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Original research article

Have stump piles any effect on the pine weevil (*Hylobius abietis* L.) incidence and seedling damage?

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ABSTRACT

Tree stumps are being increasingly used for bioenergy purposes, which may have significant effects on pine weevil (*Hylobius abietis* L.) populations and the level of damage they can cause to seedlings. Pine weevils are attracted by the smell of fresh stumps in clear-cut areas, and have been shown to cause serious damage to planted coniferous seedlings in European forests. This study was conducted to measure the incidence of pine weevil and damage caused to Norway spruce (*Picea abies*) seedlings in a field experiment including single stump pile plots (SSP), multiple stump pile plots (MSP) and control plots in North Karelia, Finland. Pine weevils were significantly more abundant in MSP stump plots (22% higher) than in SSP plots, and are 23% more abundant compared to the control plots. The extent of seedling damage was significantly lower in the SSP (by 67%) and MSP plots (by 58%) than in the controls. Seedlings damage increased significantly with the distance from the stump pile. Stump harvesting practices should be updated and, in particular, multiple stump piles should be avoided in the clearcut area. However, future studies will be required to explore the environmental and physical factors in the stump-removal area influencing pine weevil abundance.

1. Introduction

The pine weevil (*Hylobius abietis* L.) is a major seedling pest in regenerated European forests (Långström, 1982; Lindström et al., 1986; Leather et al., 1999), which mainly affects planted seedlings of coniferous trees (Eidmann, 1974; Långström and Day, 2004). In Northern Europe, 60%–80% of planted coniferous seedlings can be expected to die if the seedlings are planted without soil scarification and protection against pine weevils (Örlander and Nilsson, 1999). Pine weevils are attracted by the smell of fresh stumps (Heritage and Moore, 2001) and are therefore attracted to clearcut areas for breeding (von Sydow, 1997; Långström and Day, 2004). Swarming adult weevils fly to freshly cut areas in the early summer when the temperature reaches approximately 18 °C (Solbreck and Gyldberg, 1979). The female weevils then lay eggs in the soil and stumps, and oviposit in the bark of the stumps and roots (Nordenhem, 1989; Nordlander et al., 1997). Pine weevil larvae can develop in roots that are less than 10 mm in diameter and when food is scarce, they can move through the soil (Heritage and Moore, 2001; Nordenhem and Nordlander, 1994). After some weeks, the eggs hatch and larvae feed on the inner bark and wood of the root. It takes between 14 months to 4 years for adults to develop from eggs, depending on the prevailing climate (Beijer-Petersen et al., 1962; Långström, 1982).

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Immature weevils are unable to fly when they emerge from stumps (Wainhouse et al., 2007). Although pine weevils can feed on the bark of several tree species, they prefer the bark of conifer species (Manlove et al., 1997; Leather et al., 1999; Löf et al., 2005). In clearcut areas, the pine weevil has two annual peaks of feeding activity (Heritage and Moore, 2001). After emerging from stumps, the development of immature pine weevils depends on a period of maturation feeding (Wainhouse and Brough, 2007). The weevil mainly feeds on the bark of young seedlings, roots and branches of trees, and the bark of shrubs, and feeding is affected by temperature, soil type, surrounding vegetation, and tree species (Örlander and Nordlander, 2003; Wainhouse et al., 2004; Petersson et al., 2005). Adult pine weevils feed on woody weeds, including willow herb, bramble, birch (*Betula pendula* R.), and regenerated natural conifers (Heritage and Moore, 2001). Under laboratory conditions, the pine weevil can feed on broadleaved seedlings such as silver birch in the presence of conifer seedlings (Toivonen and Viiri, 2006). However, the seedlings will die if the stem is girdled by pine weevil feeding. In large parts of northern Europe, and particularly in the southern part of Sweden, pine weevil damage is severe during the first 3 years after clearcutting (Långström, 1982; Nordenhem, 1989; von Sydow, 1997; Moore et al., 2004).

Pine weevils tend to avoid mineral soil because it provides no shelter, and instead show preference for humus soil, which provides hiding places (Björklund et al., 2003). Even in scarified soil, the feeding intensity increases with the presence of vegetation when the weevil is utilizing vegetation for protection from predators or extreme temperatures (Petersson et al., 2006).

In Finland, the UPM Kymmene Company began to harvest Norway spruce (*Picea abies*) stumps from clearcut areas in 2001 (WETP, 2004). Normally, stump harvesting is performed in a site where logging residues have been collected (Röser et al., 2008). Stump extraction is often performed in combination with the regeneration process (Saarinen, 2006). When the stump extraction programme was launched, fuel production from stumps was not a realistic option; however, after the invention of stationary crushers, stumps rapidly became the preferred fuel at combined heat and power (CHP) plants (Hakkila, 2004). In Finland, an excavator equipped with a special stump rake extraction-splitting device is used for stump extraction (WETP, 2004). After extraction, stumps are piled into small heaps in the stand to allow the rain to wash off any soil that is still clinging to the roots (Laitila et al., 2008). Later, a forwarder uploads stumps from piles and moves them to another loading stop. When the load is full, the forwarder unloads stumps along the roadside and once they are unloaded, the forwarder returns to the stand or performs another activity (Laitila et al., 2008). In Finland, the storage and drying time for stump piles is typically less than 2 years and is often only 1 year long (WETP, 2004); thus, pine weevil larvae cannot fully develop during this time, and are potentially eliminated during this process.

Stumps from regeneration areas are an important source of raw material for bioenergy purposes (von Hofsten, 2006), which might influence pine weevil population growth and the damage that they can cause to seedlings. Tree stumps are a key component of the pine weevil life cycle; therefore, stump removal might help to decrease the damage that they cause (Lekander and Lindelöw, 1977). There are also some negative effects of stump harvesting, including changes to the physical characteristics of the soil, damage to forest biodiversity, and the loss of habitat for different organisms (Walmsley and Godbold, 2010).

The use of stumps as a source of bioenergy is increasingly common, because modern combustion technologies can handle different qualities of raw materials (Röser et al., 2008). In Finland, the use of stumps for wood chips to produce heat and electricity in power plants began around the year 2000 and it has been rapidly increasing ever since (Ylitalo, 2010).

The species–energy theory states that the regulation of species richness is dependent on the availability of energy (Wright, 1983; Hawkins et al., 2003). Species richness and available energy are positively correlated (Wright, 1983). Kaspari et al. (2003) also found that areas containing large energy resources have large numbers of species and individuals. A previous study by Nordlander et al. (2003) estimated that over 14,000 pine weevils could be found per hectare of clearcut area after immigration. Therefore, clearcut land is a suitable energy resource for pine weevils during breeding and feeding. This explains why there was debate over the removal of stumps from clearcut areas before new seedlings are planted, which causes pine weevils to lose their habitat and leads to increased survival of plantation seedlings. However, after stump removal, stump piles remain along the road side of the clearcut area to allow them to be washed and dried. During the drying period, pine weevil larvae can still develop and subsequently emerge from the stump pile. Therefore, the aim of our study was to investigate stump piles in clearcut areas for individual pine weevils and for damage in planted coniferous seedlings.

Specifically, we investigated the incidence of pine weevils (*H. abietis*) in control plots (with no stump piles), single stump pile plots (SSP), and multiple stump pile (MSP) plots. We investigated damage caused by pine weevil feeding in the three types of plots and tested whether fresh stump piles attract more pine weevils than do regeneration sites where stump removal has not been performed. Furthermore, we investigated whether feeding damage to seedlings planted closer to the stump piles is worse than that caused to seedlings planted further away.

2. Materials and methods

2.1. Study sites and pitfall traps

The field experiments were conducted at eight sites in North Karelia, Finland (Fig. 1), including three control plots, three SSP plots and two MSP plots where stump removals were performed by UPM Kymmene Company (Table 1). In control and stump removal area slash were already removed by forwarder before our experiment. At each site, 40 baited pitfall traps (Nordlander, 1987) were installed in 4 rows of May, 2010 and May, 2011. The adult weevils are most active in early summer

Table 1
Description of experimental sites.

Site name	Area (ha)	Amount of wood (m^3)	Composition of previous stand	Logging time (month/year)	Stump removal time (month/year)
Nuottilampi, Joensuu	5.3	2048	Spruce 53%, Pine 29%, Birch 18%	Part 08/2008, Rest 11/2009	11/2009
Rypymäki, Eno, Joensuu	5.7	1834	Spruce 33%, Pine 49%, Birch 18%	10/2009	05/2010
Jokikumpu, Rääkkylä	8.2	2584	Spruce 90%, Pine 2%, Birch 8%	12/2009	05/2010
Särkipuro, Tohmajärvi	11.4	3218	Spruce 63%, Pine 25%, Birch 12%	10/2009	No stump removal
Seponvaara, Joensuu	3.0	833	Spruce 90%, Pine 7%, Birch 3%	12/2009	9/2010
Uskali, Lieksa	9.4	3437	Spruce 68%, Pine 20%, Birch 12%	9/2009	8/2010
Värtsilä 1, Tohmajärvi	3.3	1090	Spruce 96%, Pine 3%, Birch 1%	4/2010	No stump removal
Värtsilä 2, Tohmajärvi	3.3	1090	Spruce 96%, Pine 3%, Birch 1%	4/2010	No stump removal

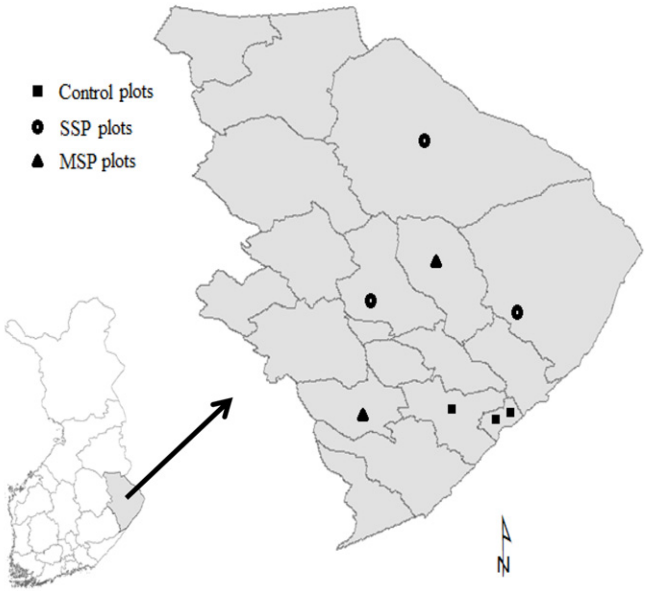

Fig. 1. Experimental plots distribution map in North Karelia, Finland.

and that was why the trapping was timed like that. The distance between adjacent rows of pitfall traps was 5 m, and the distance between the first trap of each row and the stump pile was 1 m for the SSP plots. In the other two MSP plots, many small stump piles were located inside the sites. Seedling lines and trap lines were located alternately at each plot (Fig. 2). Traps were buried underground, with the tops of the traps extending approximately 2–3 cm above the ground, and were protected from the rain with a plastic cover. The top wall of the trap had holes to allow pine weevils to access the traps. Scots pine (*Pinus sylvestris* L.) twigs (length 6–7 cm) were used as a bait to attract existing pine weevils and to offer them feeding through a 14 days trapping period. No attractant chemicals were added to the traps. The inside of trap walls was treated with polytetrafluoroethylene to prevent the weevils from escaping. The traps were emptied after 14 days and new fresh twigs were put again in the same traps for next 14 days. Therefore after 28 days of trapping period, traps were emptied finally; and all the pine weevils collected were brought to the laboratory to be counted and identified to species level.

2.2. Seedling material and measurements

At all the stump removal plots, the stumps were removed before the experimental seedlings were planted. A total of 1600 seedlings were planted within the frame of this study. At each plot, 200 seedlings were planted near the stump pile in unscarified soils, or along the road-side at the non-stump removal plots. The seedlings were planted in 4 rows in different plots between the 6th to the 10th of May, 2010 and between the 8th to the 11th of May, 2011. The distance between seedlings within each row was 1 m. The seedlings were grown using normal nursery procedures at the Suonenjoki Research Nursery of the Finnish Forest Research Institute in Suonenjoki, central Finland. Seed-orchard seeds (origin: EY/FIN T03-06-0414) of Norway spruce (*Picea abies*) from central Finland were sown onto sphagnum-peat-containing medium. All the seedlings used were one year old and individually contained (container size 85 cm^3, type PL-81F, Finland) and they were not treated with insecticides against pine weevil.

Pine weevil feeding damage was scored from one to five after two and four week periods following the Heiskanen and Viiri (2005) classification (no damage = 0; less than 25% of the stem circumference of seedling gnawed = 1; 25%–50% of

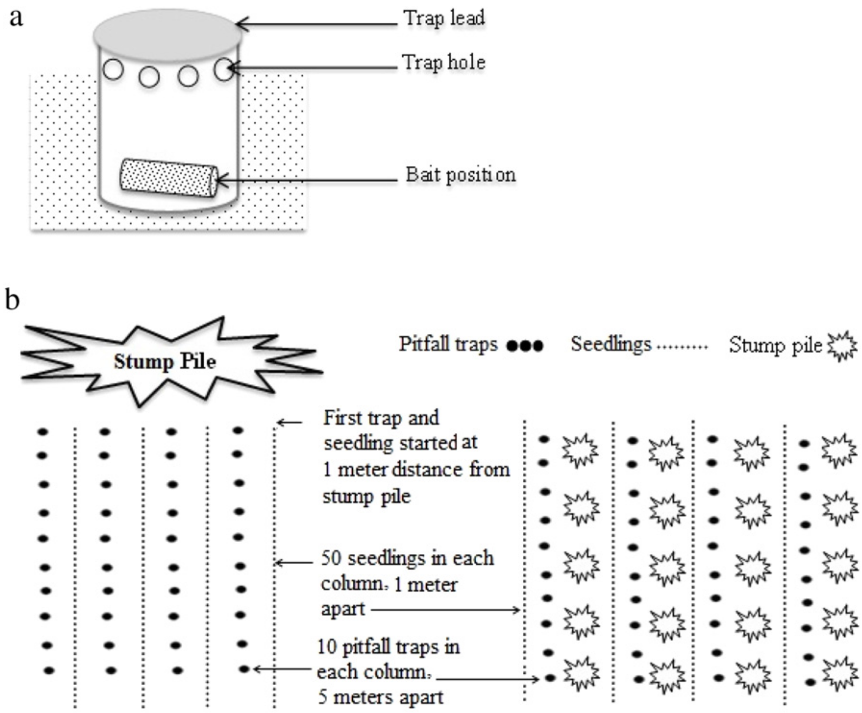

Fig. 2. (a) Used pitfall trap in the experiment; (b) Field experiment design of seedlings and traps for single stump pile (SSP) and control plots (in left) and multiple stump pile (MSP) plots (in right).

Table 2
Traps and seedlings distribution in different plots based on soil type classification.

Soil type	Traps/seedlings in control plots	Traps/seedlings in SSP stump removal plots	Traps/seedlings in MSP stump removal plots
Mineral soil	0/5	0/40	4/85
Mineral soil–humus	2/2	28/293	14/52
Humus–mineral soil	8/70	63/156	31/126
Humus	110/523	29/111	31/137

Table 3
Traps and seedlings distribution in different plots based on different logging residues.

Amount of logging waste	Traps/seedlings in control site	Traps/seedlings in SSP stump removal sites	Traps/seedlings in MSP stump removal sites
Low logging residues	59/295	39/225	14/170
Moderate logging residues	42/187	46/247	41/149
High logging residues	19/118	35/128	25/81

the circumference of the seedling gnawed = 2; more than 50% of the circumference of the seedling gnawed, or an almost entirely gnawed circumference = 3; and dying or dead seedling = 4).

Soil type data were also collected using the following classification (mineral soil: for seedlings or traps only in contact with mineral soil = 0; mineral soil–humus: for seedlings or traps in contact with soils where the proportion of mineral soil is larger than that of humus = 1; humus–mineral soil: for seedlings or traps in contact with soils where the proportion of humus exceeds that of mineral soil = 2; humus soil: for seedlings or traps in contact only with humus = 3).

The amount of logging residue around seedlings and traps was also assessed according to the following classification (low logging residue: logging residue was scarce surrounding the seedling or the trap = 0; moderate logging residue: Some logging residue was found surrounding the seedling or the trap = 1; high logging residue: large amounts of logging residue could be found surrounding the seedling or the trap = 2).

Tables 2 and 3 represent the distribution of seedlings and traps for each different soil type and levels of logging residues.

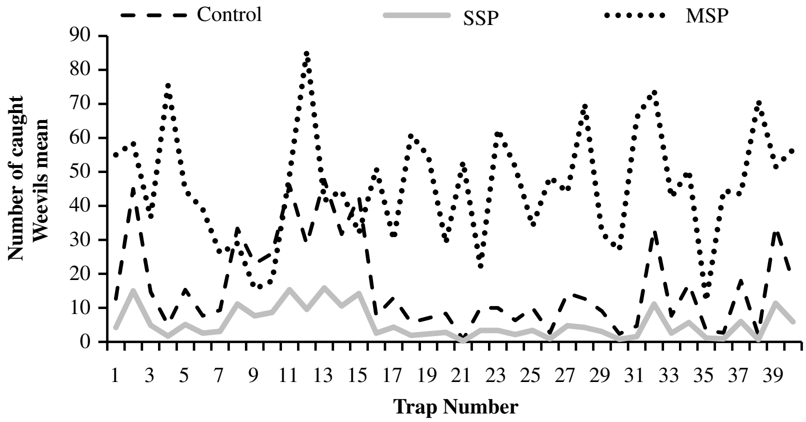

Fig. 3. Mean of caught pine weevils by traps in control, single stump pile (SSP) and multiple stump pile (MSP) plots.

Table 4
Results of generalized linear model test effects of pine weevil population in control, Single stump pile (SSP) and Multiple Stump Pile (MSP).

Source	Type III		
	Wald chi-square	df	*p*
Intercept	1543.570	1	0.000
Control, SSP and MSP	102.916	2	**0.001**
Soil type surrounded traps	39.704	1	**0.001**
Logging residues surrounded traps	3.018	2	0.221

Dependent variable: Pine weevil population.

2.3. Data analysis

Generalized linear models were used whether there were significant differences in pine weevil incidence and seedling damage among plots, considering pine weevil population (continuous variable) and seedling damage (categorical variable) as dependent variables. Control, SSP and MSP plots (categorical) were considered primary factors, and soil type (categorical) and logging residue (categorical) were considered as secondary factors. Mean population data were used for statistical analysis because the trap: seedling ratio varied among soil types and levels of logging residue. Mode data were used as categorical variable to test for statistical differences in seedling damage among soil types, levels of logging residue. Whether seedling damage (categorical variable) varied with the distance from the stump pile (categorical variable) was estimated using linear regression. Tukey's Post Hoc test was performed for statistical difference within different plot group in seedling damage classification. Data were analyzed using the SPSS statistical software package (SPSS for Windows, version 19.0, SPSS, Chicago, IL).

3. Results

3.1. Incidence of pine weevil in the experimental plots

A total of 7585 pine weevils were caught using pitfall traps in all experimental sites. The number of pine weevils captured in the MSP plots was larger compared to the SSP and the control plots (Fig. 3). Considering all the pine weevils captured, 48% of the weevils were collected from MSP plots, 26% from SSP plots and 26% from control plots. A greater number of weevils were captured from humus-rich soils in the control and MSP plots than in SSP plots (Fig. 4). For humus soils, MSP traps contained 8 times as many weevils as SSP traps. Furthermore, for humus mixed soils, the number of weevils captured in the MSP plots exceeded that of the SSP ones. The plots presenting greater quantities of logging residue yielded a large number of weevils at both the stump-removal (SSP and MSP) and control plots. Generalized linear models showed a significant difference among the control, SSP and MSP plots if the soil types were considered in the model. Table 4 shows those statistically significant results regarding pine weevils captured.

3.2. Seedling damage in the experimental plots

Statistical generalized linear model analysis showed that pine weevil damage and soil type differed among control, SSP and MSP plots (Table 5). No feeding damage was found in 73% and 64% of the seedlings in the SSP and MSP plots, respectively; on the other hand, this value was reduced to only 6% in the control plots (Fig. 5). A total of 56% of the seedlings were dying or dead by pine weevils at the control plot; however, only 11% and 20% of the seedlings were dead in the SSP and MSP plots.

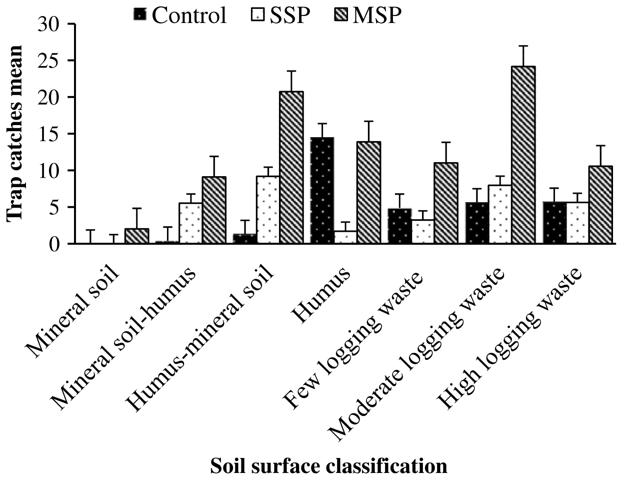

Fig. 4. Mean catches of *Hylobius abietis* in control, single stump pile (SSP) and multiple stump pile (MSP) plots based on soil and logging residue classification.

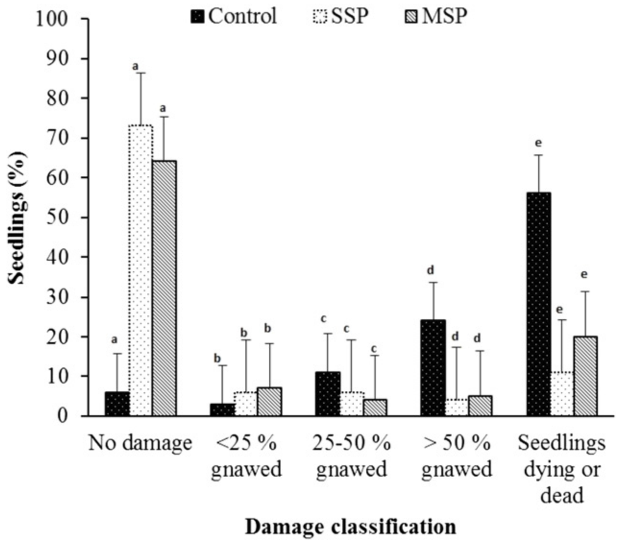

Fig. 5. Comparing feeding damage classification of seedlings in control, single stump pile (SSP) and multiple stump pile (MSP) plots. The letters indicate above the error bar the significant differences within column group of damage classification according to Tukey's test at $p < 0.05$.

Our results also showed that more seedling damages occur in MSP plots than in the SSP plots. Fig. 5 shows that SSP plots presented less seedling damage than MSP and control plots.

In mineral soils, 92% of the MSP seedlings showed no damage and none of the control and SSP plot seedlings were damaged (Fig. 6). For humus soils, only 4% of the control seedlings survived, while 46% and 51% did in the SSP and MSP plots, respectively. Seedling survival was higher at the SSP plots compare to MSP and control plots, where the amount of logging residue was smaller.

Seedling damage increased with the distance from the stump pile in SSP plots. Distances from the stump pile and seedling damage were significantly correlated ($n = 50$; $r = 0.37$; $p < 0.009$).

4. Discussion and conclusion

In our experiment, established traps and seedlings were placed close to stump piles to determine the effect of the stump pile on pine weevil infestation and seedling damage. The experimental design was shown in Fig. 2, which indicates how close the pitfall traps and seedlings should be from the stump pile. In the control plot it was difficult to find out spot of mineral soil because the soil was not scarified. Therefore, there were no mineral soil sites available for traps in our experiment, and few mineral soil spot for seedlings were available in the control site. Again, in the SSP and MSP plots only a few mineral soil spots were found for traps and seedlings due to the presence of unscarified soils. Because of the stump harvesting process, there

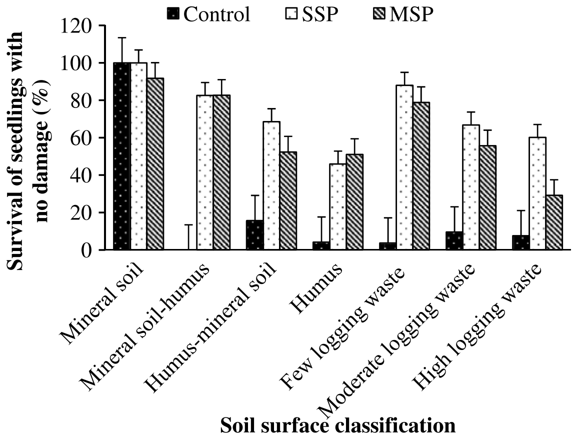

Fig. 6. Comparing only the survival of seedlings based on soil and logging residue classification in control, single stump pile (SSP) and multiple stump pile (MSP) plots.

Table 5
Results of generalized linear model test effects of pine weevil seedling damage in control, Single stump pile (SSP) and Multiple Stump Pile (MSP).

Source	Type III		
	Wald chi-square	df	*p*
Intercept	99.810	1	0.000
Control, SSP and MSP	149.011	2	**0.001**
Soil type surrounded seedlings	16.163	3	**0.001**
Logging residues surrounded seedlings	1.343	2	0.511

Dependent variable: Seedling damage.

was less intact humus soil left in stump removal plots than in control plots. Due to the experimental design, which included unscarified soil and three types of plot (control, SSP, and MSP), the traps/seedlings ratio in different types of soil and logging residue type were unevenly distributed. This experimental design was optimized to examine the effect of stump piles on pine weevil incidence and subsequent seedling damage, and the trapping methods used were limited to those occurring near to the stump piles. To conform to the experimental design, traps and seedlings were established at 5-m and 1-m distances. Therefore, after 5 or 1 m distance soil spot or logging residue type can be same or different for traps and seedling spot. As a consequence, it was difficult to obtain an even distribution of traps and seedlings for each soil spot and logging residue.

In this experiment, we showed that areas with a single stump pile present reduced weevil abundance compared to areas with multiple stump piles. Our study showed that if the number of stump piles in a stump harvesting area varies, then so does the incidence of pine weevils. This finding is consistent with the species–energy theory proposed by Wright (1983). The weevils appeared to be attracted to the stump piles, possibly because fresh stumps and logging residues emit volatile compounds such as monoterpenes and ethanol. These volatile compounds emit a scent that attracts pine weevil into clearcut locations where they then breed (Nordlander, 1987; Brattli et al., 1998). Generally, pine weevils do not breed in live plants (Heritage and Moore, 2001). In areas where multiple stumps were piled, there were more suitable breeding places for pine weevils. The stump piles in MSP plots were placed in an open clearcut area and as a consequence, adult pine weevils that also prefer to breed in stump piles could remain in the plot for longer periods compared to the time they spent in SSP plots. In shelter pine, weevils often remain for long periods and on wind exposed mineral soil spots pine weevils move away from these areas faster (Björklund, 2008). Furthermore, our experiment was performed in early summer when stump removal was carried out just in multiple stump pile areas, and pine weevils normally enter clearcut areas in early summer. Seasonal timing of felling is the most significant factor for the colonization of pine weevils. Therefore, knowledge of felling time can help to predict the growth of pine weevils and forecast the time when adults emerge in a given site (Moore, 2004). When temperature increases, the high soil temperature will result in an increased rate of insect development (Heritage and Moore, 2001). The rate of larval development depends on temperature, season, and altitude, because in lowland areas and on pine, 12 months are needed for larval development, whereas in upland areas and on spruce 18–24 months are required (Wainhouse et al., 2007).

The variation in pine weevil incidence depends on the quality of the previous forest, the timing and duration of logging and scarification operations, and the quality of the different working phases of stump recovery and overall regeneration operations (Viiri, 2008). Our experimental plots previously contained coniferous dominated forest, and as discussed, pine weevils favour coniferous clearcut areas. Pine weevils can fly long distances; they can travel 80 km in one season (Solbreck, 1980) and over 2 km in a few days (Heritage and Moore, 2001).

It has previously been shown that pine weevil populations decreased by 80% when stumps were removed before the new generation of weevils emerged from the stumps (Lekander and Lindelöw, 1977). In our study, most of the traps were set in humus-rich soils in areas with either a single stump pile or multiple stump piles. Our results showed that pine weevils do not appear to have a preference for bare soils; in fact, they tended to avoid mineral soils, which do not provide any shelter. This study confirms the result by Björklund et al. (2003) that the pine weevils showed a strong preference for humus soils, which do provide shelter.

In this study, there was less seedling damage in the stump harvesting area than in the control area. Even though the control plots presented less pine weevils than the stump removal areas, feeding damage was more intensive in the control plots. A previous study also showed that stump removal decreases the amount of damage caused by pine weevils in a stump removal area (Egnell et al., 2007). Hence, the different steps taken during stump harvesting can potentially influence the amount of damage caused by pine weevils. Thus, stump removal areas might be less suitable places for seedling damage. If stump removal is carried out after pine weevil swarming and egg laying, larvae might develop inside the stump piles during stump-storage. In fact, it has also been shown that if stumps are removed after the egg laying period, larval development will continue under the bark and the extent of the damage will not be reduced (Heritage and Moore, 2001).

In addition, most of the seedlings were planted on humus and humus mix soils in both stump removal and control plots, although less seedling damage was observed in stump removal plots than in control plots. Norway spruce seedlings planted on humus soils appeared to be more vulnerable to pine weevil feeding. Therefore, humus soils in typical regeneration sites present higher seedling mortality than those in stump removal plots. According to Björklund et al. (2003), the soil type significantly influences the feeding behaviour of pine weevils and, consequently, soil should be scarified after stump removal before seedlings are planted. In our study, soil was unscarified in stump removal areas and the seedling damage was observed to be less than that in the control areas. This is because the planted seedlings were close to the stump pile and due to stump harvesting management, humus soils were disturbed by the stump excavator and forwarder near to the stump pile. Near the single stump piles, soils tend to be strongly disturbed due to the activity of the stump extractor and forwarder (Laitila et al., 2008). However, more than 30% of planted seedlings were gnawed by pine weevil in the multiple stump pile plots in the present study. Even in scarified soil, feeding intensity increases with the presence of vegetation, since pine weevils use vegetation for predator avoidance or for protection from extreme temperatures (Petersson et al., 2006). In late summer and autumn when the adults emerge, pine weevil feeding causes serious damage to seedlings (Nordenhem, 1989; von Sydow, 1997; Örlander and Nilsson, 1999) and significant damage may still occur for up to 5–6 years thereafter (Heritage and Moore, 2001). The highest amount of damage was shown to occur when seedlings were planted before the pine weevils emerged in autumn and spring (Wainhouse et al., 2007). It has been suggested that planting clearcut areas shortly after soil scarification is an efficient method to reduce pine weevil damage (Örlander and Nordlander, 2003). If logging residues are not harvested, the presence of residues inside the mound can also increase the risk of pine weevil damage (Viiri, 2008). The combination of stump extraction and mounding has potential, but the quality of mounds can be affected during the stump extraction operation (Saarinen, 2006). There is a risk that mounds can be destroyed by flattening and by the mixing of humus with mineral soil if stump extraction and site preparation are performed at the same time (Viiri, 2008). Forwarding of stumps with site preparation can improve harvesting productivity (Laitila et al., 2005).

Although most of the traps were set in humus and humus mix soils in SSP, MSP, and control plots, more weevils were captured from the stump removal plots, especially where multiple stump piles were present. This is probably the consequence of an increased movement of pine weevils to stump removal sites from around the stump pile. Attraction to trap bait might also vary depending on the surrounding environment, although the size of trap bait was similar in all plots. This suggests that the presence of more stump piles in the clearcut area leads to an increase in the incidence of pine weevils near the stump pile. Even in the presence of unscarified soil in a stump removal area, the seedling damage caused by pine weevils was lower than in the control area. Therefore, stump harvesting practices should be updated and, in particular, multiple stump piles should be avoided in the clearcut area. Even though our study shows that the presence of stump piles can influence the incidence of pine weevils, future work is required to further elucidate the relationship between pine weevil abundance and environmental and physical factors in stump removal areas.

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