of sediments and trace metals to nearby streams (Ring & Sikström 2024). Site preparation can temporarily increase nutrient concentrations in soil water, especially for areas at lower elevations (Ring & Sikström 2024). The large surface area affected by MSP consequently results in removal of a substantial proportion of the vegetation cover, reducing abundance of species, including lichens (Bergstedt et al. 2008).

1.2 Impact of soil scarification on reindeer grazing

The Reindeer Husbandry Act provides the Sami people right to herd and graze on approximately 55% of Sweden's land area, where ground and tree lichen are the primary winter fodder for reindeer (*1971:437*; Eggers et al. 2024). Between 1950 and 2010, approximately 70% of lichen-rich forests (forests with > 50% lichen cover) have been lost. Furthermore, between 1950 and 1990 approximately 50% of the forests classified as having moderate lichen cover (25-50%) were reclassified as having less than 25% lichen cover (Sandström et al. 2016). The reduction of lichen cover have reduced the amount of available reindeer grazing land, while at the same time putting more pressure on remaining areas, making it even more difficult for reindeer herders to adapt to the challenges of climate change (Horstkotte 2022).

Forestry operations strongly affect lichen abundance, and soil disturbances from MSP reduce lichen availability both momentarily and several years after treatment (Roturier & Bergsten 2006). Previous studies have shown that the intensity of soil disturbance affects recovery time of vegetation cover and that recovery time differ between species. While dwarf shrubs, especially heather (*Calluna vulgaris*), recolonize within 8-10 years, lichens recover more slowly due to the limited spread which is mainly vegetatively rather than by spores (Roturier et al. 2011; Brus 2023). A study from Bergstedt et al. (2008) conducted in Sweden showed that soil scarification significantly impacts ground and field vegetation, especially abundance of lichens (*Cladonia spp.)* which declined following disturbance of the organic layer and mineral soil. MSP initially removes a substantial area of ground and field vegetation, and even after 10-20 years up to 20% of the surface may remain unvegetated following disc trenching (Eriksson & Raunistola 1990). Overall, soil scarification alters species composition and delays recovery of both lichens and dwarf shrubs, with recovery of lichen being particularly slow.

To reduce the loss of reindeer grazing areas caused by forestry operations, national guidelines highlight the need to limit soil disturbance in lichen-rich areas. The Swedish Forest Agency's general guidance to the Forestry Act states that soil preparation required for forest regeneration should be carried out with limited impact on lichen-rich sites (SKSFS 2011:7). On sites were lichen covers 10-25% of the ground and field vegetation, soil preparation should affect no more than 40% of the surface area. And, on sites with more than 25% lichen cover, no more than 20% of the surface area should be disturbed. These recommendations emphasize the importance of acceptable forest regeneration quality while maintaining a sufficient lichen cover for reindeer grazing.

1.3 Soil disturbance from conventional MSP methods

The two most common MSP methods used in Sweden, disc trenching and mounding, disturb a relatively large portion of the forest soil and vegetation surface. Disc trenching has been estimated to disturb approximately 52% (33-70%) of the surface area and mounding 37% (17-67%) (Sikström et al. 2020). From an environmental perspective, disturbing more soil than needed for seedling establishment is undesirable. Previous research has shown that planting spots of approximately 0.25 m^2 are sufficient for successful regeneration (Örlander et al. 1990) and establishing 2000 planting spots per hectare of this size would disturb 5% of the ground surface area. This highlights the potential to reduce the proportion of disturbance by using other MSP methods (Sikström et al. 2020; Ring & Sikström 2024). Ring & Sikström (2024) concludes that lichen-rich areas require special caution and that further efforts are needed to develop site preparation methods that better balance disturbance intensity with the requirements for successful regeneration to mitigate conflicting objectives. Likewise, Ersson et al. (2023) suggests development of gentle site preparation methods that maintains higher biodiversity and reduce the conflict between forestry and reindeer herding communities.

1.4 Alternative MSP methods

Although disc trenching and mounding remain as the conventional and most used scarification methods, covering approximately 90% of treated sites, alternative methods have been developed in an effort to reduce soil disturbance levels. Soil inversion is one of the alternative methods that have been suggested as a potential replacement for conventional scarification methods due to its promising regeneration success, while at the same time reducing environmental impact. In 2014, Hansson et al. (2014) published a literature review, including expert interviews, where current scarification methods and their effects on regeneration quality and environment where described. The study discussed likely future development of scarification methods and suggested that by 2024, soil inversion would replace disc trenching as the dominating scarification method in Sweden due to its low environmental impact and improved conditions for planted seedlings. Despite these expectations, soil inversion has to this day not been widely used operationally. Johansson et al. (2013) pointed out that the lack of alternative scarification methods may be explained by limited technical development and equipment's. However, new technical improvements and development of high precision forestry systems have once again raised the interest for the method. It has been estimated that soil inversion disturb approximately 15% (10–30%) of the surface area (Hallsby 2004; Chaves Cardoso et al. 2020). Nevertheless, relatively few studies have been conducted regarding soil disturbance following soil inversion.

Autoplant is a collaboration project between scientists, manufacturers, industry, and end users of future forest machines. The goal of the project is to develop an autonomous site preparation and planting system that is formed to meet the future needs of a sustainable forestry management, providing high precision soil preparation and planting to minimize environmental impacts (Hansson et al. 2024). The suggested system reduces the disturbed area by treating only the soil immediately surrounding the planting spot, and may therefore benefit other values in the forest, including reindeer herding. As the goal in the project is to establish the new stand fast and better than current methods, and at the same time as lowering soil disturbances, soil inversion has been suggested as suitable method for precision scarification. This offers the potential to create advantageous conditions for seedling establishment while maintaining minimal soil disturbance, making it especially suitable for regeneration in lichen-rich grazing areas.

Kicken is a scarification implement developed by Bracke Forest AB that utilizes the concept of soil inversion and will be one of the possible implements in the Autoplant system. Kicken establishes, under optimal conditions, 0.25 m² planting spots by inverting the humus layer and covering it with mineral soil (Figure 2) (Skogsaktuellt 2014). Kicken should in theory disturb approximately 5% of the ground surface, assuming a planting density of 2000 seedlings per hectare. The implement has been used operationally by the forestry industry (Skyttmos Skogsentreprenad AB n.d.) between 2015 and 2020, mounted on a forwarder, for gentle scarification on lichen-rich sites important for reindeer grazing

(Skogskunskap 2024). To date, no long-term survey has been conducted to assess soil and vegetation disturbance following operational use of Kicken. It is still not known whether sites treated with Kicken resulted in less soil disturbance over time compared with disc trenching, and no previous study has investigated the vegetation recovery after scarification with Kicken. These knowledge gaps should be addressed before the Kicken implement is integrated within the Autoplant system.

Figure 2. Photo of the soil inversion implement Kicken mounted on two arms behind a forwarder during operational use where humus and mineral soil layer is flipped upside down before being placed back in the original spot (Westendorp n.d.).

1.5 Aim and research question

The purpose of this thesis is to investigate the level of soil disturbance between two different scarification methods, soil inversion and conventional disc trenching, and how the disturbance levels relate with time after treatment. The thesis aims to study differences in total disturbance of surface area on sites harvested 8-12 years ago, where soil disturbance following scarification is defined and categorised as either exposed mineral soil or disturbed ground and field vegetation depending on severity. The thesis is conducted to provide knowledge when considering scarification methods for high precision and gentle scarification systems.

The thesis aims to answer the following questions:

- How do disturbance levels on soil and vegetation cover differ between soil inversion compared with disc trenching?
- How do ground and field vegetation recovery differ between soil inversion compared with disc trenching?

2. Method

To evaluate surface soil disturbance and vegetation recovery following soil inversion and disc trenching, a field survey was conducted in 2025 across 30 sites harvested between 2013 and 2017 in northern Sweden. 15 of the sites had been treated with soil inversion using the Kicken implement, while the remaining 15 sites were treated with conventional disc trenching. Disc trenching is currently the most used MSP method and therefore served as control sites for comparison between the treatments. Most of the sites were located on reindeer grazing land and were managed by three forest companies: Holmen Skog, SCA, and Sveaskog.

2.1 Sample selection and site conditions

The selection of sites treated with soil inversion was based on a database provided by Skyttmos Skogsentreprenad AB through Skogforsk, containing stands harvested between 2013 and 2017 where soil inversion with the Kicken implement had been used as scarification method. The selection of sites was geographically restricted to Västerbotten county, with most sites located in the surrounding area of Lycksele and Umeå. To identify potential control sites, an analysis using Geographical Information Systems (GIS) was performed using the Swedish Forest Agency database of harvested stands. The analysis was restricted to sites within 5 km radius of the soil inversion site (increased search radius if no match) and harvested the same year (in reality no more than ±2 years apart). Site preparation method was investigated manually by aerial photos to make sure the control sites were disc trenched.

The GIS analysis generated several potential control sites for each site with soil inversion, and to ensure comparable site conditions, all potential control sites were visited in the field. The site judged to have the most similar conditions to the soil inversion site regarding soil texture, field vegetation, and soil moisture, was selected as the control site to be inventoried. Soil texture classes for each site were simplified by combining similar soil and texture classes according to SLU´s classification chart (Stendahl 2025). Vegetation type was determined following the classification system used in the Swedish Forestry Agency’s flowchart for assessing site index on forest land (Skogskunskap n.d.). Soil moisture was classified according to SLU´s soil moisture classification system (Sveriges lantbruksuniversitet 2025).

Overall, the inventoried sites were regenerated with Scots pine (*Pinus sylvestris* L.) and generally located on sandy till. Soil moisture was always classified as dry, and the field vegetation was dominated by lichen (*Cladonia spp.*), heather

(*Calluna vulgaris* L.), lingonberry (*Vaccinium vitis-idaea* L.), and bilberry (*Vaccinium myrtillus* L.) (Table 1). Only sites where slash had been removed after harvesting were included in the inventory to ensure comparable site conditions between treatments. The average and median site size were 8.5 and 7.4 hectares for control sites, respectively. For soil inversion sites, the average and median site size were 4.9 and 3.9 hectares, respectively. The distance between each soil inversion site and its corresponding disc-trenched (control) site was within 10 km for 10 of the sites (the remaining sites were separated by 13, 18, 22, 35, and 66 km). The average distance was 13 km and the median was 8 km (Figure 3).

Table 1. Site characteristics of the sampled sites.

Harvesting year	MSP-method	Vegetation type	Soil classification
2013	Control	Heather	Medium-grained sediment
2013	Control	Lingonberry	Coarse-grained till
2014	Control	Heather	Medium-grained sediment
2014	Control	Heather	Coarse-grained till
2014	Control	Lingonberry	Coarse-grained till
2014	Control	Lichen	Coarse-grained till
2015	Control	Lichen	Coarse-grained till
2015	Control	Lichen	Coarse-grained till
2015	Control	Heather	Medium-grained till
2016	Control	Lichen	Coarse-grained till
2016	Control	Heather	Medium-grained till
2016	Control	Lichen	Medium-grained till
2017	Control	Lichen	Medium-grained till
2017	Control	Lichen	Medium-grained till
2017	Control	Lichen	Coarse-grained till
2013	Soil inversion	Lingonberry	Medium-grained sediment
2013	Soil inversion	Lichen	Coarse-grained till
2014	Soil inversion	Lichen	Medium-grained sediment
2014	Soil inversion	Lichen	Medium-grained till
2014	Soil inversion	Lichen	Coarse-grained till
2014	Soil inversion	Lichen	Medium-grained till
2015	Soil inversion	Lingonberry	Medium-grained sediment
2015	Soil inversion	Lichen	Medium-grained till
2015	Soil inversion	Heather	Medium-grained till
2015	Soil inversion	Lichen	Medium-grained till
2015	Soil inversion	Lingonberry	Coarse-grained till
2015	Soil inversion	Lichen	Medium-grained till
2015	Soil inversion	Heather	Medium-grained till
2017	Soil inversion	Lichen	Medium-grained till
2017	Soil inversion	Lichen	Medium-grained till

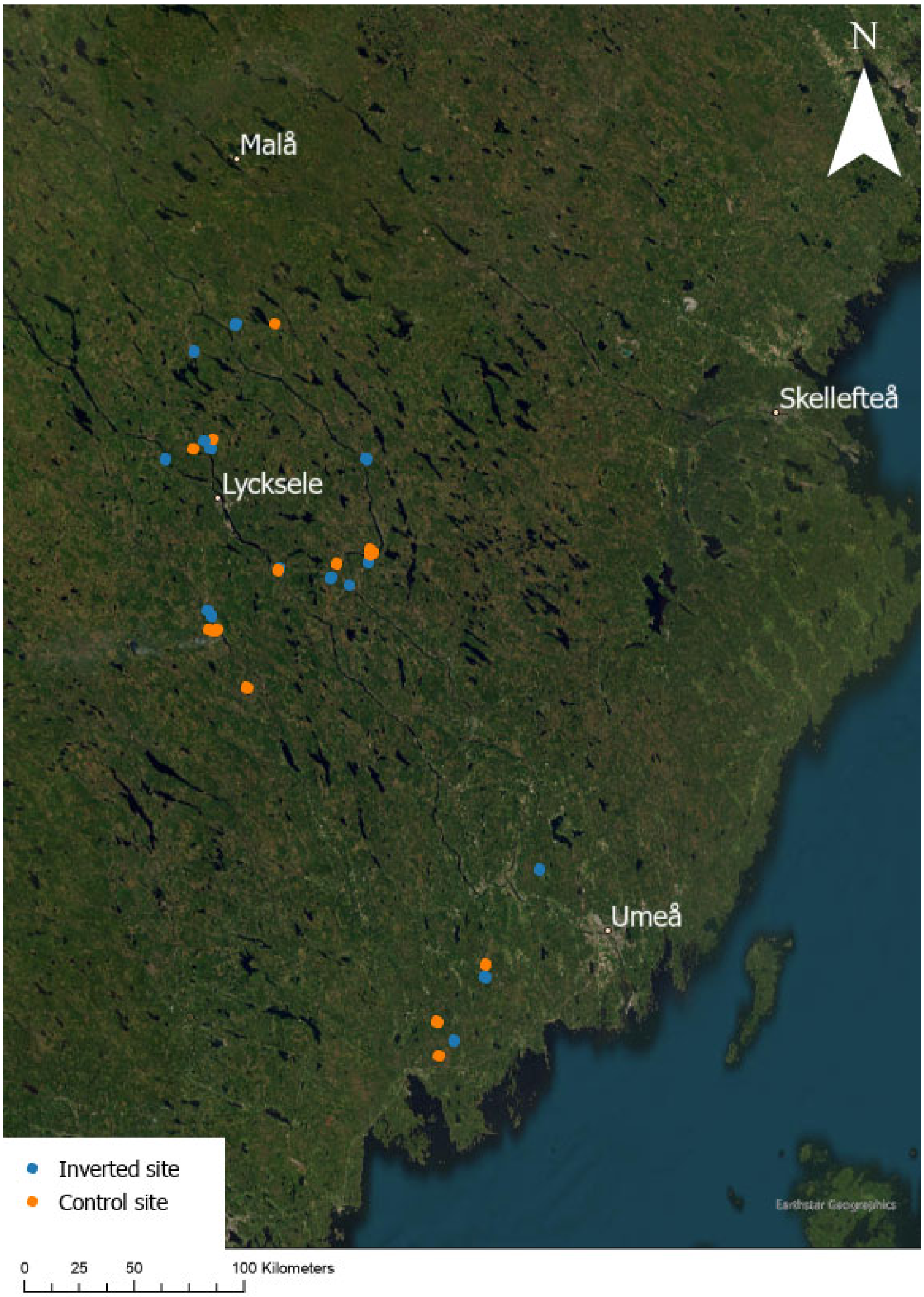

Figure 3. Geographical locations of the study sites in Västerbotten county. Blue points represent sites treated with soil inversion and orange points represent control sites treated with disc trenching.

2.2 Field inventory

For each site, 10 digital sampling points were systematically generated in GIS using the software Envisim prior to fieldwork. Systematic sampling was chosen since its commonly used in forest assessments and maximizes the distance between plots while minimizing spatial correlation between observations. It also increases statistical efficiency and provides representative coverage of the study area (McRoberts et al. 2015). The sampling points were visited in the field and served as centre points for circular sample plots with a radius of 2.52 m, equivalent to an area of approximately 20 m^2.

As the sample plot centre points were positioned in GIS before fieldwork, some plots were placed in areas not affected by the scarification treatments, such as retention patches, buffer zones, and ditches. Since the aim was to assess the effects of soil scarification, plots located outside the scarified operational area were relocated. To maintain a systematic and objective sampling design, relocated plots were consistently moved 20 m north or south, depending on the surrounding environment, to ensure their placement within areas where forest operations and scarification had been done.

Within each sample plot, vegetation type was classified using the Swedish Forestry Agency's flowchart (Skogskunskap n.d.), and all soil disturbance resulting from scarification was recorded. The surface area of disturbed soil was quantified using Real-Time Kinematic Global Navigation Satellite Systems (RTK-GNSS) with an accuracy of 1.4 cm. Visible disturbances were measured in the field by defining three or more points around the disturbed area using the RTK-GNSS receiver, forming a polygon that was stored in ESRI Field Maps for later analysis (Figure 4). Each uniform disturbance area was classified as either *Exposed mineral soil*, *Disturbed ground and field vegetation* or *Undisturbed ground and field vegetation* according to the criteria in Table 2.

Figure 4. In-field soil disturbance following disc trenching performed 2016 (left) and digital representation shown as brown coloured areas within the same sample plot (red circle) area in ESRI Field Maps (right). Photo taken by the author.

Table 2. Classification of disturbance.

Category	Criteria	Description
Exposed mineral soil	Ground and field vegetation cover < 20%	The soil surface is mostly bare, with little or no vegetation present.
Disturbed ground and field vegetation	Ground and field vegetation cover 20–80% or altered vegetation > 50%	The ground is partially covered and/or the vegetation has been substantially altered compared to its original (surrounding) state.
Undisturbed ground and field vegetation	Ground and field vegetation cover > 80%	The ground is well covered by vegetation and shows little or no signs of disturbance.

The classes and criteria were chosen to provide a simple, time-efficient, standardized, and repeatable method for classifying the effects from scarification on soil and vegetation cover. They were designed to provide a simple field inventory method, while providing sufficient resolution to distinguish between heavily disturbed (exposed mineral soil) and partially disturbed (disturbed ground and field vegetation) areas. This method allows quantitative comparison of disturbance level between the two scarification treatments. The method also enables comparison on how the disturbance levels relate over time, making it suitable for investigating vegetation recovery patterns.

The treatments resulted in different spatial patterns of soil disturbance depending on the scarification method. Soil inversion typically resulted in square-shaped disturbances distributed regularly across the site, while disc trenching resulted in long continuous strips of disturbances (Figure 5). The soil inversion scarification patches were estimated to be no smaller than approximately 0.10 m². The disc trenching furrows were generally much larger and sometimes contained multiple disturbance categories within the same sample plot. In these cases, the area was divided into separate polygons to reflect the different categories. However, no disc trenched area was subdivided into units smaller than 0,10 m² to avoid overrepresenting very small, non-representative disturbance patches. All collected data were stored in a database for further analysis (Table 3).

Figure 5. Spatial patterns of soil disturbance following scarification performed with Kicken 2016 (left) and conventional disc trenching 2018 (right). Photo taken by the author.

Table 3. Example of soil disturbance data collected in the field.

Unit ID	MSP-method	Disturbance category	Area (m²)	Vegetation type (sample plot)	Site ID	Plot ID	Harvest year
1	Soil inversion	Disturbed ground and field vegetation	0.213	Heather	1	1	2015
2	Soil inversion	Exposed mineral soil	0.218	Heather	1	1	2015
3	Soil inversion	Disturbed ground and field vegetation	0.355	Heather	1	2	2015
4	Disc trench	Exposed mineral soil	0.573	Lichen	1	2	2017
…	…	…	…	…	…	…	…
964	Disc trench	Exposed mineral soil	0.491	Lichen	30	1	2014

2.3 Statistics

The collected data were analysed to compare area of soil disturbances between the two treatments (soil inversion and disc trenching), where each treatment type were treated as a group. Each site was treated as a replicate, represented by the mean value for the 10 sample plots for each disturbance category. As the collected data (containing disturbance area) did not meet the assumption of normality required for parametric tests, non-parametric approaches were used.

A Kruskal-Wallis test is a non-parametric method that compares group medians by ranking all observations (Kruskal & Wallis 2012). This test was used to assess differences in disturbance levels for each disturbance category (*exposed mineral soil* and *disturbed ground and field vegetation*) between the two groups.

The effects on ground and field vegetation recovery following soil inversion and disc trenching were analysed using Spearman's rank correlation. Spearman's rank correlation is a non-parametric test that measures the strength and direction of association between two ranked variables (Spearman 1904). The test was done to evaluate how soil disturbance levels relate with treatments performed at different years.

3. Results

3.1 Soil disturbance levels following soil inversion and disc trenching

The Kruskal-Wallis test on soil disturbance levels indicates that soil inversion results in lower surface area of soil disturbances compared to disc trenching (Table 4). Both median and variability of soil disturbance were lower for sites treated with soil inversion (Figure 6-8). The surface proportion of exposed mineral soil averaged 0.45% on sites treated with soil inversion compared with 5.76% on sites treated with disc trenching. The surface proportion of disturbed ground and field vegetation averaged 1.03% on soil inversion sites compared with 6.30% on disc trenched sites. In total, soil inversion resulted in an average of 1.48% disturbed area per site, whereas disc trenching resulted in 12.06%. Differences in proportion of exposed mineral soil, disturbed ground and field vegetation, and total soil disturbance between the treatment groups were all significant ($p < 0.05$). For sites treated with soil inversion, 30% of the total surface disturbance area consisted of exposed mineral soil and 70% as disturbed ground and field vegetation. For site treated with disc trenching, 48% of the total surface disturbance area consisted of exposed mineral soil and 52% as disturbed ground and field vegetation. Number of measured disturbance patches were 584 for sites treated with soil inversion and 372 for sites treated with disc trenching.

Table 4. Mean proportion of disturbed surface area for soil inversion (Kicken) and disc trenching (control. Values in parantheses represent the relative proportion (%) of each disturbance category within the total disturbed area for the respective treatment. The total number of recorded disturbance patches is also presented.

	Soil inversion (Kicken)	Control (disc trenching)
Exposed mineral soil	0.45% (30%)	5.76% (48%)
Disturbed ground and field vegetation	1.03% (70%)	6.30% (52%)
Total soil disturbance	1.48% (100%)	12.06% (100%)
Number of measured disturbance patches	584	372

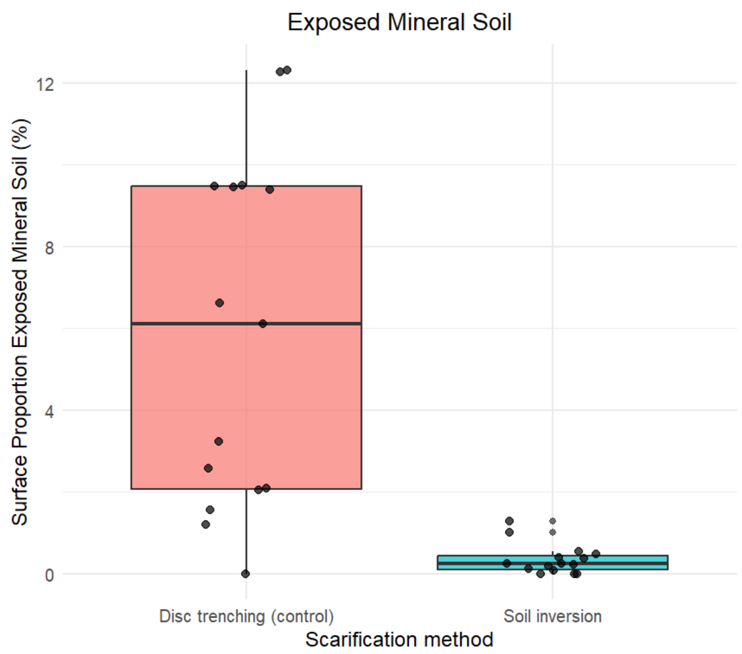

Figure 6. Proportion exposed mineral soil on sites treated with disc trenching (control) and soil inversion. Boxplots show the median (horizontal line) and the middle 50% of the data (box). Points represent each site (n=15 per group). Differences in proportion exposed mineral soil between the groups is significant (p < 0.05).

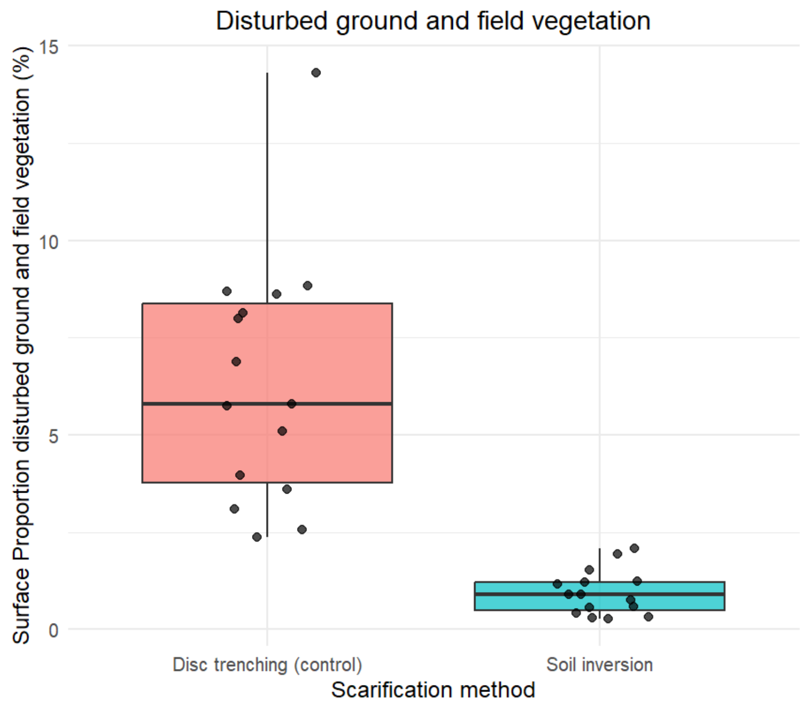

Figure 7. Proportion disturbed ground and field vegetation on sites treated with disc trenching (control) and soil inversion. Boxplots show the median (horizontal line) and the middle 50% of the data (box). Points represent each site (n=15 per group). Differences in proportion disturbed ground and field vegetation between the groups is significant (p < 0.05).

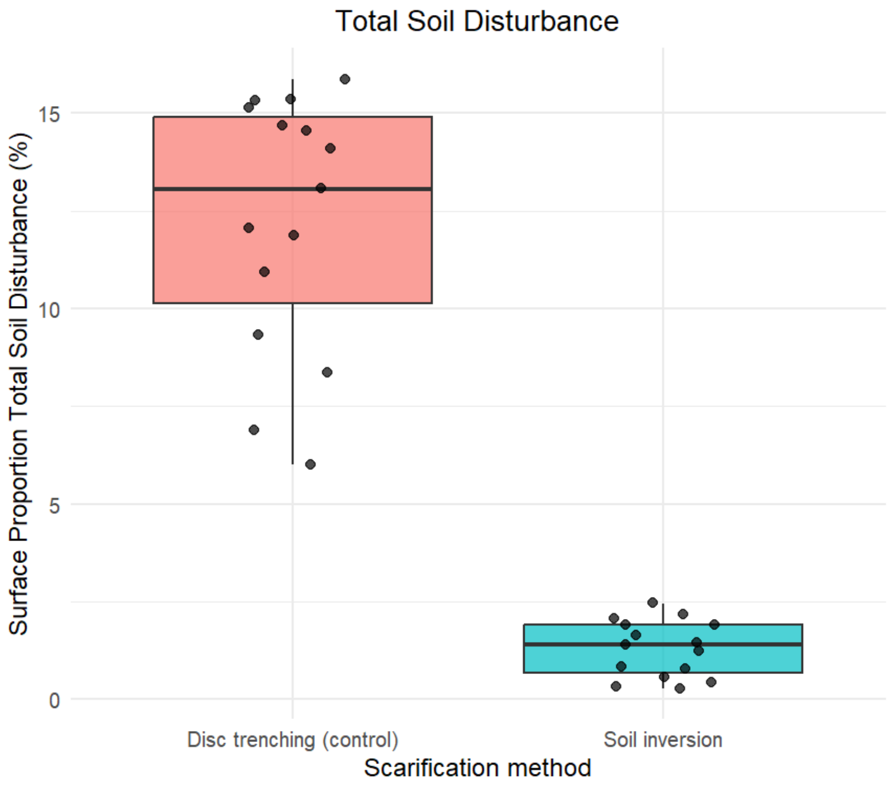

Figure 8. Proportion total soil disturbance on sites treated with disc trenching (control) and soil inversion. Boxplots show the median (horizontal line) and the middle 50% of the data (box). Points represent each site (n=15 per group). $p < 0.05$. Differences in total proportion disturbance between the groups is significant ($p < 0.05$).

3.2 Ground and field vegetation recovery following soil inversion and disc trenching on sites harvested 8-12 years ago

On sites treated with soil inversion, the Spearman rank correlation showed no significant relationship ($p > 0.05$) between sites harvested at different years and disturbance levels (Table 5).

Table 5. p-value and correlation factor (rho) for Spearman rank corelation between sites harvested at different years and proportion exposed mineral soil and proportion disturbed ground and field vegetation on sites treated with soil inversion.

	Proportion disturbed ground and field vegetation	Proportion exposed mineral soil
p-value	0.260	0.823
rho	0.31	0.06

For sites treated with disc trenching harvested more than 10 years ago, the disturbance proportion of ground and field vegetation is greater than the proportion exposed mineral soil (Figure 9). For sites harvested less than 10 years ago, the relative proportion change, and exposed mineral soil becomes greater than disturbed ground and field vegetation. The Spearman's rank correlation shows no significant correlation ($p > 0.05$) between proportion disturbed ground and field vegetation and sites harvested at different years. However, there is a significant correlation ($p < 0.05$) between proportion exposed mineral soil and sites harvested at different years (8-12 years ago).

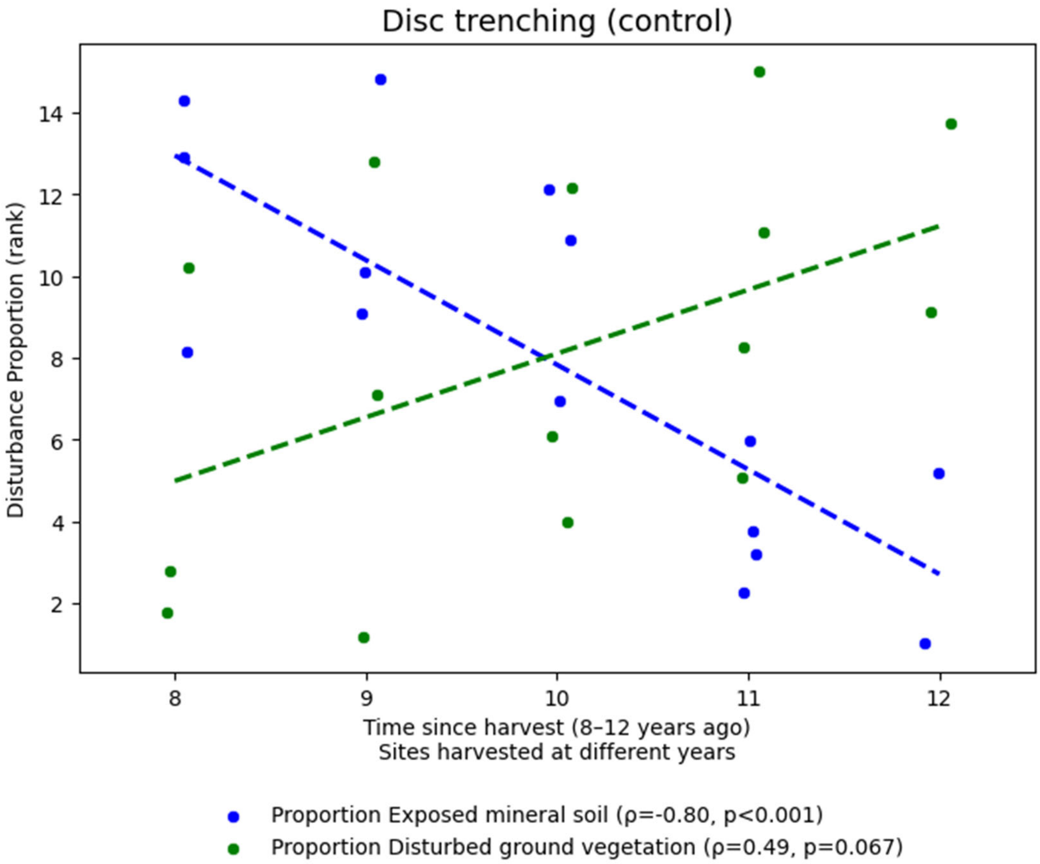

Figure 9. Spearman ranked correlation between sites harvested at different years (8-12 years ago) and disturbance proportion for exposed mineral soil (blue line) and proportion disturbed ground and field vegetation (green line) for sites treated with disc trenching.

4. Discussion

4.1 Impact of site preparation method on soil and vegetation disturbances

This thesis was conducted to provide knowledge about soil disturbances resulting from gentle scarification using soil inversion compared to conventional disc trenching. The results show that soil inversion with the Kicken implement caused significantly lower soil disturbance levels than disc trenching (Table 4). Sites treated with soil inversion had on average 92% less exposed mineral soil and 83% less disturbed ground and field vegetation compared with disc trenching. Overall, the total soil disturbance was 88% lower for soil inversion. The disturbance proportion for soil inversion were quantified to 1.48% and disc trenching to 12.06%. The results indicate that disc trenching causes higher disturbance levels, affecting a larger surface area, as well as causing more severe soil disturbances (exposing higher amounts of mineral soil) compared with soil inversion.

Ground and field vegetation recovery had a significant correlation when measuring proportion exposed mineral soil on disc trenched (control) sites harvested at different years (Figure 9). Exposed mineral soil decreased significantly during the time span 8-12 years after harvest (followed by site preparation), implying that vegetation recovery is still taking place on sites harvested 8-12 years ago. The proportion of ground and field vegetation did not significantly correlate with sites harvested at different years but indicated a trend towards increased proportion of disturbed ground and field vegetation on sites harvested longer ago ($p = 0.067$). Since the category of disturbed ground and field vegetation was defined as; including vegetation having altered composition compared to the surrounding state, this means that the recovered vegetation not necessarily has the same composition as the surrounding vegetation. This is in line with previous studies where species composition has been altered after soil scarification (Prévosto et al. 2011).

In contrast, no significant correlation could be detected on sites treated with soil inversion when measuring disturbance levels across sites harvested at different times (Table 5), indicating no vegetation recovery. However, 70% of the disturbances were classified as disturbed vegetation on sites treated with soil inversion, whereas 52% of the disturbances were classified as disturbed vegetation on sites treated with disc trenching (Table 4). The absence of significant recovery following soil inversion on sites harvested 8-12 years ago, together with higher levels of disturbed vegetation, may suggest faster vegetation recovery following soil inversion compared with disc trenching. This is in line with previous research. A study conducted in northern Sweden by Roturier et al. (2011) investigated the re-establishment of reindeer lichens (*Cladonia spp*.) following disc trenching and gentle scarification with HuMinMix in Scots pine-lichen forests. The study found that lichen cover and species diversity recovered more slowly on areas treated with disc trenching than on areas treated with gentle scarification methods. The study concluded that the intensity of soil preparation affects recolonization of reindeer lichens, with gentler methods enabling lichens to recover within a decade, whereas more intensive disturbances may require several decades. Also, soil inversion with Kicken resulted in on average 0.18 m^2 disturbance patches, which is substantially smaller compared to continuous disturbances caused by disc trenching. As discussed by Paine (2012), ecological impact following disturbances is dependent on different factors, including intensity, spatial distribution, and size of the disturbed patches. Smaller disturbance patches are closer to undisturbed vegetation, improving dispersion of seeds from surrounding vegetation, hence increasing vegetation recovery rates. Smaller disturbance patches also increase edge to area ratio. A higher edge to area ratio increases the influence of surrounding intact vegetation, supporting vegetation recovery. Overall, minimizing disturbance size, for example by using a patch-wise scarification method, can be beneficial for faster vegetation recovery. However, to determine whether soil inversion using Kicken results in faster vegetation recovery, a study assessing vegetation cover before scarification together with repeated samplings from the same sample plot during several years after scarification is needed.

A total of 584 disturbance patches following soil inversion were recorded across all sample plots (Table 4), corresponding to approximately 1950 planting spots per hectare, and falls within the Swedish Forestry Agency’s recommendation of 1800–2200 planted seedlings per hectare (Skogsstyrelsen 2025). The total disturbance level following disc trenching was in this study measured to be on average 12.06% on sites harvested 8-12 years ago. This number is lower than values reported in previous research, where the initial disturbance levels have been estimated to approximately 52% (33-70%) (Sikström et al. 2020). The lower values reported in this study is likely due to the older stand age of the inventoried sites, compared to other studies where initial disturbances following scarification have been measured. This interpretation is supported by Figure 9, which show that soil disturbance decreases with increasing time after treatment due to vegetation recovery. When the total disturbance proportion were extrapolated to 0 years after harvest using linear regression, the model estimated a disturbance level of approximately 26%, which is closer to the previous estimates of 33-70% (Sikström et al. 2020). However, vegetation recovery is rarely linear, as initial recovery of pioneer species is faster followed by slower secondary succession

(Kramer et al. 2005). This suggests that a linear prediction likely underestimates the initial disturbance, and that initial disturbance levels above 26% are expected.

Although few studies have been conducted regarding soil disturbance level following soil inversion, it has been estimated to initially affect approximately 15% (10–30%) of the surface area (Hallsby 2004; Chaves Cardoso et al. 2020). However, in this study a disturbance level closer to 5% was expected following soil inversion with Kicken since the implement, during optimal conditions, creates patches of 0.25 m². Creating 2000 spots per hectare of this size results in an initial disturbance level of 5%.

4.2 Implications for reindeer grazing areas

The Swedish Forestry Agency general guidance to the Forestry Act regarding consideration to reindeer husbandry states that sites where lichens cover more than 25% of the ground layer, soil preparation should affect no more than 20% of the ground surface (SKSFS 2011:7). The result from this thesis indicates that soil inversion performed by Kicken causes a level of soil disturbance well below 20%, with measured values of 1.48% of total area, whereas disc trenching on average disturbs 12.06% of the surface area. Even though disc trenching also were measured to be below the 20% threshold in this study, other studies have reported initial values well above the limit immediately after treatment (Sikström et al. 2020). Other studies have reported mounding to disturb approximately 37% (17-67%) of the area immediately after treatment, hence often exceeding the 20% limit (Sikström et al. 2020), while the HuMinMix has been estimate to disturb 10-15% of the soil surface (Roturier 2010). The comparisons between these different methods suggest site preparation with HuMinMix and soil inversion using Kicken is below the 20% soil surface disturbance when comparing with disc trenching and mounding.

Although disc trenching proved no significant correlation of disturbed ground and field vegetation and sites harvested at different years, the results indicated a trend of recovery (p=0.067) 8-12 years after treatment. Since the category was defined as having altered species composition compared to the original state, recovery of this category may include a different species composition than before scarification. This suggest that even tough vegetation in reindeer grazing areas is undergoing recovery, the recovered vegetation may alter substantially from the original state. This is in line with previous studies where recovery of lichens were slower compared to dwarf shrubs (Roturier et al. 2011) and disturbed sites having altered species composition following scarification (Bergstedt et al. 2008). This implies that the recovery of vegetation in this study not necessarily leads to recovery of lichens, but instead recovery of other species, hence decreasing reindeer grazing opportunities.

4.3 Regeneration success

A parallel study was conducted by Granström (2026) within the same project, using the same sites and sample plots as the present study. The study investigated stand growth and pre-commercial thinning needs following soil inversion and disc trenching. Data for both studies were collected simultaneously during the 2025 field inventory. The results from the parallel study showed no significant difference in height growth of Scots pine (*Pinus Sylvestris*) between seedlings planted after soil inversion with Kicken and those planted after disc trenching. However, sites treated with Kicken had significantly lower regeneration of birch stems, which may reduce pre-commercial thinning needs. Overall, regeneration success of planted seedlings did therefore not appear to be negatively affected when soil inversion was used instead of disc trenching. However, survival rates on planted seedlings were not considered in the parallel study.

Ring & Sikström (2024) have previously concluded that lichen-rich areas require caution and that further efforts are needed to develop site preparation methods that better balance disturbance intensity with the requirements for successful regeneration. The low disturbance levels observed for soil inversion in this study indicates that Kicken may be particularly suitable for lichen-rich sites, where minimizing soil and vegetation disturbance is critical for maintaining reindeer grazing resources. At the same time, regeneration is not negatively affected. Altogether, this makes Kicken an interesting tool when developing high precision and gentle regeneration systems that mitigates conflicting objectives and better balance multiple stakeholders' diverse interests. For instance, scarification with Kicken may be a valuable tool in areas where wood production and reindeer grazing coexist.

4.4 Strengths and limitations of the study

This study was conducted as a follow-up inventory, where the research question was formulated after the treatments had already been completed. As a result, no formal experimental design, such as randomized complete block design (RCBD), was used. RCBD is a widely used experimental design in forestry research, as it allows for controlled comparisons between treatments, reducing the influence of confounding factors such as stoniness or terrain variability (Mandal & Nicodemus 2025). In this study, differences in factors such as scarification date, machine settings, number of planting spots, or operator could not be controlled. There was no randomization, which introduces a potential risk of bias. For instance, soil inversion may consistently have been applied on soils with other conditions compared with disc trenching.

Despite the lack of a formal experimental design, the follow-up approach provides other advantages. The study has high practical relevance, as it captures how methods perform under real operational conditions, making the results directly applicable to forestry practise. Observational field studies are valuable as they reflect the diversity of site conditions and management practices under operational conditions that cannot be easily replicated in controlled experiments (Zhao et al. 2014). The data collected in this study cover a wider selection of soil types, terrain, and operational conditions across a larger geographic area, hence increasing the generalizability of the results.

A limitation in this study is the use of harvesting year instead of scarification year. For all soil inversion sites, scarification occurred 0-2 years after harvest, but this information is missing for the disc trenched sites. As a result, the temporal comparison in this study is associated with uncertainty, and the observed disturbance levels for soil inversion represent the conditions 0-2 years later than presented in the results (for example, a site harvested 11 years ago may have been scarified 9-11 years ago). However, the Swedish forest ordinance states that regeneration should be executed within three years after harvest (SFS 1979:791), implying that the maximum deviation can be no more than three years, and that all control sites were treated 0-3 years after harvest. Still, access to more complete operational data, including exact scarification dates, would have improved accuracy of temporal comparison and strengthen the conclusions from the study.

The field inventory was conducted using an RTK-GNSS with an accuracy of 1.4 cm to measure and collect disturbed areas after soil scarification. Although the equipment has high precision, the outcome is still dependent on a subjective assessment of judgment of the disturbance location, severity, and where the vegetation has been disturbed and altered, or if it's the original species composition. However, visual assessments and classification are commonly used in other studies to quantify vegetation cover and disturbance proportions (Bergstedt et al. 2008; Saursaunet et al. 2018; Wheater et al. 2020; Sörensen et al. 2023). An alternative approach to the RTK-GNSS would have been to use the more traditional method of quadrat sampling. Quadrat sampling is a common ecological method that can be used to estimate the abundance, density or distribution of vegetation (Wheater et al. 2020). Using the quadrat sampling would have provided vegetation cover estimates through a more established and scientifically accepted method. Although, the advantages of using an RTK-GNSS are that the exact area of disturbance can be quantified, giving precise measurement of the disturbed area. All disturbance within each sampling plot was recorded, and the resolution of the data is determined by the number of points used to define each disturbed area, ensuring accurate representation of patch shape and size.

4.5 Sources of uncertainty

The results from this study are directly influenced by the selection of sites included in the inventory. Soil inversion is a patch-wise method that generates fewer planting spots than disc trenching, and is generally more suitable on sediment soils with low levels of obstacles, such as forest residues and stones (Wallertz et al. 2018; Uotila et al. 2022). Disc trenching, on the other hand, is advantageous on stony soils since it produces higher number of acceptable planting spots than intermittent methods (Wallertz et al. 2018). This reasoning suggests that different methods are used to a different extent depending on the site conditions. In this project, most soil inversion treatments had been implemented following consultations with reindeer herding communities, meaning that soil inversion was mainly applied on lichen-rich, sandy sedimentary soils, whereas the disc trenched control sites often were located on stony soil with less lichen cover.

The systematic differences in site characteristics may have affected the results from the study. Scarification on sandy sediments typically results in more visible soil disturbance, whereas on stony sites much of the mechanical impact from the scarification is absorbed by stones rather than the organic layer, resulting in lower disturbance of vegetation. Site features such as soil texture, stoniness, and soil wetness have previously been demonstrated to strongly influence the proportion of disturbed area during scarification (Saksa et al. 2018; Ring & Sikström 2024). Given that disc-trenched sites generally were located on more stony soils in this study, the measured soil disturbance may have been underestimated. This suggests that the difference in disturbance levels between the methods would have been even greater if the disc-trenched sites had been under the same conditions as the soil inversion sites. A previous study conducted by Saursaunet et al (2018) used a “other cover” classification during inventory following scarification. The methodology used in the present study could have been improved by classifying larger stones and obstacles as “other cover” if they were assumed to have absorbed the mechanical impact that otherwise would have disturbed soil, ground and field vegetation. However, difficulty in determining these occurrences would also introduce uncertainty and subjective assessment that potentially could bias the results.

Soil disturbance from other operations than MSP, such as wheel tracks from harvesting machines, can be difficult to separate in field settings. Disturbances from non-MSP sources were excluded as far as possible, but a subjective assessment is always required to determine whether a disturbance originates from the scarification tool or from other machinery. This introduces a potential source of error, although the risk is present for both treatment groups. Challenges with separating disturbances depending on their origin have been acknowledge by other studies, and to further develop the methodology, a third group representing harvested sites without scarification treatment could have been included, as done by Hallsby (2004). This would give an estimation of how much of the disturbances that are expected to occur regardless of scarification, and how much it increases when scarification is performed.

The plot sampling design in this study was systematic, which increases statistical efficiency and ensures good spatial coverage. However, systematic sampling can be problematic if the grid coincides with other regular spatial patterns (McRoberts et al. 2015). Soil scarification is typically performed in a systematic layout, and if the sampling grid unintentionally aligns with the scarification pattern, over- or underestimation may occur depending on whether sample plots are positioned directly in furrows or between them.

Another source of uncertainty is the variation in how disc trenching is performed. Different machines, operators, settings, blade angels and pressures can produce varying disturbance patterns (Ersson et al. 2017). In this study, there was no way to control such operational differences. In contrast, soil inversion with Kicken was carried out with the same machine across all sites, which likely reduced the variance within that treatment group.

4.6 Future research

This study quantified the surface area of disturbance and did not assess the depth or structure of the disturbance. Depth of disturbance is a crucial factor for the degree of impact on ecological and cultural values. Previous research has estimated the depth of disturbance after soil inversion to be comparable to mounding, implying similar risks of damaging cultural remains (Hallsby 2004). Scarification with intermittent methods, such as soil inversion, has been recognized to damage fewer dead wood logs, which are an important ecological source, compared to disc trenching (Magnusson 2015). A systematic comparison of disturbance depth and impact on dead wood between soil inversion with Kicken and other scarification methods would provide a more complete understanding of their effects on ecological and cultural values.

The survey was conducted in northern Sweden (Västerbotten county) on sandy, lichen-rich pine sites. Conditions across Sweden vary considerably in terms of soil type, ground and field vegetation, and soil moisture. Consequently, the results cannot be assumed to apply to all forest types. Further research where soil inversion is applied on other conditions would help assess the generalization of this study. Furthermore, in this study sample plots dominated by lichen were more frequent on soil inversion sites than on control sites. This raises the question whether this distribution is a consequence of soil inversion being used more frequently on lichen soils, or if lichen is more abundant on soil inversion sites due to less disturbed area following Kicken. To investigate this further, a study where ground and field vegetation cover is assessed before and after treatment would be necessary to determine the cause of effect. This could also include a more detailed inventory of species and composition to determine to which degree disturbance from scarification alters species composition in the long-term.

The result from this inventory concludes that soil inversion with Kicken has high potential to lower soil disturbance in reindeer grazing areas, preventing loss of ground lichen. However, the potential is limited to areas where the machine and local conditions are suitable. To evaluate the large-scale potential for this scarification method, an analysis could be conducted to identify potential areas for soil inversion and help decision makers prioritize to maximize the utility. Previous studies have concluded that soil inversion can be a favourable alternative to mounding since both methods are suitable for sites with a low proportion of large stones and rocks (Hallsby 2004). Since both soil inversion and mounding often is more applicable on the same soil type and conditions, a comparison between the methods could help understand which scarification method that is most suitable depending on the local site conditions.

The most used MSP-methods, disc trenching and mounding, have been used extensively for a long time, and economic analysis of the two methods have been done (Uotila et al. 2010). Lack of technical equipment has earlier been pointed out as one of the main factors for limited operational use of soil inversion (Johansson et al. 2013), which has led to inadequate knowledge of costs and productivity in operational use. New innovations, such as Kicken and autonomous systems, require new knowledge of cost and productivity in different settings. Compared to disc trenching, soil inversion using Kicken has a less negative impact on the environment, but for the method to become competitive, economical aspects must be weighed in. There is also a lack of knowledge on how site conditions, for example larger rocks, affect the productivity and scarification quality of Kicken. Soil inversion has the potential to substantially reduce environmental impact and may therefore be an interesting method when developing new site preparations methods. Future research could evaluate how soil inversion performs in autonomous settings. High precision autonomous scarification using machine learning has the potential to further reduce disturbances and improve regeneration conditions by limiting unnecessary disturbances and adapt site preparation to site conditions, but more research is needed.

4.7 Conclusions

Soil inversion using Kicken resulted in substantially lower soil disturbance level than conventional disc trenching on lichen-rich sites in northern Sweden, with total disturbed surface area measured at 1.5% compared to 12.1%. The study indicated a lower severity of disturbances on soil and vegetation following soil inversion compared with disc trenching. In contrast to current scarification methods, soil inversion performed with Kicken has the potential to mitigate conflicting objectives and better balance multiple forest values and may be of particular interest in reindeer grazing areas. Further research is needed to assess applicability of soil inversion across diverse site conditions and how the method can become economically competitive with conventional methods.

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References

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

Blattert, C., Mönkkönen, M., Burgas, D., Di Fulvio, F., Toraño Caicoya, A., Vergarechea, M., Klein, J., Hartikainen, M., Antón-Fernández, C., Astrup, R., Emmerich, M., Forsell, N., Lukkarinen, J., Lundström, J., Pitzén, S., Poschenrieder, W., Primmer, E., Snäll, T. & Eyvindson, K. (2023). Climate targets in European timber-producing countries conflict with goals on forest ecosystem services and biodiversity. *Communications Earth & Environment*, 4 (1), 119. https://doi.org/10.1038/s43247-023-00771-z

Chaves Cardoso, J., Burton, P.J. & Elkin, C.M. (2020). A Disturbance Ecology Perspective on Silvicultural Site Preparation. *Forests*, 11 (12), 1278. https://doi.org/10.3390/f11121278

Chen, S., Chen, J., Jiang, C., Yao, R.T., Xue, J., Bai, Y., Wang, H., Jiang, C., Wang, S., Zhong, Y., Liu, E., Guo, L., Lv, S. & Wang, S. (2022). Trends in Research on Forest Ecosystem Services in the Most Recent 20 Years: A Bibliometric Analysis. *Forests*, 13 (7), 1087. https://doi.org/10.3390/f13071087

Eggers, J., Roos, U., Lind, T. & Sandström, P. (2024). Adapted forest management to improve the potential for reindeer husbandry in Northern Sweden. *Ambio*, 53 (1), 46–62. https://doi.org/10.1007/s13280-023-01903-7

Ersson, B.T., Cormier, D., St-Amour, M. & Guay, J. (2017). The impact of disc settings and slash characteristics on the Bracke three-row disc trencher's performance. *International Journal of Forest Engineering*, 28 (1), 1–9. https://doi.org/10.1080/14942119.2017.1272286

Ersson, B.T., Hansson, L., Manner, J., Sandström, P. & Sonesson, J. (2023). Forest management in northern Fennoscandia: the need for solutions that mitigate conflicts during forest regeneration and increase the use of continuous cover forestry. *Silva Fennica*, 57 (3). https://doi.org/10.14214/sf.23053

Granström, A. (2026). *Growth of Pinus sylvestris 6-11 years after inverted site preparation.* (Examensarbeten). Swedish University of Agricultural Sciences. Department of Forest Ecology and Management

Hallsby, G. (2004). A comparison of mounding and inverting to establish Norway spruce on podzolic soils in Sweden. *Forestry*, 77 (2), 107–117. https://doi.org/10.1093/forestry/77.2.107

Hannerz, M., Lindhagen, A., Forsberg, O., Fries, C. & Rydberg, D. (2016). *Skogsskötsel för friluftsliv och rekreation*

Hansson, L. (2019). *Impacts of forestry operations on soil physical properties, water and temperature dynamics*. (Diss). Swedish University of Agricultural Sciences. https://res.slu.se/id/publ/104077

Hansson, L. & Forsmark, V. (2020). *Attityder till markberedning hos privata skogsägare*. https://www.skogforsk.se/kunskapsbanken/kunskapsartiklar/2020/attityder-till-markberedning/ [2025-10-30]

Hansson, L., George, M.R. & Gärdenäs, A.I. (2014). Markberedning i svenskt skogsbruk nu och i framtiden med fokus på miljökonsekvenser litteraturstudie och expertintervjuer med Skogsstyrelsen och Skogforsk (Site preparation in Swedish Forestry now and in the future - litterature review and expert interviews with the Swedish Forestry Agency and the Forestry Research Institute of Sweden). https://doi.org/10.13140/RG.2.2.10282.82887

Hansson, L.J., Sten, G., Rossander, M., Lideskog, H., Manner, J., van Westendorp, R., Li, S., Eriksson, A., Wallner, A., Rönnqvist, M., Flisberg, P., Edlund, B., Möller, B. & Karlberg, M. (2024). Autoplant—Autonomous Site Preparation and Tree Planting for a Sustainable Bioeconomy. *Forests*, 15 (2), 263. https://doi.org/10.3390/f15020263

Hansson, L. (2014). *Schematiska skisser av harvning/fläckmarkberedning, högläggning, inversmarkberedning samt hyggesplöjning.* [Sketch]. https://www.researchgate.net/doi/10.13140/RG.2.2.10282.82887. [2025-01-10]. Used with permission from the creator.

Hjelm, K., Nilsson, U., Johansson, U. & Nordin, P. (2019). Effects of mechanical site preparation and slash removal on long-term productivity of conifer plantations in Sweden. *Canadian Journal of Forest Research*, 49 (10), 1311–1319. https://doi.org/10.1139/cjfr-2019-0081

Horstkotte, T. (2022). *Reindeer Husbandry and Global Environmental Change: Pastoralism in Fennoscandia*. Taylor & Francis Group. (Earthscan Studies in Natural Resource Management Series)

Johansson, K., Nilsson, U. & Örlander, G. (2013). A comparison of long-term effects of scarification methods on the establishment of Norway spruce. *Forestry: An International Journal of Forest Research*, 86 (1), 91–98. https://doi.org/10.1093/forestry/cps062

Kramer, K., Brinkman, B., Loek, K. & Verdonschot, P. (2005). Is ecological succession predictable?

Krekula, B., Bergqvist, J., Fries, C., Gällerspång, J., Reisek, J., Ringagård, J., Sollander, E., Svensson, L. & Wågström, K. (2018). *Föreskrifter för anläggning av skog*

Kruskal, W.H. & Wallis, W.A. (2012). Use of Ranks in One-Criterion Variance Analysis. *Journal of the American Statistical Association*. 47(260), 583-621. https://www.tandfonline.com/doi/abs/10.1080/01621459.1952.10483441

Spearman, C. (1904). The Proof and Measurement of Association between Two Things. *The American Journal of Psychology.* 15(1), 72-101. https://doi.org/10.2307/1412159

Magnusson, L. (2015). *Soil scarification in bouldery terrain*. (Examensarbeten). Swedish University of Agricultural Sciences. Department of Forest Ecology and Management. http://urn.kb.se/resolve?urn=urn:nbn:se:slu:epsilon-s-4212 [2025-12-01]

Mandal, A.K. & Nicodemus, A. (eds) (2025). *Textbook of Forest Science*. Springer Nature Singapore. https://doi.org/10.1007/978-981-97-8289-5

McRoberts, R.E., Tomppo, E.O. & Czaplewski, R.L. (2015). *Knowledge reference for national forest assessments*. Food and Agriculture Organization of the United Nations.

Nilsson, U. & Örlander, G. (1999). Vegetation management on grass-dominated clearcuts planted with Norway spruce in southern Sweden. *Canadian Journal of Forest Research*, 29 (7), 1015–1026. https://doi.org/10.1139/x99-071

Örlander, G., Hallsby, G., Gemmel, P. & Wilhelmsson, C. (1998). Inverting improves establishment of Pinus contorta and Picea abies— 10-year results from a site preparation trial in Northern Sweden. *Scandinavian Journal of Forest Research*, 13 (1–4), 160–168. https://doi.org/10.1080/02827589809382972

Paine, R.T. (2012). *Ecological disturbance*. *Britannica*. https://www.britannica.com/science/ecological-disturbance/Characteristics-of-disturbance-and-recovery [2025-12-03]

Prévosto, B., Bousquet-Mélou, A., Ripert, C. & Fernandez, C. (2011). Effects of different site preparation treatments on species diversity, composition, and plant traits in Pinus halepensis woodlands. *Plant Ecology*, 212 (4), 627–638. https://doi.org/10.1007/s11258-010-9852-4

Ring, E. & Sikström, U. (2024). Environmental impact of mechanical site preparation on mineral soils in Sweden and Finland — a review. *Silva Fennica*, 58 (1). https://doi.org/10.14214/sf.23056

Roturier, S., Sundén, M. & Bergsten, U. (2011). Re-establishment rate of reindeer lichen species following conventional disc trenching and HuMinMix soil preparation in Pinus-lichen clear-cut stands: a survey study in northern Sweden. *Scandinavian Journal of Forest Research*, 26 (2), 90–98. https://doi.org/10.1080/02827581.2010.528019

Roturier, S. (2010). Markberedning på vinterbetesland. Fakta. Skog, (2010:6). https://res.slu.se/id/publ/31782 [2026-02-13]

Saksa, T., Miina, J., Haatainen, H. & Kärkkäinen, K. (2018). Quality of spot mounding performed by continuously advancing mounders. *Silva Fennica*, 52 (2). https://doi.org/10.14214/sf.9933

Sandström, P., Cory, N., Svensson, J., Hedenås, H., Jougda, L. & Borchert, N. (2016). On the decline of ground lichen forests in the Swedish boreal landscape: Implications for reindeer husbandry and sustainable forest management. *Ambio*, 45 (4), 415–429. https://doi.org/10.1007/s13280-015-0759-0

Saursaunet, M., Mathisen, K.M. & Skarpe, C. (2018). Effects of Increased Soil Scarification Intensity on Natural Regeneration of Scots Pine Pinus sylvestris L. and Birch Betula spp. L. *Forests*, 9 (5), 262. https://doi.org/10.3390/f9050262

SFS 1971:437 (n.d.). *Rennäringslagen*

SFS 1979:429 (n.d.). *Skogsvårdslagen*

SFS 1979:791 (n.d.). *Skogsvårdsförordning*

Sikström, U., Hjelm, K., Holt Hanssen, K., Saksa, T. & Wallertz, K. (2020). Influence of mechanical site preparation on regeneration success of planted conifers in clearcuts in Fennoscandia – a review. *Silva Fennica*, 54 (2). https://doi.org/10.14214/sf.10172

Skogsaktuellt (2014). *Bracke Forest har fokus på skogsföryngring*. *Skogsaktuellt*. https://www.skogsaktuellt.se/artikel/46435/bracke-forest-har-fokus-pa-skogsforyngring.html [2025-11-19]

Skogskunskap (2024). *Markberedning*. *Skogskunskap*. https://www.skogskunskap.se/hansyn/hansyn-till-rennaring/rennaring-och-skogsbruk/markberedning/ [2025-10-31]

Skogskunskap (n.d.). *Markvegetation*. *Skogskunskap*. https://www.skogskunskap.se/rakna-med-verktyg/mata-skogen/markvegetation/ [2025-11-20]

Skogsstyrelsen (2024a). *Åtgärdsstatistik i skogsbruket*. *Skogsstyrelsen*. https://www.skogsstyrelsen.se/statistik/skogsskotsel/atgarder-i-skogsbruket/ [2025-10-30]

Skogsstyrelsen (2024b). *Statistik om kulturmiljöhänsyn vid föryngringsavverkning*. *Skogsstyrelsen*. https://www.skogsstyrelsen.se/statistik/miljohansyn/kulturmiljohansyn-vid-foryngringsavverkning/ [2025-10-30]

Skogsstyrelsen (2025). *Plantering av skog*. *Skogsstyrelsen*. https://www.skogsstyrelsen.se/bruka-skog/ny-skog-efter-avverkning/plantering/ [2025-11-21]

SKSFS 2011:7 (n.d.). *Skogsstyrelsens föreskrifter och allmänna råd till Skogsvårdslagen*

Skyttmos Skogsentreprenad AB (n.d.). *Skyttmos Skogsentreprenad AB*. https://www.skyttmos.se/Markberedning [2025-12-16]

Sörensen, R., Johansson, F. & Gålnander, H. (2023). *Ökad skogsproduktion och förbättrad miljöhänsyn*

Stendahl, J. (2025). *Jordart*. *SLU*. https://www.slu.se/om-slu/organisation/institutioner/mark-miljo/miljoanalys/markinfo/markprofil/jordart/ [2025-11-20]

Sundblad, L.-G. & Hajek, J. (2015). *Inversmarkberedning - ett bra alternativ till harv*. *Skogforsk*. https://www.skogforsk.se/kunskapsbanken/kunskapsartiklar/2015/invers_alternativ_till_harv/ [2025-10-31]

Sveriges lantbruksuniversitet (2025). *Markfuktighet*. https://www.slu.se/om-slu/organisation/institutioner/mark-miljo/miljoanalys/markinfo/standort/markfuktighet/ [2025-11-20]

Uotila, K., Luoranen, J., Saksa, T., Laine, T. & Heiskanen, J. (2022). Long-term growth response of Norway spruce in different mounding and vegetation control treatments on fine-textured soils. *Silva Fennica*, 56 (4). https://doi.org/10.14214/sf.10762

Uotila, K., Rantala, J., Saksa, T. & Harstela, P. (2010). Effect of soil preparation method on economic result of Norway spruce regeneration chain. *Silva Fennica*, 44 (3). https://doi.org/10.14214/sf.146

Wallertz, K., Björklund, N., Hjelm, K., Petersson, M. & Sundblad, L.-G. (2018). Comparison of different site preparation techniques: quality of planting spots, seedling growth and pine weevil damage. *New Forests*, 49 (6), 705–722. https://doi.org/10.1007/s11056-018-9634-8

Westendorp, R. (n.d.). [photo]. [2026-02-12]. Used with permission from the creator.

Wheater, C.P., Bell, J.R. & Cook, P.A. (2020). *Practical Field Ecology*. John Wiley & Sons.

Zhao, X., Corral-Rivas, J., Zhang, C., Temesgen, H. & Gadow, K. v. (2014). Forest observational studies-an essential infrastructure for sustainable use of natural resources. *Forest Ecosystems*, 1 (1), 8. https://doi.org/10.1186/2197-5620-1-8

Popular science summary

Forests play a key role in society's transition towards a sustainable development. As trees are cut down to become bio-based products, new trees must be re-planted to ensure sustainable forestry. To ensure successful regeneration of new forests, scarification is often performed prior to planting to improve growth conditions for new seedlings. Although scarification is beneficial for forest regeneration, negative impacts on the environment following scarification have been reported.

Today's scarification methods affect a large proportion of the soil surface in the forest and removes a large proportion of the vegetation. This is a problem in particular reindeer grazing areas where ground lichens are used a fodder for reindeer grazing. The immediate removal of lichens following scarification leads to a conflict between wood production and reindeer herding. To mitigate these conflicts, new scarification methods are needed that reduces the impact and disturbance on vegetation.

In this study, the new soil inversion scarification implement Kicken was investigated by conducting a field inventory in northern Sweden. Soil disturbances 8-12 years after harvest where measured and classified depending on the severity. The levels of disturbance following Kicken were compared to conventional disc trenching, which is the conventional and most used scarification method in Sweden as of today.

The results from the study proved that Kicken leads to substantially lower soil disturbances levels compared to disc trenching and suggests that Kicken may be an important tool in areas where soil disturbance must be minimized. Vegetation recovery had a significant recovery when measuring disturbance levels on disc trenched sites harvested at different years. No significant recovery could be observed for sites treated with soil inversion.

In conclusion, the result from this study suggests that Kicken is a suitable scarification implement on sites where various stakeholders coexist and where impact on environment must be minimized. However, the method is not suitable on all areas, and further research is needed to fully understand the potential.

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SENASTE UTGIVNA NUMMER

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
2026:03	Författare: August Hedberg Human Tree-Selection Behaviour in Continuous Cover Forestry Insights from Marteloscope Exercises
2026:04	Författare: Johannes Turesson Comparison of Soil Inversion and Disc Trenching: Soil Disturbance on Regeneration Sites in Northern Sweden 5-10 years after scarification. Gentle Scarification Using the Kicken Implement.