Efficiency of chemical and mechanical plant protection on sites without mechanical site preparation in Scania

Effektivitet av kemiska och mekaniska plantskydd på icke markberedda hyggen i Skåne

Gustav Nylander

Master's thesis • 30 hp
Swedish University of Agricultural Sciences, SLU
Southern Swedish Forest Research Centre
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Abstract

An important part of the regeneration after clearcutting is to have a high growth and a high level of survival of the planted seedlings. A big threat to the seedlings is the pine weevil (*Hylobius abietis*), but the black spruce beetle (*Hylastes conicularius)* can cause some serious damage too, as well as *Strophosoma capitatumn*. Mechanical site preparation in combination with some sort of plant protection reduces the damage, but in some cases here in Sweden, mechanical site preparation is not possible due to cultural remains or technical reasons. And, with chemical protections being phased out of Swedish forestry, it's important to understand the efficiency of mechanical plant protection compared to chemical on sites without mechanical site preparation. Therefore, the objective of this study was to see what the consequences could be when replacing chemical protection with mechanical protection on fresh or one year old clear-cuts. The results showed that seedling mortality caused by pine weevils was 3,5% for mechanical protection and 2,4% for chemical protection. The seedling mortality caused by the black spruce beetle was 3,0% for mechanical protection and 4,2% for the chemical protection. No significant difference was seen between the two treatments when looking at damage caused by pine weevil, black spruce beetle and S*trophosoma capitatumn*, neither did it affect total height and shoot height.

Keywords: Pesticide, Mechanical protection, Pine Weevil, *Hylobius abietis*, Black spruce beetle, *Hylastes conicularius, Strophosoma capitatum,* No mechanical site preparation, Norway spruce, *Picea abies*, Regeneration, Seedlings, Hylonox, Imprid Skog, Forester, Woodcoat, wax

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1. Introduction

The Swedish productive forests consist of 82% conifer forest (SLU, 2021). It is common to manually plant conifers one to three years after the clear-felling has been carried out (Skogsstyrelsen, 2021c). 80% of all regenerated areas in Sweden are planted, and Norway spruce is the most common species to plant (Sikström *et al.*, 2020). In 2020 the containerized seedling stood for 87% of all the seedlings produced, 11% were bareroot seedlings and 3% were hybrid seedlings (Skogsstyrelsen, 2020). In Sweden, mechanical site preparation is used on the majority of the planted sites. Site preparation favours the growth of the seedlings, reduces damage by pine weevil, reduces competition from vegetation and gives the seedlings a more secure access to water and nutrients (Nilsson & örlander, 1999; Nilsson *et al.*, 2010). But in some cases, it's not possible to apply site preparation due to cultural values or because the competition from naturally regenerated seedlings like birch that will outweigh the benefits (Skogsstyrelsen, 2021b).

To avoid insect damage on planted seedlings, the seedlings were commonly treated with insecticides at the nursery before planting and then treated annually in field (Långström & Day, 2007). The seedlings were treated annually because the chemical protection lost its effectiveness after one year (Viiri *et al.*, 2007). Chemical protections have been used for a long time but as of 2021 there are only two chemical protection agents that are allowed to be used in forestry and the permission for those two will run out in November 2021 and in November 2022 (Kemikalieinspektionen, 2021.a; Kemikalieinspektionen, 2021.b). In forests certified by FSC and PEFC the use of chemical protection is completely banned (FSC 2019; PEFC 2017). Due to those heavy restrictions, mechanical protections have been developed as an alternative to insecticides. Mechanical protections are often applied in the nursery by coating the stem of the seedling acting as a feeding barrier (Nordlander *et al.*, 2009). During 2020, 53% of all seedlings planted in Sweden had some sort of protection against insect damage, whereof 50% had mechanical protection and 3% of all seedlings supplied where chemically treated (Fig. 1). The trend shows that the mechanical protection is increasing while the chemical protection is decreasing (Skogsstyrelsen, 2021a). Forest owners are very sceptical and believe the change from chemical to mechanical protection will cause more damage from the pine weevil, black spruce beetle and *Strophosoma capitatum.* Because research behind the two protection types is limited, some forests owners are sceptical to the change from insecticides to mechanical protection.

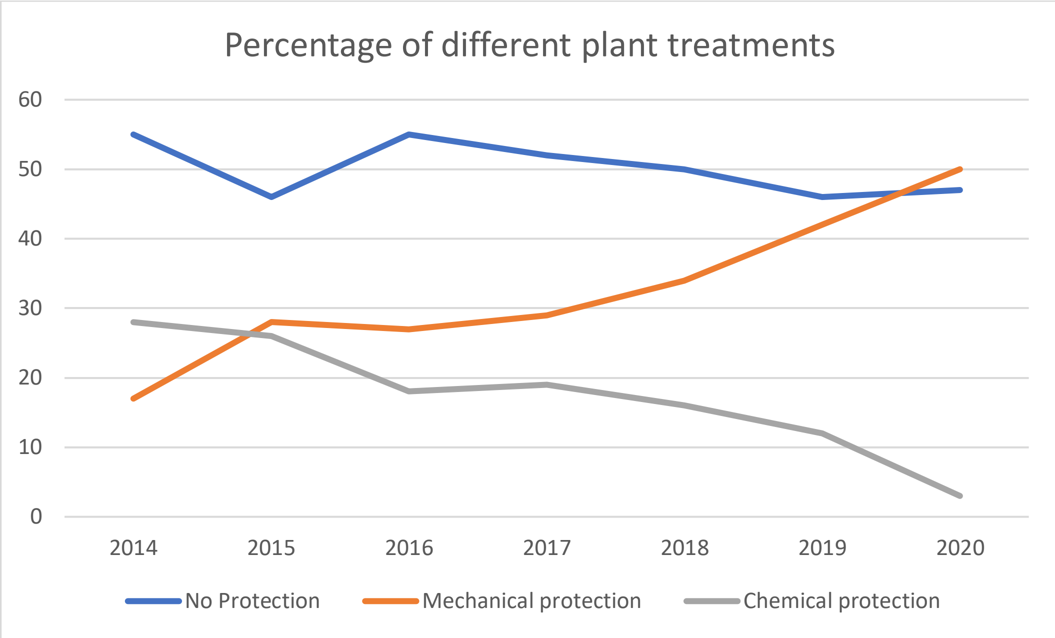

Figure 1. (Skogsstyrelsen, 2021a) *the percentage of different protection types applied to seedling in Sweden from 2014-2020*

1.1. Pine weevil

The pine weevil, (*Hylobius abietis* (L.)) is the forest pest that causes one of the highest economical losses in regenerations. The weevils feed on the cambium of conifer seedlings and sometimes kill the seedling in this process (Day et al., 2004; Day & Leather, 1997; Långström & Day, 2004). With no chemical or mechanical protection on sites without mechanical site preparation, mortality can be as high as 80% after three years. This was confirmed in a study, which showed that after the first growing season after clear cutting, about 80-90% of the seedlings had some degree of damage from pine weevil (von Sydow, 1997). To minimise damage from pine weevils mechanical coatings or chemical protection are applied in the nursery to prevent the pine weevils from causing damage to the seedling (Petersson and Örlander, 2003).

In southern Sweden reports have shown average mortality to vary between 38%-63% on unprotected seedlings planted without site preparation (Eriksson *et al.*, 2017; Eriksson *et al.*, 2018). It has been shown earlier that after one year about 10-15% of all seedlings treated with mechanical coatings on sites without site preparation had died due to the pine weevils and in the same experiment only 1-2% of the chemically protected seedlings died (Petersson & Örlander, 2003). However, in recent reports the mechanical protection is just as effective in repelling pine weevils as the chemical protection (Eriksson *et al.,* 2018).

There are several ways to reduce damage from pine weevils. The use of site preparation can reduce damage in the stand to about 20% compared to no site preparation. In one study, no site preparation lead to 60% mortality after one growing season (Wallertz *et al.*, 2018). The use of shelterwood can also reduce damage. As an example it was reduced from 82% in the clear cut area to 58% in the shelterwood over the span of one growing season (Nordlander *et al.*, 2003). Another way to reduce damage from pine weevils is to plant three to five growing seasons after harvest since the feeding pressure from pine weevils is highest during the first three growing seasons, and decrease to very low levels in the fifth growing season after harvest (von Sydow, 1997; Örlander and Nilsson, 1999). The pine weevils use newly clear-felled stands as their breeding ground and the pine weevil will feed on the cambium of seedlings occasionally girdling them. (fig. 2) (Day & Leather, 1997; Långström & Day, 2007). The life cycle of the pine weevil is divided into the following steps (Nordlander, 1987; Nordenhem, 1989):

One growing season after harvest: The first generation of pine weevils will swarm to the clear-cut attracted by the chemicals released from the stumps. They will feed on the nearby vegetation and females will lay eggs in the roots of the newly harvested trees.

Two growing seasons after harvest: During spring and early summer the pine weevils that hibernated on the site will continue feeding until early summer and then most of them will swarm and find a new clear-cut. During late summer and autumn, the second generation is hatched and will feed on the vegetation, including the seedlings, before going into hibernation.

Three growing seasons after harvest: The second generation, like the first generation, will feed during spring before swarming in the summer and hence the majority of the weevils will leave.

Fourth and fifth growing season after harvest: the process repeats itself but this time with the offspring that choose not to leave the clear-cut but instead stay and breed for one more year, i.e., with reducing numbers the older the clear-cut gets.

Figure 2.. "Pågående snytbaggegnag" by Claes Hellqvist. A picture depicting damages done by the pine weevil feeding on the cambium.

1.2. Black spruce beetle

The black spruce beetle *(Hylastes cunicularius)* primarily breeds on Norway spruce (Saalas, 1923), but can occasionally be found on Scots pine (Palm 1931). The black spruce beetle is attracted to a mixture of α-pinene and ethanol that is released in masse from clear-cuts and therefore there are higher populations of the black spruce beetles on clear-cuts (Lindelöw et al., 1993). The black spruce beetle is a pest that can cause an accumulated mortality of approximately 25% of all the seedlings in the first seven growing seasons after clear-cutting in northern Sweden, where damage are the most severe (Lindelöw, 1992 a). The black spruce beetle will reach its peak on the amount of damage caused between the fourth and sixth growing season after harvest, and it will decrease to very low levels in the seventh growing season. (Lindelöw, 1992 a). The black spruce beetle will feed on the phloem of the roots and occasionally on the root collar of the seedlings if no other fresh phloem is available (fig. 3) (Lindelöw, 1992 b). The damage by black spruce beetle can sometimes be confused by drought or other abiotic damage since it's not always visible above ground, and when it's visible above ground it is commonly confused with pine weevil damage.

Figure 2." Gnag av svart bastborre på granplanta" by Claes Hellqvist. A picture depicting damages caused by black spruce beetle on a spruce plant where it has eaten both on the roots and on the stem.

1.3. *Strophosoma capitatum*

The *Strophosoma capitatum* have two periods during the growing season, lasting about three weeks, when it is active, in spring and in the autumn. Then the *Strophosoma capitatum* will feed on the needles of the leader and the upper whorls of conifers and other plants (fig. 4) (Nielsen *et al.*, 2006). *Strophosoma capitatum* does not possess the ability to fly and have to move by foot. Therefore they rarely cause any major damage on newly planted clear-cuts, but occasionally the local population is large enough to kill some of the seedlings when they are forced to feed on the bark instead of the needles (Lindelöw, 2021).

Figure 3. " Angrepp av ögonvivel på granplanta" by Claes Hellquist. Damages caused by Strophosoma capitatum on a Norway spruce seedling.

1.4. Purpose and hypothesis

The purpose of this study was to understand the differences in the effectiveness of preventing insect damage between mechanical and chemical protection of seedlings planted on sites without site preparation. There are few studies published on the efficiency of mechanical and chemical protection on sites without site preparation, so this knowledge is currently lacking. The null hypothesis is that the chemical protection will be more effective than the mechanical protection in reducing insect damage. Therefore, chemical protection will also show an increase in total height and shoot height compared to the mechanical protection.

2. Materials and methods

19 sites were used in this study to identify the differences between mechanical and chemical protection. The sites used in the study where clear-felled during winter 2019-2020 and planted in the spring of 2020. The sites were planted with Norway spruce seedlings, either bareroot or large containerised seedlings, that had been treated with either chemical protection or a mechanical coating. The mechanical coatings used where either Woodcoat, Hylonox or a wax coating. No differentiation was made between these three mechanical coatings. No site preparation was made prior to planting. A selection of the sites was obtained from foresters in charge of replanting from the companies Sydved, Sundins skogsplantor, Derome and Skånetimmer. From the sites acquired from these companies the ones in closest proximity to each other and with similar site conditions were chosen for the study. The sites were located in the eastern or northern parts of Scania and in some cases in the southwestern part of the county Småland just a few kilometres from the border to Scania. Ten of the sites utilized mechanical protection and nine utilized chemical protection (Table 1.).

Table 1. Number of seedlings per ha is the inventoried amount of seedlings on each site, seedling type is explaining what type of seedling was planted "-" = no data, LC = large containerized seedlings, and B = bareroot seedlings. The coordinates are RT 90 2,5 gon V 0:-15. coordinates.

Stand Number	Number of seedlings per ha	Planted area	Seedling type	Coordinates	Protection type
1	2680	1,5	LC	6259448, 465456	Mechanical
2	2680	3,8	LC	6251914, 457759	Mechanical
3	1520	1,7	LC	6256918, 456443	Mechanical
4	2000	2,7	LC	6252994, 456949	Mechanical
5	1880	1,3	-	6267437, 419170	Mechanical
6	1520	0,9	B	6273150, 405347	Mechanical
7	1600	0,7	B	6237497, 416968	Mechanical
8	2120	7,2	B	6250157, 393286	Mechanical
9	1840	3,3	-	6275794, 405385	Mechanical
10	2440	1,5	-	6269345, 407180	Mechanical
11	3320	1,4	-	6194277, 432123	Chemical
12	1600	1	B	6201906, 435766	Chemical
13	1680	1,3	-	6230554, 409884	Chemical
14	2800	1,2	LC	6274039, 413079	Chemical
15	2440	1,2	LC	6250040, 399575	Chemical
16	3640	1,1	LC	6210312, 436136	Chemical
17	2640	1,1	-	6261797, 416384	Chemical
18	2120	0,8	-	6266469, 410162	Chemical
19	1800	1,5	B	6256709, 401263	Chemical

2.1. Seedling measurements

On every site 10 circular plots with a radius of 2,82 m were inventoried. The plots were evenly spaced out over the site with a 5-meter buffer zone from the edges of the sites. All the planted seedlings in the plots had their total height measurement taken and the height of the top shoot. The inventory of damage caused by pine weevil, black spruce beetle and *Strophosoma capitatum* was performed using a damage scale from 0-5:

0: equals no damage,

1: Traces of the bugs were shown on the seedlings,

2: Some damage but not enough to decrease growth the following year, 3 The growth was affected by the damage and that the following year the growth will probably be less than the current year,

4: The damage was severe, and the seedlings will probably die,

5: The damage caused by the bugs was so severe that the seedling was already dead.

For the black spruce beetle, it was in most cases registered as a 5 or a 0 on the damage scale since they usually feed on the roots of the seedling and it was only possible to check the roots on dead seedlings since the inventories were done on private forest land. But, occasionally, the black spruce beetle will feed on the root collar and the stem of the seedling while the seedling is still alive. The inventories were done during the time period of 21th of November to the 27th of December.

2.2. Statistical analyses

The statistical analysis was done in R studio by taking the average on every plot inventoried and then the average of all the plots in each stand. To put more focus on the plots than every individual seedling it will be mentioned as weighted mean onwards (appendix 1).

From this data two linear models where created: shoot height and total height were response variables with mechanical and chemical protection as the explanatory variables. Later, an Anova and a TukeyC test were run separately on the total height and the shoot height to compare the mechanical and chemical treatments (Appendix 2).

The statistical analysis on damage caused by pine weevil, black spruce beetle, and the *Strophosoma capitatum* was done by combining the classes; 1-5, 2-5, 3-5, 4-5 and just 5 and also by changing the values into either within the restrictions (1) or (0) outside of the restrictions to create binominal data. The data was weighted into means just like for the shoot height and total height. An arcsine transformation was used on the percentages of damaged seedlings since they were binominal. Then the data was put into a linear model where the damage of each bug were run together with the mechanical and chemical protection as the explanatory variabels. Herefter an Anova test and a TukeyC were used to see the statistical significance with a confidence interval of 0,05 as a way to check the null hypothesis (Fig. 16).

3. Results

3.1. Pine Weevil

The total inventory of damage showed that the pine weevil caused the most amount of damage on the seedlings and that it didn't matter what kind of protection was utilized. (Table 2, 3.).

Table 2. An explanation of how many damaged seedlings there were in each category for the mechanical protection. The total amount of seedlings inventoried where 507

	Damage Categories				
Type of damage: Mechanical	1	2	3	4	5
Pine weevil	93	36	25	5	13
Black spruce beetle	0	2	1	0	15
Strophosoma Capitatum	41	17	1	0	0
Other damages	8	47	44	4	23
Total number of seedlings affected	142	102	71	9	51

Table 3. An explanation of how many damaged seedlings there were in each category for the chemical protection. The total amount of seedlings inventoried where 551

	Damage Categories				
Type of damage: Chemical	1	2	3	4	5
Pine weevil	145	35	26	3	10
Black spruce beetle	2	0	0	0	23
Strophosoma Capitatum	22	4	3	0	0
Other damages	19	31	34	11	20
Total number of seedlings affected	188	70	63	14	53

The statistical analysis of pine weevil damage showed that there were no statistically significant differences between the two protection treatments. The least significant value was found when combining all categories of damage that yielded a P-value of 0,723 (Table 4). The one that was closest to being significant was categories 4-5 combined, i.e., seedlings that were dead or were going to die soon, which gave the P-value 0,195 and thus still not significant. Therefore, the hypothesis that the chemical protection will be more effective than mechanical protection can be rejected.

Table 4. The amount, in percent, of damage 1:5 means all damage within the categories 1,2,3,4 and 5 and the p-values.

	Damage categories				
Protection type	1:5	2:5	3:5	4:5	5
Chemical protection	39,7%	13,4%	7,1%	2,4%	1,8%
Mechanical protection	33,9%	15,5%	8,5%	3,5%	2,6%
p-value	0,723	0,198	0,295	0,195	0,381

Damage on seedlings with mechanical protection in the category 1 equals to 18,3% of the total number of seedlings, damages in the category 2 stands for 7,1% of the total number of seedlings (Fig 5). Damage within category 3 accounts for 4,9%. Damage within the categories 4 and 5 combined equals to 3,5% of the total number of seedlings inventoried.

Damage on on seedlings with chemical protection in the category 1 equalled to 26,3% of the total number of seedlings, damage in the category 2 stands for 6,3% of the total number of seedlings (Fig. 6). Damage within category 3 accounts for 4,7%. damages within the categories 4 and 5 combined equals to 2,4% of the total number of seedlings inventoried.

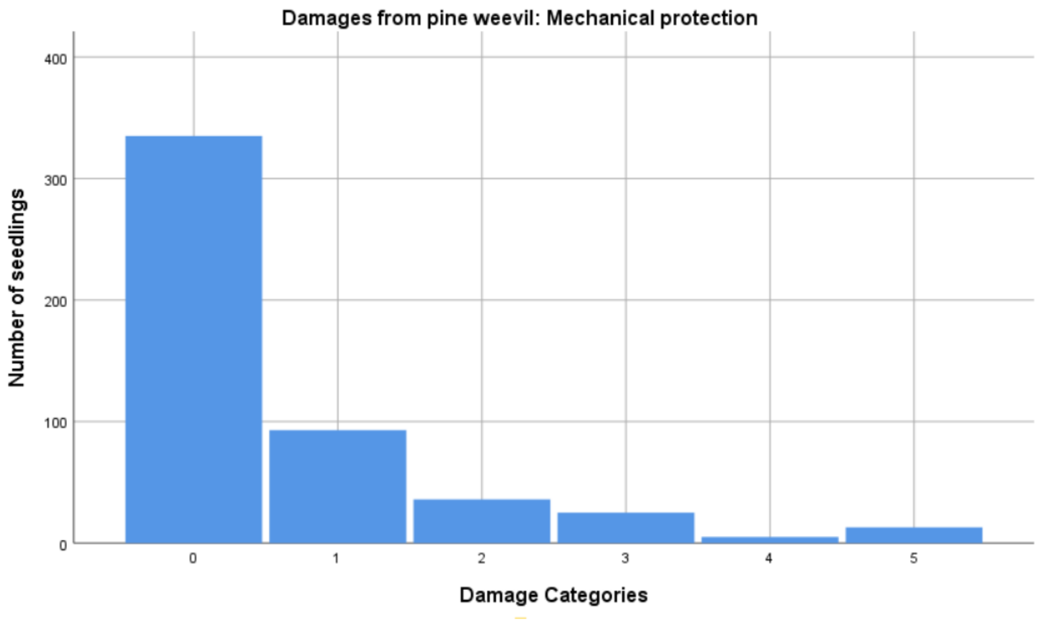

Figure 4. Number of seedlings in each damage category caused by pine weevils on mechanical protection. Total number of total seedlings is 507, Number of seedlings in each category; 1=93, 2=36, 3=25, 4=5, 5=13.

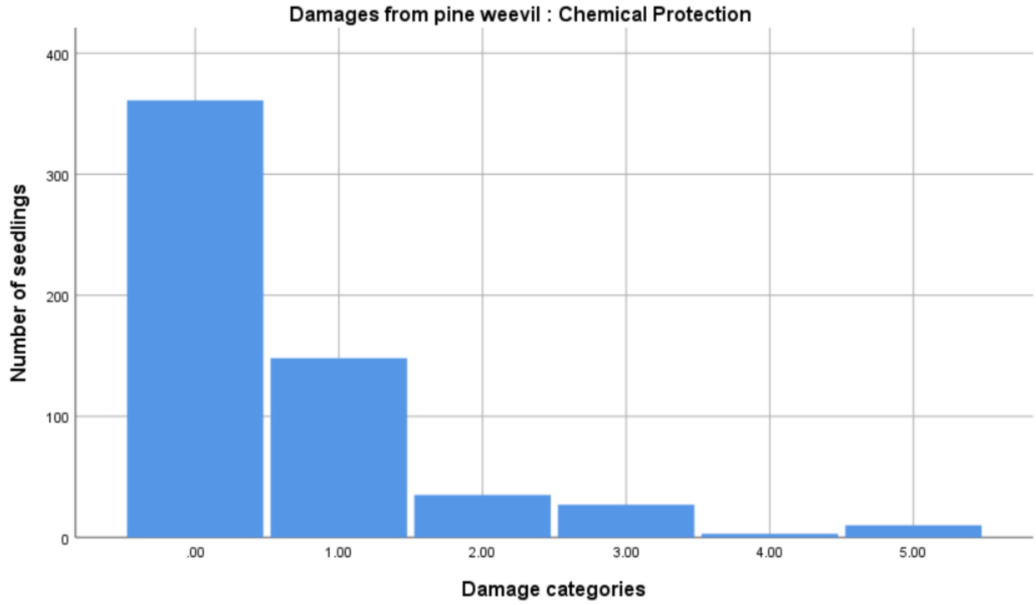

Figure 5. Number of seedlings in each damage category caused by pine weevils on Chemical protection. Total number of total seedlings is 551, Number of seedlings in each category; 1=145, 2=35, 3=26, 4=3, 5=10.

3.2. Black spruce beetle

The P value was only calculated for category 5 due to the distribution of damage (Figure 7, 8). The p-value for category 5 was 0,488. Since the value was higher than the significance level of 0,05, the null hypothesis that says that chemical protection is more efficient than mechanical protection can be rejected.

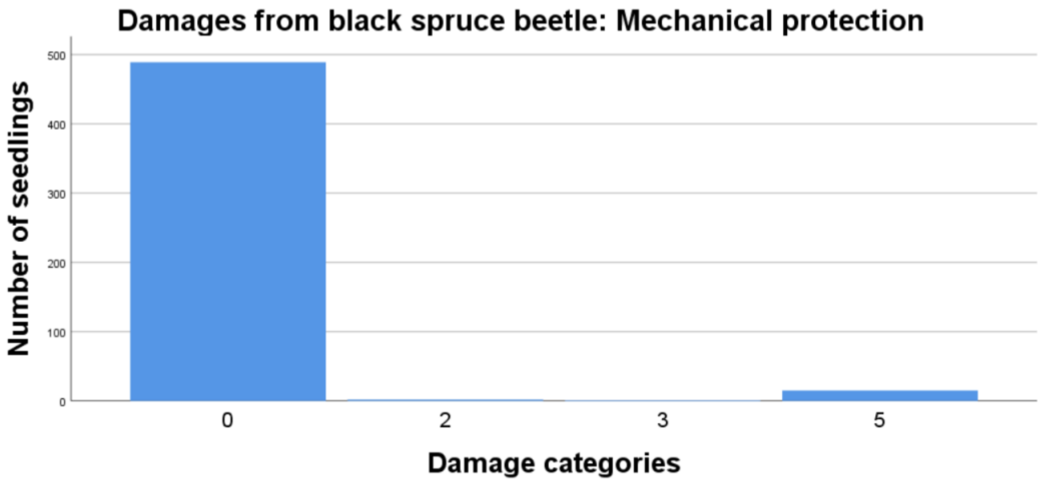

Figure 6. Number of seedlings in each damage category caused by Black spruce beetle on mechanical protection. Total number of total seedlings is 507, Number of seedlings in each category; 1=0, 2=2, 3=1, 4=0, 5=15.

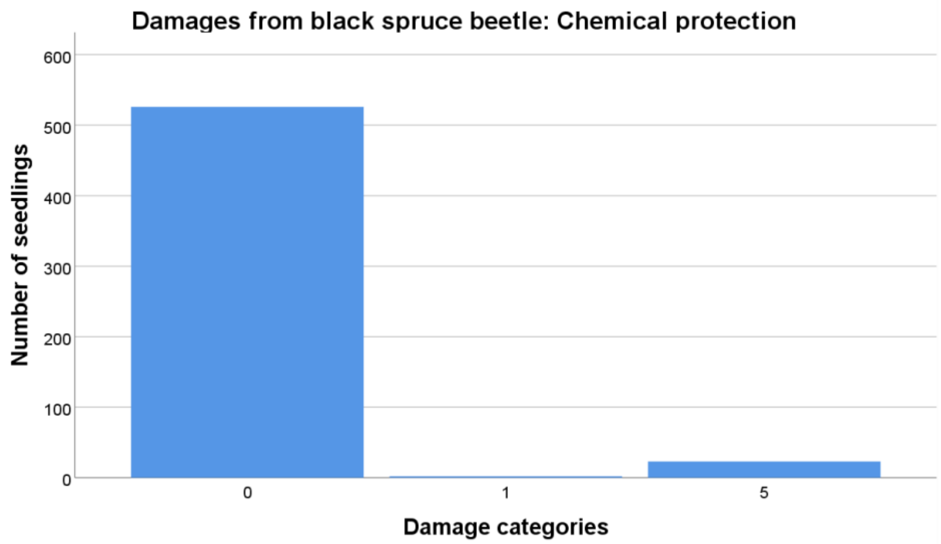

Figure 7. Number of seedlings in each damage category caused by Black spruce beetle on Chemical protection. Total number of total seedlings is 551, Number of seedlings in each category; 1=2, 2=0, 3=0, 4=0, 5=23.

3.3. Strophosoma Capitatum

The damaged caused by *Strophosoma capitatum* was not statistically significant. The P values varied from 0,066 in the categories 1:3 to 0,662 in category 3 (Table 5). A statistical analysis was made only on category 1 and gave the P-value 0,216. Since none of the results showed any statistical significance, the hypothesis can be rejected.

Table 5. The amount of damages 1:5 means all damage within the categories 1,2, and 3. the p-values from the statistical analysis

	Damage categories			
Protection type	1:3	2:3	3	1
Mean Chemical	5,7%	1,4%	0,6%	4,3%
Mean Mechanical	11,6%	3,5%	0,2%	8,1%
P-Values	0,066	0,100	0,662	0,216

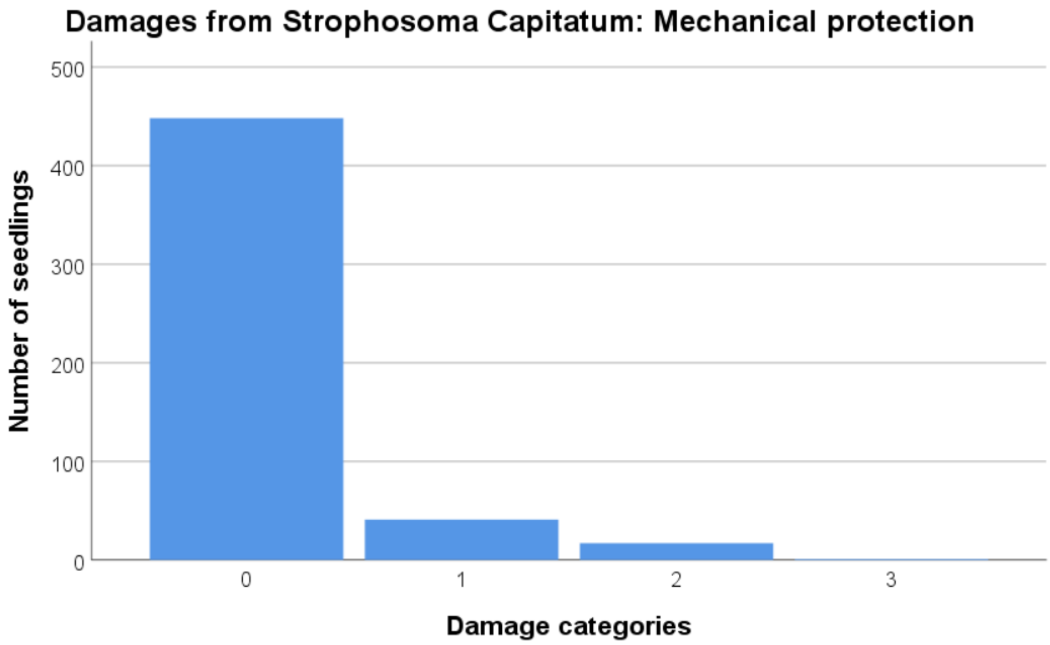

Figure 8. Number of seedlings in each damage category caused by Strophosoma capitatum on mechanical protection. Total number of total seedlings is 507, Number of seedlings in each category; 1=41, 2=17, 3=1, 4=0, 5=0.

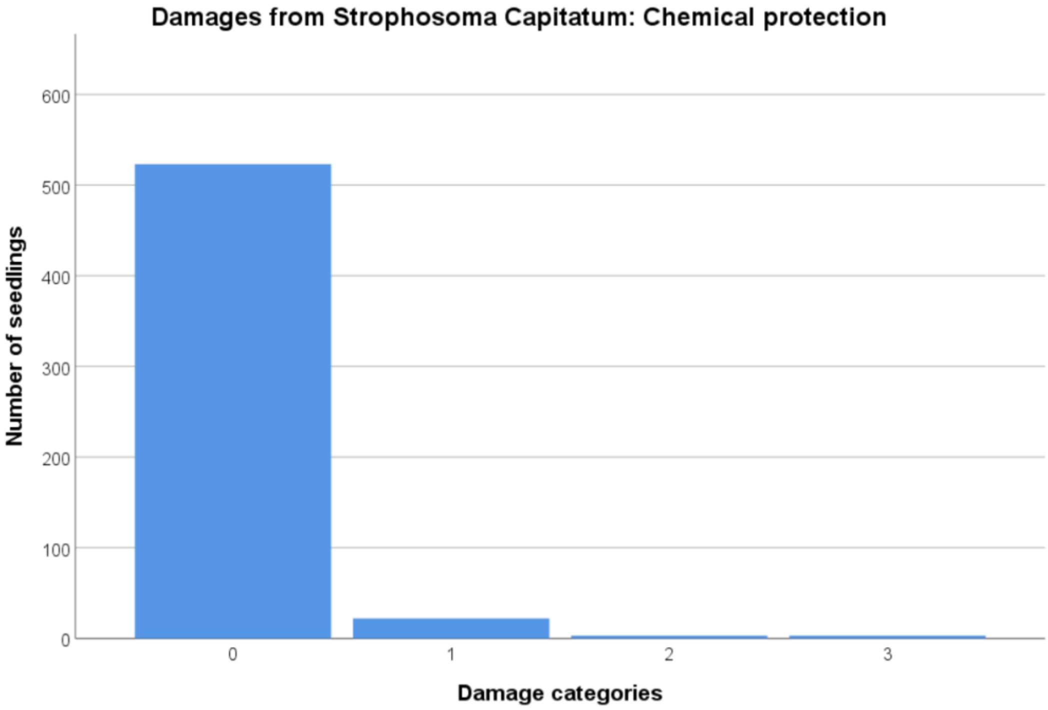

Figure 9. Number of seedlings in each damage category caused by Strophosoma capitatum on Chemical protection. Total number of total seedlings is 551, Number of seedlings in each category; 1=22, 2=4, 3=3, 4=0, 5=0.

3.4. Total Height

The statistical analysis for the total height shows that there was no statistical significance between treatments. The P-Value for the total height comparing treatments gave the value 0,618 that discards the hypothesis that chemical protection should increase the total growth on the seedling planted. The mean of the two inventories of the treatments was 40,35 cm (mechanical) (Fig. 11) and 38,75 cm (chemical) (Fig. 12). The weighted results for the statistical analysis gave the slightly different mean values of 40,56 cm for the mechanical protection and 39,02 cm for the chemical protection.

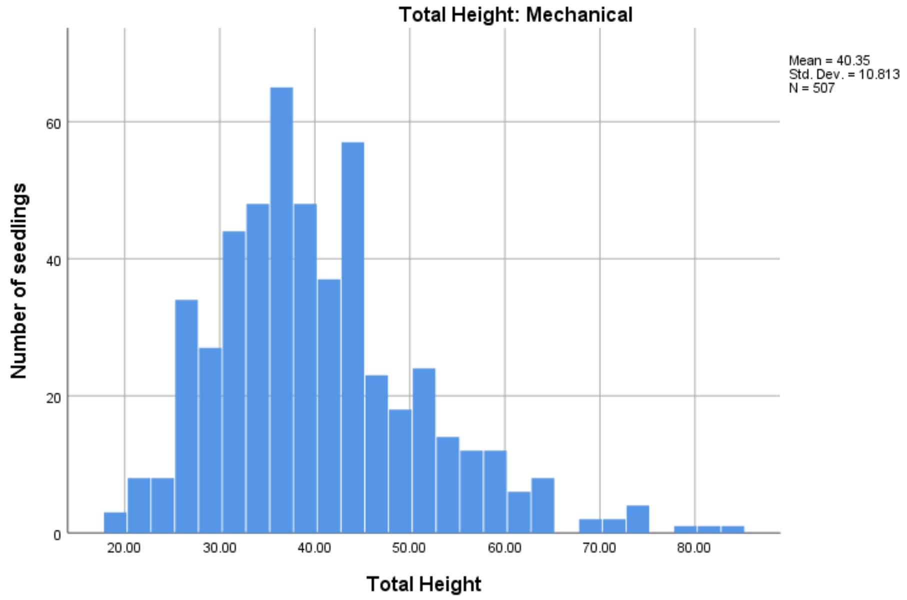

Figure 10. Histogram of the total height on the mechanically protected seedlings divided into brackets of 2,5cm each.

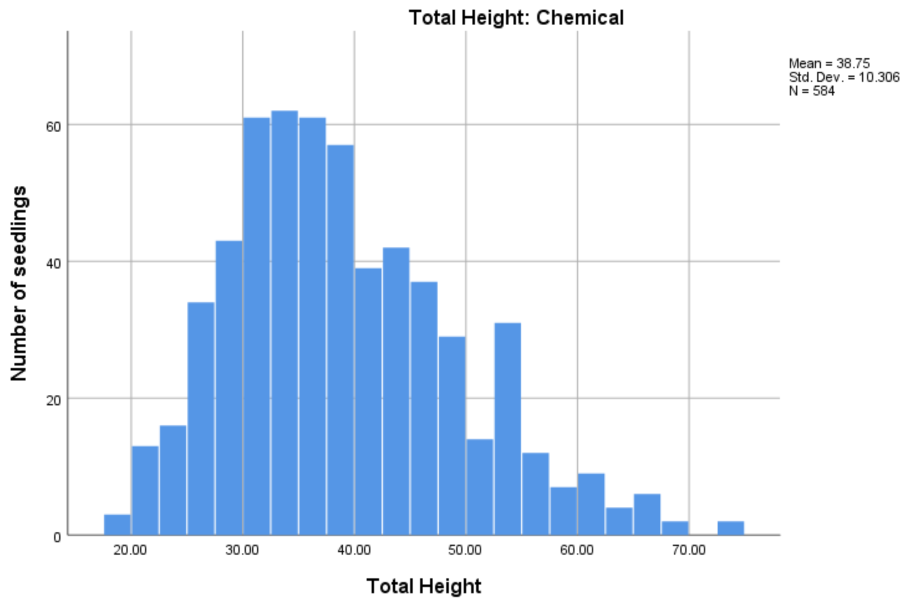

Figure 11. Histogram of the total height on the chemically protected seedlings divided into brackets of 2,5cm each.

3.5. Leading shoot height

The leading shoot height mean of mechanically treated seedlings was 6,96 cm (fig. 13). The leading shoot height mean for the chemically treated seedlings was 7,15 cm (fig. 14). The weighted mean used in the statistical analysis differed a bit and gave the mean of 7,39 cm for the chemical and 7,17 cm for the mechanical protection, respectively. The calculated p-Value was 0,897 that shows that it was not statistically significant, and the hypothesis can be rejected.

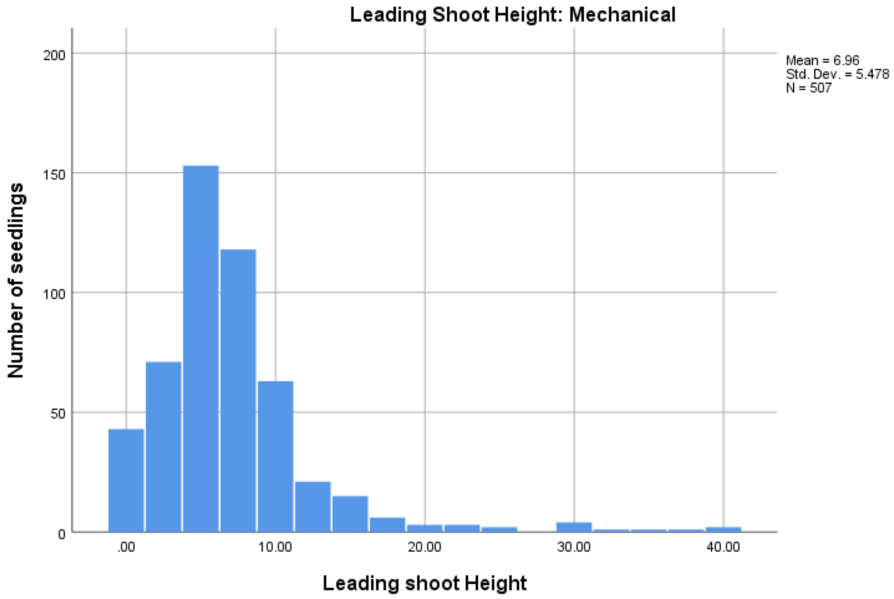

Figure 12. Histogram showing the Leading Shoot height on the mechanically protected seedlings divided into brackets of 2cm each.

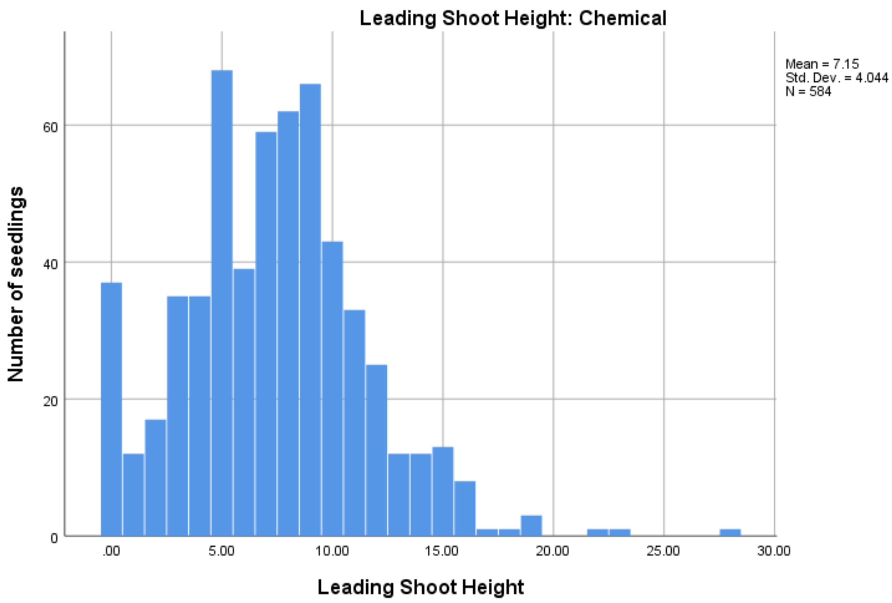

Figure 13. Histogram of the leading shoot height on the chemically protected seedlings divided into brackets of 2cm each.

4. Discussion

In this study we can see that during the first growing season there were no statistically significant differences between the mechanical and chemical protection on sites without mechanical site preparation. This correlates to a report made from the field research station situated in Asa, on an experiment set up 2015, where they used the insecticide “Imprid skog” in two plots (Eriksson *et al.*, 2018). The mortality for these two plots where 1,3% and 2,7% for insecticides, which were applied in the field. The mechanical protection “Hylonox”, “Bugwax typ F” and “Woodcoat” had a mortality of 4,7%, 0% and 6,7% respectively after one growing season. The seedlings tested were large, containerised seedlings. In another previous report from the field research station Asa, results from an experiment set up 2013 utilizing the same insecticide but different or previous versions of mechanical protections were reported (Eriksson *et al.*, 2017). Hylonox, called K13 in the report, had a mortality of 3,4% after the first growing season, Bugwax type D had a mortality of 0,7% after one growing season. Woodcoat was not included in this report. This shows that the mortality inventoried in our study of 3,5% for the mechanical protection and 2,4% for the chemical protection is reasonable.

Mechanical site preparation has shown to be effective against pine weevils (Wallertz *et al.*, 2018) but in some cases site preparation is not recommended or possible on all sites. This since wetter sites sometimes have high ecological values, or from a production standpoint it can increase the regeneration of deciduous trees that can outcompete the conifers. It is also not possible to utilize site preparation on some sites if they contain cultural or historical values (Skogsstyrelsen, 2021 b). In this study sites without site preparation were investigated because it is important that the protection works even without site preparation. Considering that if you do not have the possibility to utilize site preparation it would be wise to plant as soon as possible to establish the seedlings before competing vegetation establishes on the site. Also, larger seedlings with a diameter above 8-9 mm is recommended since they have a higher chance of not being girdled by the pine weevils (örlander & Karlsson, 2000; Thorsén *et al.* 2001; Wallertz *et al.*, 2005). Another option is to wait five years so the newly planted seedlings do not have to both compete with vegetation and cope with damage from pine weevils.

In the Figure 11 and 13 there are some extreme outliers that shows abnormally high shoot and total heights on the mechanical treatment. There was one site that had larger seedlings than average. This site was a very fertile and wet site that led to abnormally high shoots when the seedlings were planted on a favourable spot. Due to the high p-value I do not think this outlier caused any interference with the results and the results should still not have been significant even if this one site was excluded. Because this is a survey study and not a controlled experiment there is no possibility to influence the seedling material to avoid differences in the seedlings. This is a drawback in these types of studies and if it was a controlled experiment this could have been avoided. In such cases it would be possible to plant all the sites with the same batch of seedlings.

The black spruce beetle damage showed no difference between chemical and mechanical protection in my study. It has been previously shown that there is no significant difference when it comes to the effectiveness between mechanical and chemical protection, but the damage were halved when comparing protected vs unprotected seedlings (Wallertz *et al.*, 2020). As for pine weevils, site preparation has shown to decrease damage caused by the black spruce beetle. But more research is needed and there should be regular inventories and experiments on the damage caused by the black spruce beetle in all parts of Sweden just to see how the populations are developing. This since in northern Sweden, in some extreme cases, the black spruce beetle has caused an accumulative mortality up to 25% on some sites (Lindelöw, 1992).

The *Strophosoma capitatum* is a species where there is very little available literature in English, or in Swedish, and thus the knowledge regarding the damage it can cause on seedlings is limited. The *Strophosoma capitatum* showed that there was no statistical significance between treatments. However, a P-value of 0,06 shows that there could be a tendency that the *Strophosoma capitatum* cause more damage on seedlings protected with mechanical protection than with chemical protection. Since *Strophosoma capitatum* can’t fly and only travel by foot it can occasionally lead to large local populations that can cause some seedlings to die from the damage (Lindelöw, 2021). More experiments need to be carried out to see if this tendency was due to local populations or if there is a small effect from the protection. The *Strophosoma capitatum* generally only feeds on the needles of leading shoot and on the upper whorls (Nielsen *et al.*, 2006). Because the mechanical protection is applied on the lower part of the stem this makes the mechanically treated seedlings vulnerable to *Strophosoma capitatum* damage.

This study was only done the first growing season after harvest. Previous studies have shown that the protection with both mechanical and chemical protection will decrease in efficiency for every growth season due to the protection deteriorating

(Eriksson *et al.*, 2018; Wallertz *et al.*, 2018). With chemical protection, it needs to be reapplied every or every other year to keep the protective effect. The mechanical protection will continue to have some effect 2 or even 3 years after applying it. This since mechanical protection is designed to grow together with the seedling and to disappear after approximately 3 years (Eriksson *et al.*, 2017; Eriksson *et al.*, 2018). So further studies needs to be done over several years to determine the long term efficiency of the different seedling protections, both regarding the durability of the mechanical protection and also with regards to the pine weevil feeding patterns that occur on clear-cuts of different ages (Nordlander, 1987; Nordenhem, 1989). For the black spruce beetle, the study should be carried out for at least 7 growing seasons after harvest before any conclusions about their damage rate can be drawn (Lindelöw, 1992).

5. Conclusion

No significant difference was found in this study between the chemical treatment and the mechanical treatment during the first growing season on clear-cuts without site preparation in Scania and southwestern Småland. So, there should be no difference in efficiency during the first growing season after planting and therefore it does not matter what type of protection the forest owner chooses in terms of damage and growth on the seedlings. But the forest owner should plan on having losses of around 3-4% due to pine weevil and black spruce beetle the first growing season and also for eventual losses the following years to come to achieve a satisfactory regeneration.

6. References

Day, K. R. & Leather, S. R. (1997) 'Threats to forestry by insect pests in Europe', in *Forests and insects*.

Eriksson, S. Karlsson, A.B & Härlin, C. (2017) *Test av mekaniska plantskydd och insekticider mot snytbaggar i omarkberedd och markberedd mark, anlagt våren 2011*.

Eriksson, S. Wallertz, K & Karlsson, A.-B. (2018) *Test av mekaniska plantskydd och insekticider mot snytbaggar i omarkberedd och markberedd mark, anlagt våren 2011*.

Långström, B. & Day, K. R. (2007) 'Damage, Control and Management of Weevil Pests, Especially Hylobius Abietis', in *Bark and Wood Boring Insects in Living Trees in Europe, a Synthesis*. doi: 10.1007/978-1-4020-2241-8_19.

Lindelöw, Å. (1992) ' Seedling mortality caused by Hylastes cunicularius Er. (Coleoptera, scolytidae) in Picea abies plantations in Northern Sweden ', *Scandinavian Journal of Forest Research*, 7(1–4). doi: 10.1080/02827589209382731.

Lindelöw, Å. (2021) *Ögonvivel (Strophosoma capitatum)*. Available at: https://www.slu.se/centrumbildningar-och-projekt/skogsskada/lasmer-sidor/skadeorsak/?DiagID=568&AnmSkada=568&Tradart=9&Skadetyp=3&Alder=2&SkadadDel=0,7&SkadaBestand=2.

Lindelöw, Å., Eidmann, H. H. & Nordenhem, H. (1993) 'Response on the ground of bark beetle and weevil species colonizing conifer stumps and roots to terpenes and ethanol', *Journal of Chemical Ecology*, 19(7). doi: 10.1007/BF00984884.

Nielsen, C., Vestergaard, S., Harding, S., Wolsted, C., Eilenberg, J. (2006) 'Biological control of Strophosoma spp. (Coleoptera: Curculionidae) in greenery (Abies procera) plantations using Hyphomycetes', *Biocontrol Science and Technology*, 16(6). doi: 10.1080/09583150500532824.

Nilsson, U., Luoranen, J., Kolström, T., Örlander. G., Puttonen. P. (2010) 'Reforestation with planting in northern Europe', *Scandinavian Journal of Forest Research*. doi: 10.1080/02827581.2010.498384.

Nilsson, U. & örlander, G. (1999) 'Water uptake by planted picea abies in relation to competing field vegetation and seedling rooting depth on two Grass-dominated sites in southern Sweden', *Scandinavian Journal of Forest Research*, 14(4). doi: 10.1080/02827589950152629.

Nordenhem, H. (1989) 'Age, sexual development, and seasonal occurrence of the pine weevil Hylobius abietis (L.)', *Journal of Applied Entomology*, 108(1–5).

doi: 10.1111/j.1439-0418.1989.tb00456.x.

Nordlander, G. (1987) ‘A method for trapping Hylobius abietis (L.) with a standardized bait and its potential for forecasting seedling damage’, *Scandinavian Journal of Forest Research*, 2(1–4). doi: 10.1080/02827588709382458.

Nordlander, G,. Bylund, H., Örlander, G., Wallertz, K. (2003) ‘Pine weevil population density and damage to coniferous seedlings in a regeneration area with and without shelterwood’, *Scandinavian Journal of Forest Research,* 18(5). doi: 10.1080/02827580310001634.

Nordlander, G., Nordenhem, H. & Hellqvist, C. (2009) ‘A flexible sand coating (Conniflex) for the protection of conifer seedlings against damage by the pine weevil Hylobius abietis’, *Agricultural and Forest Entomology,* 11(1). doi: 10.1111/j.1461-9563.2008.00413.x.

örlander, G. & Karlsson, C. (2000) ‘Influence of shelterwood density on survival and height increment of picea abies advance growth’, *Scandinavian Journal of Forest Research*, 15(1). doi: 10.1080/02827580050160439.

örlander, G. & Nilsson, U. (1999) ‘Effect of reforestation methods on pine weevil (Hylobius abietis) damage and seedling survival’, *Scandinavian Journal of Forest Research*, 14(4). doi: 10.1080/02827589950152665.

Petersson, M. & Örlander, G. (2003) ‘Effectiveness of combinations of shelterwood, scarification, and feeding barriers to reduce pine weevil damage’, *Canadian Journal of Forest Research*, 33(1). doi: 10.1139/x02-156.

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). doi: 10.14214/sf.10172.

Skogsstyrelsen (2020) *Levererade plantor*. Available at: https://www.skogsstyrelsen.se/statistik/statistik-efter-amne/produktion-av-skogsplantor/.

Skogsstyrelsen (2021a) *Andel (%) skogsplantor fördelade på skyddsmetod per trädslag av barr 2014-2020*. Available at: http://pxweb.skogsstyrelsen.se/pxweb/sv/Skogsstyrelsens statistikdatabas/Skogsstyrelsens statistikdatabas__Skogsplantor/JO0313_5.px/.

Skogsstyrelsen (2021b) *Markberedning*. Available at: https://www.skogsstyrelsen.se/bruka-skog/ny-skog-efter-avverkning/markberedning/.

Skogsstyrelsen (2021c) *Plantering*. Available at: https://www.skogsstyrelsen.se/bruka-skog/ny-skog-efter-avverkning/plantering/.

SLU (2021) *Produktiv Skogsmark*. Available at: https://www.slu.se/centrumbildningar-och-projekt/riksskogstaxeringen/statistik-om-skog/senaste-statistiken/produktiv-skogsmark/.

von Sydow, F. (1997) ‘Abundance of pine weevils (hylobius abietis) and damage to conifer seedlings in relation to silvicultural practices’, *Scandinavian Journal of Forest Research*, 12(2). doi: 10.1080/02827589709355397.

Thorsén, A., Mattsson, S. & Weslien, J. (2001) ‘Influence of stem diameter on the survival and growth of containerized Norway spruce seedlings attacked by pine weevils (Hylobius spp.)’, *Scandinavian Journal of Forest Research*, 16(1). doi: 10.1080/028275801300004415.

Viiri, H., Tuomainen, A. & Tervo, L. (2007) ‘Persistence of deltamethrin against

Hylobius abietis on Norway spruce seedlings’, *Scandinavian Journal of Forest Research*, 22(2). doi: 10.1080/02827580701224113.

Wallertz, K., Björklund, N., Hjelm, K., Pettersson, 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). doi: 10.1007/s11056-018-9634-8.

Wallertz, K., Eriksson, S. & Hjelm, K. (2020) *Plantskador orsakade av svart gran- eller tallbastborre, studie anlagd våren 2017.*

Wallertz, K., Örlander, G. & Luoranen, J. (2005) ‘Damage by pine weevil Hylobius abietis to conifer seedlings after shelterwood removal’, *Scandinavian Journal of Forest Research*, 20(5). doi: 10.1080/02827580500306954.

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7. Appendix

7.1. R script code

```r
library(lattice)
library(doBy)
library(car)
library(readxl)
library(dplyr)


Data<- read_excel("Data/InventoryData.xlsx")


Data$PineWeevil<-ifelse(Data$PineWeevil>1 , "1","0") #NUMBER VARYING DEPEDNING ON DAMAGE CLASSES
Data$PineWeevil <- as.numeric(as.character(Data$PineWeevil))


Data$BlackSpruce<-ifelse(Data$BlackSpruce>2 , "1","0")#NUMBER VARYING DEPEDNING ON DAMAGE CLASSES
Data$BlackSpruce <- as.numeric(as.character(Data$BlackSpruce))


Data$Strophosoma<-ifelse(Data$Strophosoma==3 , "1","0")#NUMBER VARYING DEPEDNING ON DAMAGE CLASSES
Data$Strophosoma <- as.numeric(as.character(Data$Strophosoma))
Datafixed<-Data


Datafixed$PineWeevil <- as.numeric(as.numeric(Datafixed$PineWeevil))
Datafixed$BlackSpruce <- as.numeric(as.numeric(Datafixed$BlackSpruce))
Datafixed$Strophosoma <- as.numeric(as.numeric(Datafixed$Strophosoma))


Datafixed<-Datafixed %>%
  group_by(Plot) %>%
  summarise_if(is.numeric, mean)

Datafixed<-Datafixed %>%
  group_by(Stand) %>%
  summarise_if(is.numeric, mean)

Datafixed$Treatment<-ifelse(Datafixed$Treatment==1 , "mech","chem")
```

Appendix 1. Picture 1 of 2 of the complete R code used for statistical analysis

```r

Datafixed$PineWeevil<-asin(sqrt(Datafixed$PineWeevil))
Datafixed$BlackSpruce<-asin(sqrt(Datafixed$BlackSpruce))
Datafixed$Strophosoma<-asin(sqrt(Datafixed$Strophosoma))

Datafixed$Stand <- as.factor(Datafixed$Stand)

DatafixedPineWeevil<-lm(PineWeevil~Treatment,data=Datafixed)
DatafixedBlackSpruce<-lm(BlackSpruce~Treatment,data=Datafixed)
DatafixedStrophosoma<-lm(Strophosoma~Treatment,data=Datafixed)


summary(DatafixedPineWeevil)

Anova(DatafixedPineWeevil)

T.PineWeevil<-TukeyC(x=DatafixedPineWeevil ,which="Treatment")

summary(T.PineWeevil)


summary(DatafixedBlackSpruce)

Anova(DatafixedBlackSpruce)

T.DatafixedBlackSpruce<-TukeyC(x=DatafixedBlackSpruce ,which="Treatment")

summary(T.DatafixedBlackSpruce)


summary(DatafixedStrophosoma)

Anova(DatafixedStrophosoma)

T.DatafixedStrophosoma<-TukeyC(x=DatafixedStrophosoma ,which="Treatment")

summary(T.DatafixedStrophosoma)



DatafixedShootHeight<-lm(Shootheight~Treatment,data=Datafixed)
Anova(DatafixedShootHeight)


T.DatafixedShootHeight<-TukeyC(x=DatafixedShootHeight ,which="Treatment")
summary(T.DatafixedShootHeight)

DatafixedHeight<-lm(Totalheight~Treatment,data=Datafixed)
Anova(DatafixedHeight)


T.DatafixedHeight<-TukeyC(x=DatafixedHeight ,which="Treatment")

summary(T.DatafixedHeight)
```

Appendix 2. Picture 2 of 2 of the complete R code used for statistical analysis

```r
library(lattice)
library(doBy)
library(car)
library(readxl)
library(dplyr)
Data<- read_excel("Data/InventoryData.xlsx")
Data$PineWeevil<-ifelse(Data$PineWeevil>1 , "1","0") #NUMBER VARYING DEPEDNING ON DAMAGE CLASSES
Data$PineWeevil <- as.numeric(as.character(Data$PineWeevil))
Data$BlackSpruce<-ifelse(Data$BlackSpruce>2 , "1","0")#NUMBER VARYING DEPEDNING ON DAMAGE CLASSES
Data$BlackSpruce <- as.numeric(as.character(Data$BlackSpruce))
Data$Strophosoma<-ifelse(Data$Strophosoma==3,"1","0")#NUMBER VARYING DEPEDNING ON DAMAGE CLASSES
Data$Strophosoma <- as.numeric(as.character(Data$Strophosoma))
Datafixed<-Data
```

```
Datafixed$PineWeevil <- as.numeric(as.numeric(Datafixed$PineWeevil))
Datafixed$BlackSpruce <- as.numeric(as.numeric(Datafixed$BlackSpruce))
Datafixed$Strophosoma <- as.numeric(as.numeric(Datafixed$Strophosoma))
Datafixed<-Datafixed %>%
  group_by(Plot) %>%
  summarise_if(is.numeric, mean)
Datafixed<-Datafixed %>%
  group_by(Stand) %>%
  summarise_if(is.numeric, mean)
Datafixed$Treatment<-ifelse(Datafixed$Treatment==1 , "mech","chem")
Datafixed$PineWeevil<-asin(sqrt(Datafixed$PineWeevil))
Datafixed$BlackSpruce<-asin(sqrt(Datafixed$BlackSpruce))
Datafixed$Strophosoma<-asin(sqrt(Datafixed$Strophosoma))
Datafixed$Stand <- as.factor(Datafixed$Stand)
DatafixedPineWeevil<-lm(PineWeevil~Treatment,data=Datafixed)
DatafixedBlackSpruce<-lm(BlackSpruce~Treatment,data=Datafixed)
DatafixedStrophosoma<-lm(Strophosoma~Treatment,data=Datafixed)
summary(DatafixedPineWeevil)
Anova(DatafixedPineWeevil)
T.PineWeevil<-TukeyC(x=DatafixedPineWeevil ,which="Treatment")
summary(T.PineWeevil)
summary(DatafixedBlackSpruce)
Anova(DatafixedBlackSpruce)
T.DatafixedBlackSpruce<-TukeyC(x=DatafixedBlackSpruce
,which="Treatment")
summary(T.DatafixedBlackSpruce)
summary(DatafixedStrophosoma)
Anova(DatafixedStrophosoma)
T.DatafixedStrophosoma<-TukeyC(x=DatafixedStrophosoma
,which="Treatment")
summary(T.DatafixedStrophosoma)
DatafixedShootHeight<-lm(Shootheight~Treatment,data=Datafixed)
Anova(DatafixedShootHeight)
T.DatafixedShootHeight<-TukeyC(x=DatafixedShootHeight
,which="Treatment")
summary(T.DatafixedShootHeight)
DatafixedHeight<-lm(Totalheight~Treatment,data=Datafixed)
Anova(DatafixedHeight)
T.DatafixedHeight<-TukeyC(x=DatafixedHeight ,which="Treatment")
summary(T.DatafixedHeight)
```