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Measures against pine weevil *Hylobius abietis* also reduce damage by *Hylastes cunicularius and Hylastes brunneus*

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ABSTRACT
Hylastes species are known to cause damage to conifers in plantations in northern Sweden, and in recent years an increase in seedling damage has been observed in southern Sweden. However, there are few studies on *Hylastes spp* and the damage it can cause, so there is a lack of knowledge regarding pest management. In order to investigate an eventual interaction between damage by *Hylastes spp* and the more well-known *Hylobius abietis (L)* we registered damage by these species. Unprotected spruce seedlings were compared with seedlings protected from *Hylobius abietis* by a mechanical coating or with an insecticide. The effect of mechanical site preparation (MSP) was studied, with half of the seedlings being planted in unprepared soil and the other half after MSP. Both seedling protection and MSP significantly reduced the level of damage caused by *Hylastes spp*. MSP reduced the proportion of affected and killed seedlings and reduced the level of damage at the root collar. Protecting the seedlings reduced the level of damage, and no difference was found between seedlings treated with an insecticide and those provided with a coating. Similar responses were observed with both containerized and plug plus seedlings. In conclusion, measures against *Hylobius abietis* seem to also prevent damage by *Hylastes spp*.

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coatings; *Hylastes*; *Hylobius abietis*; insecticide; Norway spruce; seedling; site preparation

Introduction

Root-colonizing bark beetles (Coleoptera: Scolytidae) of the genus *Hylastes* are associated with coniferous forests, with 20 species known to occur in Europe. Some species of *Hylastes* are considered forest pests, causing mortality either by feeding on young coniferous seedlings, or transferring fungal pathogens (Witkovsky and Hansen 1985). Two species, *Hylastes brunneus* Erich, and *Hylastes cunicularius* Erich. occur across Sweden. They breed in newly dead wood, such as conifer stumps or logs with ground contact (Rudinsky and Zethner-Møller and 1967; Lindelöw et al.1993; Rahman et al. 2018), and feed on young seedlings. They appear to select similar habitats (Eidmann et al. 1977), although Tunset et al. (1993), in an experiment in which flying insects were captured in window traps baited with newly cut pieces of wood of Scots pine (*Pinus sylvestris L.)* and Norway spruce (*Picea abies*) (L. H. Karst), demonstrated that *H. brunneus* clearly preferred Scots pine, while *H. cunicularius* was exclusively attracted to spruce wood. It should be noted, however, that Palm (1931) occasionally found *H. cunicularius* in pine.

Adult *H. cunicularius* and *H. brunneus* (hereafter referred to as *Hylastes*) feed on the roots, root collars and stems of young conifers, which can result in high seedling mortality (Lindelöw et al. 1992; Piri et al. 2020). The adults' tunnel into the phloem and, under thin bark, can also tunnel into the xylem (Lindelöw 1992). The first sign of a severe attack is often seedlings losing their green color and becoming increasingly yellowish. Damage by *Hylastes* can therefore easily be mistaken as wilting caused by drought or other agents, and, because *Hylastes* feeding is often restricted to roots and root collars, the damage is hard to detect without destructively harvesting of the seedling (Rahman et al. 2018; Piri et al. 2020). In practical forestry, it is therefore likely that the degree of damage caused by *Hylastes* is underestimated.

Another important pest, the large pine weevil, *Hylobius abietis*, (L) (hereafter referred to as *Hylobius*) is a well-known, severe threat to young conifer seedlings. In contrast with *Hylastes*, extensive research has been carried out on *Hylobius* to ascertain effective methods for protecting seedlings from damage (Petersson et al. 2004; Nordlander et al. 2011; Lalík et al. 2020). *Hylobius* breeds in the stump roots of recently dead conifer trees, both *Picea* and *Pinus* spp. (Moore et al. 2004), and feeds mainly on the stem bark, damaging or killing the seedlings in the process (Leather et al. 1999; Örlander and Nilsson 1999). It feeds mainly at and above the root collar, and also slightly below the soil surface, but the most obvious sign of its presence is feeding scars higher on the stem. If *Hylobius* feeds extensively on the phloem and bark, stem girdling and death of the seedling can occur (Scott and King 1974; Eidmann and Klingström 1990). Seedling size, (mainly stem-base diameter), is related to mortality by *Hylobius* (Örlander and Nilsson 1999; Thorsén et al. 2001). Smaller seedling types, like containerized, are normally less able to tolerate pine weevil damage compared to bareroot

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or plug plus for example. However, if this also applies to damage of *Hylastes* is yet to be investigated.

The feeding habit of *Hylastes* differs from that of *Hylobius* mainly in that the former eats on the roots and root collar while the later eats on the seedlings stems. The gnawing is often deeper than that of *Hylobius*, and can penetrate as far as the sapwood. However, there is an area from the root collar to the lower part of the stem where any evidence of damage can be difficult to differentiate between the two species.

Severe *Hylastes* damage to Norway spruce plantations has been observed in north-central parts of Sweden, often several years after planting (Hellqvist 2010). For example, Lindelöw (1992) reported that death caused by *Hylastes cunicularius* seemed to occur mainly between the fourth and sixth growing seasons after cutting. The highest risk period for *Hylobius* damage to seedlings is during the first three growing seasons after harvest (Von Sydow 1997; Örlander and Nilsson 1999; Wallertz et al. 2016; Luoranen et al. 2017; Nordlander et al. 2017). *Hylastes* damage on the other hand can be diffuse over time and space, such that accumulated seedling mortality over several years may not be detected as clearly as for *Hylobius* during the first year after cutting (Lindelöw 1992). From studies in UK, Leahy et al. (2007) suggested that *Hylastes ater* Paykull damage is often incorrectly attributed to *Hylobius*, leading to overestimates of *Hylobius* damage and missing the contribution of *H. ater* to seedling deaths. *H. ater* is of European origin but is considered to be an introduced species in Chile and New Zeeland, it's main host being *Pinus* spp.

Treatment with insecticides has long been the most common way to protect seedlings against insect damage in Swedish forestry. Thorsén et al. (2001) noted that the proportion of severe seedling damage caused by both *Hylobius* and *Hylastes* decreased when insecticides were used. However, the use of insecticides was at the time of this experiment prohibited for certified forest owners, and the most common type of protection against *Hylobius* was and still is some kind of mechanical coating. As a result, the proportion of insecticide-treated seedlings was only 3% in 2021 (Nilsson et al. 2019). Several studies have shown that methods of mechanical site preparation (MSP) can also reduce damage caused by *Hylobius* (Lekander and Söderström 1969; Sutton 1993; Von Sydow 1997; Örlander and Nilsson 1999), especially if the planted seedlings are surrounded by pure mineral soil (Björklund et al. 2003; Petersson and Örlander 2003; Petersson et al. 2005). However, whether mechanical devices can also act as an obstacle for *Hylastes* has yet to be investigated. As *Hylastes* mostly feed on underground roots or perhaps close to the surface at the root collar, it may be that methods of protection designed to cope primarily with *Hylobius* damage will not be effective. Lindelöw (1992) argued that patches of scarified ground would probably only have a limited effect on *Hylastes cunicularius* because it is active over a longer period of time than other pest species, and the effect of MSP decreases as vegetation colonizes an area (Orlander et al. 1990). However, in southern Sweden, damage caused by *Hylastes* has also been observed during the first few years after cutting, when an effect of MSP could still be expected. To date, no study has been conducted to clarify a possible relationship between MSP and the level of damage caused by *Hylastes*.

Earlier studies have shown that fresh wounds on the host material enhance its attraction for both *Hylobius* (Tilles et al. 1986; Nordlander 1991) and *Hylastes* (Eidmann et al. 1991). It is also possible that previous damage caused by *Hylobius* feeding on conifer seedlings could increase the risk of *Hylastes* attack by releasing odors attractive *to Hylastes* and this eventual correlation could be something that should be taken into account.

This article presents the results of a multisite trial conducted in the south of Sweden, where untreated Norway spruce seedlings were compared with seedlings treated with either an insecticide (Merit Forest WG) or a mechanical coating used against *Hylobius* (Cambiguard or Ekowax). Half of the seedlings were planted after MSP, while the other half were planted in undisturbed humus. The aim of the study was to investigate if measures taken today to reduce *Hylobius* damage also prevent *Hylastes* damage.

The main hypotheses were:

- insecticides provide effective protection against damage caused by *Hylastes* feeding,
- mechanical coatings will not protect seedlings against, root-feeding, *Hylastes* species,
- MSP will reduce attacks by *Hylastes,*
- there is a correlation between *Hylobius* and *Hylastes* damage.

Material and methods

Experimental sites

The experiment was established at eight clear-felled areas, located in south-central Sweden, between latitudes 56°36′N and 57°10′N (Table 1). The sites were selected from clear-cuts harvested in the last two years and representative of the area. Four sites were situated on fresh clear-cuts (harvested during the winter of 2016–2017), and the remaining four were on 1-year-old clear-cuts (harvested during the winter of 2015–2016). The previous stands had been dominated by either Norway spruce or Scots pine (Table 1).

Experimental design

A split-plot design was used, with three blocks at each site. Each block was split into two plots consisting of six rows of either MSP or undisturbed ground. Within each MSP treatment, the combination of Norway spruce seedling type (containerized or plug plus) and seedling protection (unprotected, insecticide or mechanical) was randomly assigned to rows. In each row, ten seedlings were planted with an average spacing of two meters. Of these, five seedlings were later harvested and used in the study, i.e. the experimental unit. Thus, in total 2880 seedlings were planted, of which half, 1440, were harvested and analyzed.

Treatments

MSP was performed on each site in the early spring of 2017, and seedlings were planted in the middle of May of the same

Table 1. Description of the experimental sites.

Site	Latitude (N)	Longitud (E)	Age of clearcut at planting	Size of site (ha)	Volume (%) at the time of cutting (m^3 ha $-^1$)		
					Site index	Pine	Spruce
1	57°10′	14°46′	1	11.6	G 26	29	71
2	57°40′	15°8′	1	1.7	T 27	87	13
3	57°50′	15°9′	0	5.9	T 26	95	5
4	57°40′	15°12′	0	9.4	T 24	95	5
5	56°57′	15°35′	1	9.7	T 22	90	10
6	56°57′	15°34′	1	16.9	T 22	85	15
7	56°36′	15°43′	0	5.7	G 30	20	80
8	56°58′	14°0′	0	2.9	G 30	20	80

Site index = the highest the trees can reach within the reference age of 100 years, G = "gran" (Norway spruce) and T = "tall" (Scots pine). Volume m3 / ha-1 = standing volume.

year. The MSP technique used was disc trenching, apart from at site 2, where mounding was used. Seedlings were either left untreated, or treated with an insecticide or coating, used as mechanical protection against *Hylobius*. The insecticide used was Merit Forest WG, with imidacloprid as the active ingredient. Before planting, the seedlings were dipped into a solution containing 1.40% by weight of the commercial product, supplied pulverulent, and mixed in water. The proportion of imidacloprid in the commercial product was 70% by weight. The following spring these seedlings were resprayed with the same dose. Cambiguard (Södra Skogsplantor AB) was used as mechanical protection on containerized seedlings, and Ekowax (Norsk wax) on plug plus seedlings.

Seedling stock

The containerized seedlings, were of Bredinge seed orchard origin, and had a height range of 20–40 cm. The plug plus seedlings, were of the same origin, with a height range of 25–50 cm. The containerized seedlings were grown in Hiko v93 trays for one year, whereas the plug plus seedlings had grown in a container for 10-12 weeks and thereafter were transplanted to an outdoor nursery bed and grown as bareroot seedling for another year (Dumroese et al. 2005). There they could grow more extensive and with larger root systems which makes it possible to grow larger diameters. All seedlings used in the trial were provided by Södra Skogsplantor AB, and the applications of Cambiguard and Ekowax were carried out at its nursery.

Measurements

Immediately after planting, the height of each seedling was measured. With the aim of describing the planting areas, the dominant soil type within a radius of 10 cm from each seedling was recorded as one of four classes: 0, undisturbed humus; 1, cultivated humus; 2, a mixture of mineral soil and humus; 3, pure mineral soil. The seedling height and length of the current year's leading shoot were recorded after the first and second growing seasons.

After the final assessment, half of the seedlings planted were harvested in order to estimate the degree of damage caused by *Hylastes* on stem bases and root systems. The seedlings were selected at random within the treatments, without regard to the vitality of the sampled seedlings, and analyzed in a laboratory environment. The debarked area caused by *Hylastes* feeding on stem bases and roots (>1 mm) was estimated to be the nearest 0.1 cm^2. The attack from Hylastes differs from *Hylobius* (who is normally feeding higher up on the stem) in that it usually eats the bark on the seedling's roots and at the stem base. The gnawing damage often starts at the soil surface and then goes down to the roots. The gnawing is often deeper than that of Hylobius and can cut into the wood, a narrow passage is often visible in the bark. The severity of damage was scored according to the same scale used for *Hylastes*, *Hylobius* and other agents; no damage, damaged but alive or damaged and dead.

Statistical analyses

Only harvested seedlings were used in the calculations and statistical analyses. The two seedling types, containerized and plug plus, were analyzed together. Growth was calculated as the height at the time of harvest minus the height at planting. The response variables damaged by *Hylastes*, root area damaged, damaged by *Hylobius,* and growth, were analyzed with a mixed model using Proc Mixed if normally distributed or with Proc Glimmix if binomial (SAS 9.4, SAS Institute, Cary, NC, USA):

$$Y_{ijklm} = \mu + a_i + b_{ij} + \gamma_k + (b\gamma)_{ijk} + \delta_l + (\gamma\delta)_{kl} + \zeta_m + (\gamma\zeta)_{km} + (\delta\zeta)_{lm} + (\gamma\delta\zeta)_{klm} + \varepsilon_{ijklm} \quad (1)$$

where μ is the overall mean, a_i is the random effect of the site (i = 1–8), b_{ij} is the random effect of the block within the site (j = 1–3), γ_k is the fixed effect of site preparation (k = 1–2), $(b\gamma)_{ijk}$ is the random effect of site preparation within site and block, δ_l is the fixed effect of seedling type (l = 1–2),ζ is the fixed effect of seedling protection (m = 1–3) and ε_{ijkl} is the experimental error. All the interactions between site preparation treatment, seedling type and seedling protection were also included in the model. Where significant treatment differences were detected, the treatments were separated by overall pair-wise comparisons using differences of least squares means, and Tukey–Kramer to adjust for multiple comparisons. For all tests, an α-value of 0.05 was used to indicate statistical significance. Residuals were checked for normality and constant variance using residual panels in SAS.

In order to investigate any possible correlation between *Hylobius* and *Hylastes* damage, a correlation analysis was

Table 2. Proportion of seedlings killed by Hylastes (%).

No MSP			MSP		
Seedling type	Protection	Killed by *Hylastes (%)*	Seedling type	Protection	Killed by *Hylastes (%)*
Containerized	Unprotected	10	Containerized	Unprotected	7
	Insecticide	2		Insecticide	0
	Cambiguard	4		Cambiguard	1
Plug plus	Unprotected	18	Plug plus	Unprotected	8
	Insecticide	0		Insecticide	0
	Ekowax	4		Ekowax	3

Different letters indicate significant differences between all treatment combinations.

carried out in Proc Corr in SAS using the number of damaged seedlings by each species and treatment. All seedlings were used in this analysis irrespective of treatment (n = 283 due to some missing values). Since the data was binomial a complementary test was performed in Proc FREQ to get a Chi^2-value and a Phi-coefficient.

Results

The number of seedlings killed by *Hylastes* during the course of the experiment was relatively low (Table 2). For unprotected seedlings planted without MSP, 10% of containerized seedlings and 18% of plug plus seedlings died. For unprotected seedlings planted after MSP, the corresponding values were 7% for containerized seedlings and 8% for plug plus seedlings. For seedlings treated with either insecticide or a coating, the proportion of dead seedlings varied between 0–4%. Because of the relatively low numbers and many values around 0, the outcome of the statistical analyses was uncertain and no statistical differences were therefore reported.

MSP and seedling protection as well as their interaction had a significant effect on seedlings damaged by *Hylastes* (Table 3). No significant effects of seedling type were found, indicating a similar response of MSP and protection regardless if the seedling planted was a containerized or plug plus seedling.

With MSP and seedling protection, the percentage of seedlings damaged by *Hylastes* decreased significantly (Figure 1). For unprotected seedlings, the attacks were reduced from almost 65% without MSP to around 40% with MSP. The numbers were in the same range for both containerized and plug plus seedlings. When seedling protection was applied, the positive effect of MSP was reduced. Overall, protected seedlings were less damaged than unprotected. No differences were found between the two types of protection, i.e. insecticide or mechanical coating.

MSP and seedling protection also significantly reduced the debarked area on the root collar of the seedlings (Table 3, Figure 2). Unprotected seedlings of both seedling types planted without site preparation had an average debarked area of 1.5 cm^2 in the root collar zone. With MSP, the area was reduced to around 0.7–0.8 cm^2. The average debarked area was in general lower for protected seedlings. The significant interaction between MSP and protection (Table 3) indicated that overall, seedlings planted without MSP but protected with coating were not statistically different from unprotected seedlings planted after MSP.

The more detailed investigation of soil type surrounding the seedling showed that there was a significant effect on the amount of seedlings damaged by *Hylastes* depending on the planting area ($p < 0.0001$) (Table 4). For seedlings planted in pure mineral soil, the proportion of damaged seedlings was significantly reduced compared with seedlings planted in areas with other soil types. There was also a significant interaction effect between soil type and seedling type ($p = 0.0139$). For containerized seedlings, there was a reduction in attacks when seedlings were planted in a mixture of humus and mineral soil compared with planting in pure humus or undisturbed soil. This was not seen for plug plus seedlings, showing that the overall effects of soil type on seedling attack were less evident in plug plus seedlings compared with containerized seedlings.

Seedling mortality and damage caused by *Hylobius* were also evaluated. The highest proportion of seedlings killed by *Hylobius* was found for unprotected containerized seedlings planted without MSP (21%). For plug plus seedlings under the same treatment, the proportion of killed seedlings was 9%. For other treatment combinations, the corresponding values varied between 0 and 6%.

Overall, a large proportion of the seedlings had been damaged, including killed, by *Hylobius*. Both MSP and seedling protection had a significant effect on seedlings damaged by *Hylobius* ($p < 0.0001$ for both) (Table 5). Without protection, 75% of the seedlings were damaged. For seedlings treated with insecticide or provided with a coating, the levels were lower, 60% and 42% respectively. No significant interaction effects were found between MSP, seedling type and protection.

Table 3. *P*-values for the effects of mechanical site preparation (MSP), seedling type and protection, and their interactions, on seedlings damaged by Hylastes (%) and area of root collar damaged by Hylastes (cm^2). Bold numbers indicate statistical differences at α-level 0.05. DF = degrees of freedom.

Effect	Num DF	Den DF	Damage by *Hylastes*	Root area damaged by *Hylastes*
MSP	1	23	**0.0070**	**0.0001**
Seedling type	1	225	0.9077	0.9911
MSP * Seedling type	1	225	0.4434	0.9841
Protection	2	225	**<.0001**	**<.0001**
MSP * Protection	2	225	**0.0183**	**0.0162**
Seedling type * Protection	2	225	0.5092	0.9576
MSP * Seedling type * Protection	2	225	0.7555	0.3497

Num = numerator, Den = denominator.

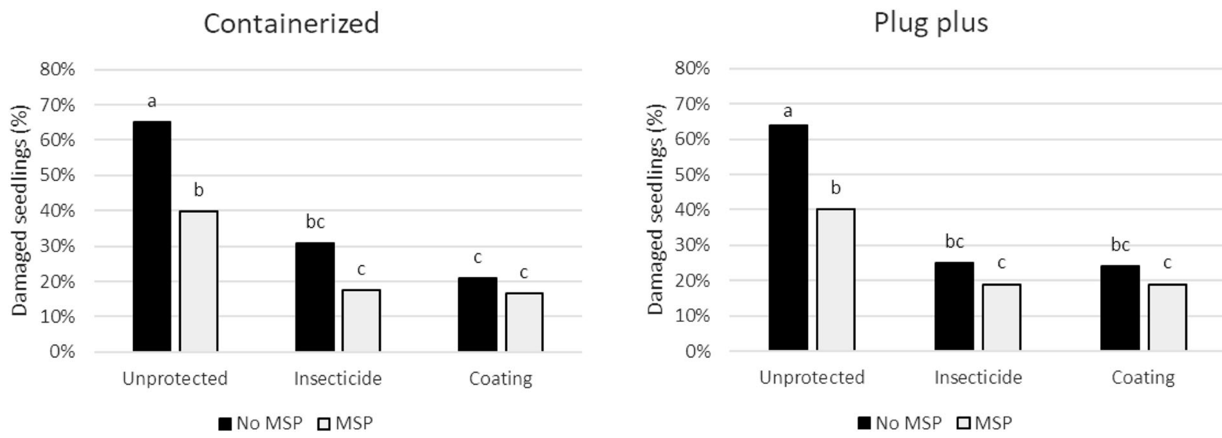

Figure 1. Containerized and plug plus seedlings damaged by Hylastes (%) when planted without (No MSP) or with (MSP) mechanical site preparation. The seedlings were planted without any protection (unprotected) or treated with an insecticide or a coating. Different letters above the bars indicate significant differences between treatments.

We found a positive correlation between seedling damage by *Hylastes* and *Hylobius*. Seedlings damaged by *Hylobius* were more likely to also be damaged by *Hylastes,* with a correlation coefficient of 0.5726 ($p < 0.0001$), $n = 283$. The Chi^2-value was 311, $p < 0.0001$ and the Phi-coefficient 1,05.

Containerized seedlings had an overall higher growth than plug plus seedlings, 12.2 cm versus 7.9 cm ($p < 0.0001$). They were slightly smaller at planting, thus indicating a higher growth rate. A significant interaction between MSP and seedling type ($p = 0.0333$) showed that containerized seedlings responded more to MSP: their growth was significantly lower without MSP, 11.4 cm, compared with MSP, 13.0 cm. No significant effect of MSP on growth was found for plug plus seedlings. Protection and seedling type by protection were also significant ($p = 0.0001$ for both). Insecticide-treated containerized seedlings achieved higher growth, 15.8 cm, than both untreated seedlings, 10.8 cm, and seedlings treated with a coating, 9.9 cm. The difference between seedling protections was greater for containerized seedlings. The growth of plug plus seedlings was slightly lower with a coating, 7.1 cm, compared with 8.5 cm for the insecticide treatment and 8.0 cm for the control.

Discussion

Seedling protection

To date, damage by *Hylastes* has not been considered a major threat to conifer plantations, and the focus has been on preventing *Hylobius* damage. However, with more frequent observations of damage in practical forestry, an important question to address is whether there is a risk that damage by *Hylastes* will increase as prohibited insecticides are replaced by mechanical protection.

Chemical treatment with insecticides seems to have an effect on *Hylastes* damage (Thorsén et al. 2001, Eidmann et al. 1991, Lindelöw 1992), thus confirming the first hypothesis. Non-systemic pyrethroids, such as cypermethrin, have been widely used in Europe since the 1980s. Merit Forest WG, the insecticide used in this study, with the active ingredient imidacloprid, is an example of a broad-spectrum, systemic, synthetic neonicotinoid insecticide (Willoughby et al. 2020). The insecticide is supposed to spread throughout the whole seedling, and could therefore protect the roots to some extent. However, in the current study, there was no statistically significant

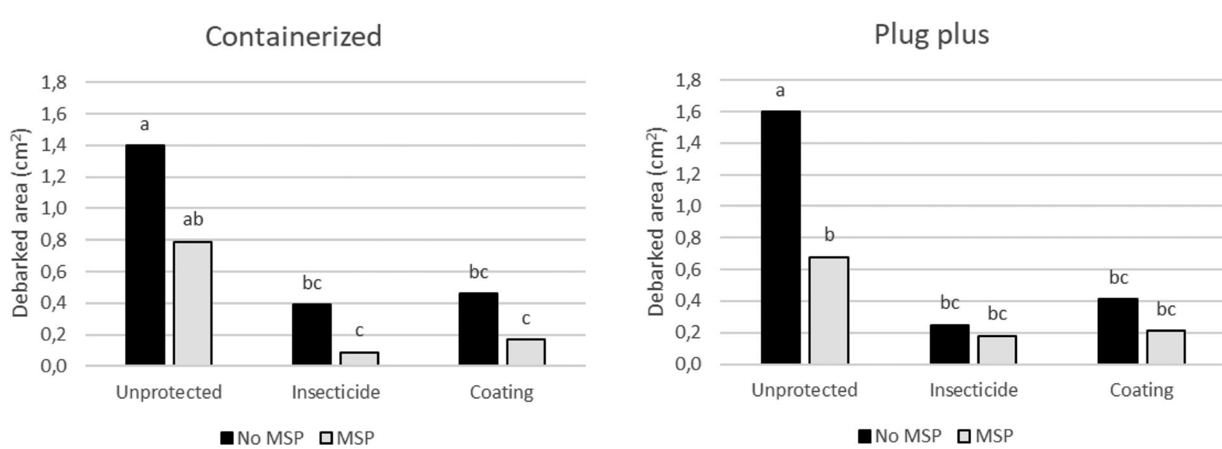

Figure 2. Average area debarked by Hylastes (cm^2) in the root collar zone of containerized and plug plus seedlings planted either without (No MSP) or with (MSP) mechanical site preparation. The seedlings were planted without any protection (unprotected), or treated with an insecticide or a coating. Different letters above the bars indicate significant differences between treatments.

Table 4. Effects of soil type in the planting area on attacks by Hylastes for the two seedling types. Different letters indicate significant differences between treatments.

Seedling type	Soil type	Damage by *Hylastes* (%)
Containerized	Undisturbed	35 a
	Cultivated humus	37 a
	Humus/mineral soil mix	28 b
	Mineral soil	13 c
Plug plus	Undisturbed	36 a
	Cultivated humus	29 a
	Humus/mineral soil mix	35 a
	Mineral soil	19 b

difference in protective effect between insecticide and coating protection, the proportion of seedlings killed by *Hylastes* varying between 0 and 4%.

To date, there have been very few studies on the effect of mechanical protection against *Hylastes*. Eidmann and Von Sydow (1989) observed that *Hylastes* was able to penetrate stockings used to protect against *Hylobius* and Merker and Sattler (1952) noticed that Hylastes could burrow under 5 cm deep barriers to be able to access spruce on the other side. However, since the mechanical protections used in this study appeared to be effective against damage caused by both *Hylastes* and *Hylobius* the second hypothesis was rejected. For seedlings provided with some kind of protection (insecticide or coating), the proportion of damage caused by *Hylastes* was more than halved compared with untreated ones.

Mechanical coatings are specifically designed to reduce *Hylobius* damage and are applied to the stem and root collar. One problem with applying mechanical coatings could be to achieve sufficient coverage of the root collar, an area where both *Hylobius* and *Hylastes* are known to feed.

Mechanical site preparation

MSP had a significant effect on *Hylastes* infestation, reducing the levels of damage, thus confirming our third hypothesis. The results clearly show that damage caused by *Hylastes* could be reduced when seedlings are planted in mineral soil. Also planting in a mixture of humus and mineral soil decreased damage but only for containerized seedlings, and to a lesser extent compared to planting in mineral soil. Several studies have shown that MSP can reduce damage caused by *Hylobius* (Sutton 1993; Örlander and Nilsson 1999; Sikström et al. 2020). However, MSP is a broad concept and can include a variety of planting environments during the period of establishment. We know that pure mineral soil surrounding seedlings after MSP reduces the level of *Hylobius* feeding on seedlings (Björklund et al. 2003; Petersson and Örlander 2003; Petersson et al. 2005), and Kindvall et al. (2000) found that *Hylobius* moves more directly and faster on pure mineral soil compared with humus, and is thus less likely to stop and feed on seedlings. A thorough literature search did not reveal any scientific analyses of the correlation between MSP and damage by *Hylastes:* most of the research was focused on *Hylastes* biology and population studies (Zethner-Møller and Rudinsky 1967; Lindelöw 1992; Rahman et al. 2018). However, *Hylastes* walks on the ground and locates the roots in the soil by scent (Eidmann et al. 1977), thus there is reason to believe that mineral soil probably could have a similar reducing effect on *Hylastes* damage as for *Hylobius*.

Hylobius-Hylastes *relationship*

The fourth hypothesis that there appears to be a correlation between previous *Hylobius* feeding and recent *Hylastes* attacks was confirmed. *Hylastes* are often accompanied by *Hylobius* (Munbo 1916), and many seedlings that are being damaged by *Hylastes* also have scars from *Hylobius* feeding. The reason why mechanical protection can reduce *Hylastes* damage of the roots and root collars requires clarification. The coatings could be a physical hinderance, but since they mostly are applied from the root collar or the substrate and up onto the stem (Lalík et al. 2020), we do not think that this is the main reason.

The application of the two coatings on the seedlings in this study was part of the regular work at the nursery and did not cover the roots, and possibly only small parts of the root collar, if any, and therefore should not have been a deterrent for root-feeding beetles such as *Hylastes*. Nordlander (1991) found that seedlings that were deliberately bark damaged were more easily found by *Hylobius* compared with undamaged ones, and Eidmann et al. (1993) found that damaged seedlings were more attractive to *Hylastes* than undamaged seedlings. Therefore, a more nuanced explanation is that feeding scars arising from *Hylobius* damage on seedlings will attract *Hylastes* as well as more *Hylobius* through the release of volatiles. Then if mechanical protection reduces that damage, the reduced level of volatiles will attract fewer subsequent insects. Mechanical protection will therefore work indirectly by reducing the attractiveness of the seedlings, rather than presenting a physical barrier.

Table 5. Proportion of seedlings damaged (including both damaged and killed seedlings) by Hylobius (%) with different treatment combinations.

No MSP			MSP		
Seedling type	Protection	Damaged by Hylobius %	Seedling type	Protection	Damaged by Hylobius %
Containerized	Unprotected	86 a	Containerized	Unprotected	60 b
	Insecticide	68 b		Insecticide	55 b
	Cambiguard	51 c		Cambiguard	33 cd
Plug plus	Unprotected	87 a	Plug plus	Unprotected	68 b
	Insecticide	71 ab		Insecticide	47 c
	Ekowax	54 bc		Ekowax	32 d

Different letters indicate significant differences between all treatment combinations.

Conclusions

A rapid seedling establishment with high survival is of great importance for future forests. Climate change might change the distribution and occurrence of pests and create different scenarios unknown to us. Today's problem with damage caused by *Hylastes spp* in southern Sweden might increase, both within the region and also in a wider geographical area.

The result from this study gives us a number of valuable tools that we are able to use to prevent damage from *Hylastes* now and hopefully also in the future. These tools initially meant to prevent from damage by *Hylobius abietis*, thus proved to be measures that reduce damage of two different types of beetles.

Why protection against pine weevil such as coatings on the stem also reduces damage by *Hylastes* is a novel and very interesting finding that needs to be further investigated. Mechanical coatings and MSP could be developed to further reduce damage by beetles and promote a fast establishment of the seedling.

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