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Soil Preparation Reduces Pine Weevil (*Hylobius abietis* (L.)) Damage on Both Peatland and Mineral Soil Sites One Year after Planting

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We studied pine weevil (*Hylobius abietis* (L.)) feeding damage to Norway spruce and Scots pine seedlings planted in regeneration areas located on peatlands or on mineral soil sites in Southern and Central Finland. The survey included two planting years and a total of 60 regeneration areas (40 areas on peatlands and 20 on mineral soil sites). Some sites classified as peatland were as transformed or transforming drained peatlands that also contained mineral soil on a prepared surface. The soil preparation method, type of surface material around a seedling, pine weevil, vole-induced or other damage and the health of each seedling were observed in systematically selected circular sample plots. There was slightly more pine weevil damage on peatland than on mineral soil sites. More seedlings were damaged on unprepared peat and humus than on a prepared surface. Seedlings surrounded by a prepared surface had a slightly greater risk of being gnawed by pine weevil when planted on prepared peat compared to planting on prepared mineral soil. Vole damage was observed only in one region during one year. Mounded areas had slightly less vole damage than patched areas. In order to reduce damage caused by pine weevils and voles, it is important to scarify the regeneration area properly before insecticide-treated seedlings are planted. Mounding and patching are recommended so that seedlings can be planted in mineral soil whenever possible, even in the case of peatlands.

Keywords mineral soil, peatland, pine weevil, soil preparation, vole
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1 Introduction

In the near future, approximately 400 000 ha of forests on drained peatlands will be regenerated in Finland (Hökkä et al. 2002). During practical forest regeneration operations carried out in Finland, it has been noticed that the large pine weevil (*Hylobius abietis* (L.)) can sometimes cause serious damage even on peatlands. However, the preliminary results of Saarinen et al. (2009) are thus far the only documented observations of pine weevil feeding on peatlands in Finland. In a few field experiments, Saarinen and coworkers found that pine weevils could induce considerable damage on peatlands, especially if the seedlings were planted on unprepared peat. Pine weevil damage on peatlands has also been observed in Sweden (Hånell 1993, von Sydow, 1997). The only comparison of pine weevil damage on drained peatlands and on mineral soil sites was done by Ozols et al. (1989) in Latvia. More information is needed about the occurrence and extent of pine weevil damage on peatlands compared to that on mineral soil sites.

The risk of damage to seedlings caused by the pine weevil has been studied mainly on mineral soil sites. According to the studies of Örlander and Nordlander (1998), Petersson and Örlander (2003), Nordlander et al. (2005) and Petersson et al. (2005), seedlings face an increased risk for pine weevil feeding in unprepared soil or if prepared soil is covered by humus or a mixture of humus and mineral soil. Saarinen et al. (2009) considered that soil preparation might be feasible way to reduce pine weevil damage on peatlands. On the other hand, Åkerström and Hånell (1997) observed that seedlings planted in peat and in mounds covered by a mixture of peat and mineral soil died more often than seedlings planted in mounds covered by mineral soil on peatlands. They did not specify the exact agents causing the damage, but we can assume that pine weevil caused at least some of it.

According to Björklund et al. (2003), the pine weevil's decision on whether or not to feed on a seedling is strongly influenced by the surrounding soil type, and this decision is taken in the close vicinity (less than 2.5 cm) of the seedling. The presence of a pure mineral soil layer a few centimeters deep around the seedling strongly reduces the likelihood that an approaching pine weevil would feed on the seedling (Björklund et al. 2003).

A longer interval between clear-cutting and planting has been shown to reduce damage by pine weevils (von Sydow 1997, Örlander and Nilsson 1999). However, the amount of competing vegetation increases at the same time, thereby increasing seedlings' risk for vole-induced damage (Teivainen et al. 1986) and mortality (Nilsson and Örlander 1995), depleting the water available in the rooting zone (Nilsson and Örlander 1995) and decreasing seedling growth (e.g. Nilsson and Örlander 1995, 2003, Löf et al. 2006). Vegetation around seedlings also increases damage by pine weevils (Petersson et al. 2006). Vegetation develops especially rapidly on peatlands (e.g. Moilanen et al. 1995), for which reason it may be better to plant as soon as possible after clear-cutting if seedlings' risk for pine weevil damage is not too high.

The main aim of this study was to evaluate the occurrence of pine weevil (*Hylobius abietis*) damage in forest regeneration areas on peatlands, and to compare the probability of pine weevil damage on peatlands and on mineral soil sites. Another aim was to identify the factors affecting seedlings' risk for damage by pine weevils on peatland forests. In particular, we investigated whether soil preparation reduces the pine weevil damage in peatlands. Results one year after planting are presented here; the occurrence of pine weevil damage on the same sites three years after planting will be published later.

2 Material and Methods

2.1 Study Sites and Sampling Design

For the study, 30 fresh regeneration areas planted in 2008 and 30 areas planted in 2009 were selected from all regenerated areas in later mentioned regions. The regeneration areas were located in Pirkanmaa region (regions A and B) and in South and North Savo region (region C) of Southern and Central Finland, ranging between latitudes 61°N and 63°N. The particular aim was to study peatlands, and in most cases more peatland sites were selected. However, at least one mineral soil site, located as close as possible to each peatland sites observed, was also selected (one site was a control for several peatland sites). It was not always possible to select mineral soil sites that were close to the peatland sites: in region C, the peatland and mineral soil sites were tens of kilometers apart, and in region B in 2008, only one mineral soil site was a control for nine peatland sites. Areas planted in spring 2008 were inspected between the end of April and the middle of May 2009, and those planted in spring 2009 between the end of September and the beginning of October 2009. One-year-old Norway spruce (*Picea abies* (L.) Karst.) or Scots pine (*Pinus sylvestris* L.) container seedlings were used in 54 regeneration areas, while two-year-old, container-grown Norway spruce seedlings were used in six areas of region C. All seedlings were treated with insecticides (active incredient deltametrin or lambda-syhalotrin) against pine weevil before planting.

Systematic plot sampling was used for the inventory. Sampling was based on the acreage of the regeneration area, which varied between 0.5 ha and 6 ha. The distance between systematically sampled circular plots (50 m^2, radius 3.99 m) was shorter in smaller regeneration areas than in larger areas; thus, on average, ten circular sample plots were sampled per area.

2.2 Observed Site and Seedling Characteristics

In systematically sampled plots, the condition of seedlings (healthy, weakened, dead) and the reasons for deterioration or mortality (pine weevil, vole and other damage) were determined. Site type (mesic, sub-mesic, sub-xeric), soil type (fine, medium coarse or coarse mineral soil or peat), tree species (Scots pine or Norway spruce) and stoniness (classified into three categories by the visible stoniness: no stones, normal stoniness, very stony) were visually determined for each planted seedling located within the sample plot. For the same seedlings, the soil preparation method [disc trenching (T), patching (P), inverting (I, soil was inverted into the same place from which it had been taken so that inverted mineral soil buried the humus layer), mounding with inverted humus on unprepared soil (M, mounds contained double humus layer below the mineral soil, with the patch from which the inverted soil had been taken beside the mound), mounding with ditching (D, soil for mounds was taken from ditches)] and the type of surface material around a seedling (defined by classifying it as unprepared peat, patch on peat, peat-covered mound, unprepared humus, disc-trenched furrow on mineral soil, patch on mineral soil, mound covered with mineral soil, mound covered with humus, patch covered with humus) were also visually defined. For further processing, the surface type was reclassified as unprepared peat, prepared peat, unprepared humus, prepared mineral soil and prepared humus. When peatlands and mineral soil sites are used here as variables, from this point onwards they are called ‘soil class’. The number of years (growing seasons) between clear-cutting and planting was used as background information.

In all regions in 2008 and in region C in 2009, there were more peatland sites than mineral soil sites. The distribution of site characteristics for both peatland and mineral soil sites is presented in Table 1. All regeneration areas on peatland sites had been drained earlier; they were classified as transformed peatlands or transforming drained peatlands with a very thin peat layer. The soil type within these peatland regeneration areas was partly mineral soil (see Table 1). A site was considered to fall in the peatland category if most observations of soil type within a regeneration area were classified as peat.

Most areas were sub-mesic or corresponding peatland sites. Scots pine seedlings were planted in three areas of region C in 2008 (one peatland site, one mineral soil site and one area containing both soil classes), while Norway spruce seedlings were planted in the rest of the areas. Thus the effect of tree species on the seedlings damaged by pine weevil was analyzed only for region C in 2008.

On both peatland and mineral soil sites, only a small proportion of seedlings was planted in unprepared soil (Table 2). In patched mineral soil sites, the proportion of seedlings planted in unprepared humus was quite high compared to that for other soil preparation methods. When some of the regeneration areas on peatland sites were already transformed peatlands, prepared mineral soil sur-

Table 1. Description of the regeneration areas on peatland and on mineral soil sites for three geographical regions (A, B, C) and two planting years included in the survey. The figures present the number of regeneration areas according to soil classes, site types, soil types, soil preparation methods and the duration between clear-cutting and planting. Peatlands are presented first. The soil class was defined as peatland if most of the soil type observations within a regeneration area was peat.

	Geographical region and planting year					
	Region A		Region B		Region C	
	2008	2009	2008	2009	2008	2009
Soil class						
Peatland*	7	4	9	5	8	7
Mineral soil sites	3	6	1	5	2	3
Site type						
Mesic (*Oxalis-Myrtillus* type)			3/0	1/0		1/0
Sub-mesic (*Myrtillus* type)	7/3	4/6	4/1	3/5	6/1	5/3
Sub-xeric (*Vaccinium* type)			2/0	1/0	2/1	1/0
Soil type						
Medium coarse mineral soil		0/1				0/1
Fine, partly medium coarse soil	0/2	0/4	0/1		0/1	0/1
Fine mineral soil	0/1	0/1		0/5	0/1	
Peat	6/0	4/0	8/0	5/0	4/0	7/0
Partly peat, partly fine mineral soil	1/0		1/0		3/0	
Partly peat, partly medium coarse mineral soil					1/0	
Soil preparation method						
Patching (P)					0/1	
Inverting (I)			7/1	2/4		
I and P				0/1		
Mounding with inverted humus onto the unprepared soil (M)	1/3	0/4				1/3
Mounding with ditching (D)	2/0	2/0			2/0	3/0
M and D	3/0	2/2			6/1	3/0
I and D	1/0		2/0	3/0		
Years between clear-cutting and planting						
0				1/1		
1			9/1	3/3	6/1	5/1
2	2/3	2/4		1/1	2/1	2/2
3	4/0	2/2				
4	1/0					

rounded seedlings in 31% of the observations on peatland sites (Table 2).

Vole damage was analyzed separately, since vole population densities were high in Southern Finland during the winter of 2008–2009 (see Metla's biannual vole population reports [in Finnish]: http://www.metla.fi/tiedotteet/list/myyrat.htm) and there was great fear of vole damage, especially in the region where the study areas were located. Damage by field voles (*Microtus agrestis* (L.)) was not separated from damage by bank voles (*Myodes glareolus*) (Schreber)).

2.3 Statistical Analysis

Probabilities of pine weevil and vole damage and the condition of seedlings for sites with different characteristics were analyzed with PASW SAS 9.1.3. for Windows. Following McCulloch et al. (2008), we employed the generalized linear mixed-models (GLIMMIX procedure). In the models, geographical region, soil class, planting years, years between clear-cutting and planting, soil preparation methods, site or soil type, type of surface material around a seedling, tree species

Table 2. The proportion of evaluated seedlings (%) in each type of surface material that surrounded seedlings within each soil preparation method, separated for peatland and mineral soil sites. Peatlands are presented first. The total number of seedlings evaluated for each soil preparation method is presented in the last column along with the proportion of seedlings evaluated for each surface type after combining all soil preparation methods.

	Proportion of seedlings in each surface type, %					Total number of seedlings
	unprepared		prepared			
	peat	humus	peat	humus	mineral soil	
Soil preparation method						
Unprepared	100/0					35/0
Patching		0/11	77/0	0/1	23/88	35/98
Inverting	4/0	0.4/4	75/2	0/2	21/93	1044/519
Mounding with inverted humus	4/0.1	0.4/1	63/1	0/3	33/95	469/1187
Mounding with ditching	3/0		61/1		36/99	2037/70
Total	*4/0.1*	*0.2/2.5*	*65/1*	*0/2.5*	*31/94*	*3620/1874*

or stoniness were used as fixed effects and the regeneration area as a random effect. Interactions among fixed effects were also analyzed, but only statistically significant ($p<0.05$) interactions are presented. We used a binomial distribution with logit-link function. The condition of seedlings and different damage factors were multinomials, and each category was analyzed as a separate binomial variable. Fixed variables and their interactions were tested with Tukey's test ($p<0.05$). Probabilities (LS-means) of fixed effects and their standard errors over a balanced population are given in the text and in Figs. 1–2 and Tables 3–4.

3 Results

3.1 Condition of Seedlings

At the time of inspection, 4% of seedlings were dead and 19% of seedlings were weakened. The probabilities of mortality and weakening were higher for the plantings of 2008 compared to those of 2009 (Table 3). The mortality of seedlings did not differ significantly between peatland and mineral soil sites, but less weakened seedlings were found in the latter (Table 3). Thus, seedlings on peatlands were completely healthy less often than seedlings on mineral soil sites. Stoniness increased the seedlings' probability of death and weakening (Table 3).

The mortality of seedlings in peat was slightly higher than that in mineral soil regardless of whether the seedlings were planted in prepared or unprepared soil (Table 3). There were no differences in the probabilities of weakened seedlings, but the probability of healthy seedlings in prepared peat was lower than that in prepared mineral soil. The soil preparation method affected the mortality of seedlings so that in mounding with ditching, the probability of seedling death was lower than that with other soil preparation methods (Table 3).

3.2 Pine Weevil Damage

For the plantings in 2008, pine weevil damage was observed at 54% of the peatland sites and 50% of the mineral soil sites. For the plantings in 2009, pine weevil damage was observed at 69% of the peatland sites and 43% of the mineral soil sites. When the two planting years were combined, the corresponding figures were 60% and 45%. On average, however, only a few seedlings within a single regeneration area were damaged by pine weevils, since the probability of pine weevil damage was 0.01 in both planting years (difference between years $p=0.998$). The probability of pine weevil damage was slightly higher on peatland than on mineral soil sites, and on very stony sites than sites without stones (Table 4). The regenerated tree species (only for region C

Table 3. Probability of seedlings being dead, weakened or healthy between planting years by soil classes, stoniness, types of surface material surrounding the seedlings or preparation methods. N indicates the number of seedlings in each category analyzed. The letters after the numbers indicate statistically significant ($p<0.05$) differences among the classes, types or methods.

		Health condition of seedlings		
	N	Dead	Weakened	Healthy
Planting year				
2008	2668	0.03±.01a	0.27±0.04a	0.62±0.06a
2009	2825	0.01±0.001b	0.06±0.01b	0.92±0.02b
p-value		*<0.001*	*<0.001*	*<0.001*
Soil class				
Peatland	3619	0.02±.005	0.19±0.03a	0.74±0.05a
Mineral soil	1874	0.01±0.004	0.06±0.02b	0.91±0.03b
p-value		*0.226*	*<0.001*	*0.007*
Stoniness				
No stones	3997	0.01±0.003	0.14±0.02a	0.81±0.03a
Normal stoniness	1141	0.01±0.005	0.10±0.02a	0.85±0.03a
Very stony	355	0.03±0.04	0.19±0.04b	0.68±0.06b
p-value		*0.062*	*<0.001*	*<0.001*
Type of surface material				
Unprepared peat	158	0.03±0.01ab	0.13±0.03	0.81±0.05abc
Unprepared humus	46	0.002±0.002ab	0.16±0.05	0.85±0.06abc
Prepared peat	2362	0.02±0.007a	0.14±0.02	0.78±0.04a
Prepared humus	54	0.02±0.02ab	0.12±0.24	0.55±0.13bc
Prepared mineral soil	2871	0.01±0.002b	0.12±0.02	0.84±0.03c
p-value		*<0.001*	*0.410*	*<0.001*
Preparation method				
Unprepared	35	0	0.20±0.07	0.82±0.07
Patching	133	0.04±0.02	0.09±0.04	0.77±0.08
Inverting	1563	0.02±0.01	0.14±0.02	0.81±0.04
Mounding with inverted humus	1656	0.02±0.01	0.11±0.02	0.80±0.04
Mounding with ditching	2106	0.01±0.003	0.14±0.03	0.82±0.03
p-value		*0.051*	*0.402*	*0.857*

in 2008), site type or soil type did not affect the probability of pine weevil damage (Table 4).

The surface type around a seedling ($p<0.001$) had a significant effect on pine weevil damage. The probability of pine weevil damage was higher for seedlings in unprepared peat and humus than for seedlings in prepared peat and mineral soil (Fig. 1). Seedlings in prepared peat had a higher probability of pine weevil damage than seedlings in prepared mineral soil. Prepared humus did not differ from other surfaces.

The probability of pine weevil damage varied in different regions, although not significantly ($p=0.088$; Fig. 2). The regeneration chains differed among the regions. In region A, there was an interval of 2–4 years between clear-cutting and planting, while in other regions the interval was 0–2 years (Table 1). There was a trend for a higher probability of pine weevil damage the shorter the interval between clear-cutting and planting was, but the differences were not statistically significant (interval: $p=0.325$; region × interval: $p=0.070$; Fig. 2).

The soil preparation method affected the risk for pine weevil damage (Table 4). The probability of pine weevil damage differed significantly between inverting and mounding with ditching, but mounding with inverted humus and patching did not differ from other soil preparation methods.

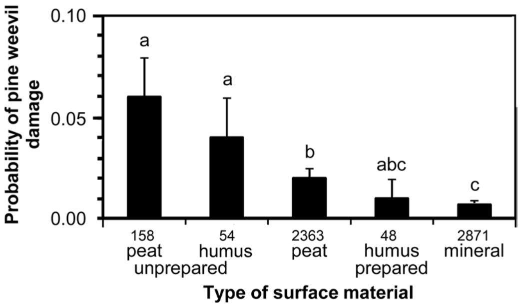

Fig. 1. Probability of pine weevil damage a seedlings surrounded by different types of surface material. The surface was scored as prepared peat, humus or mineral soil or unprepared peat or humus. The numbers below the bars indicate the number of seedlings in each surface type category. Different letters above the bars indicate statistically significant ($p<0.05$) differences among surface types around a seedling. The vertical bars are the standard error of means (SE).

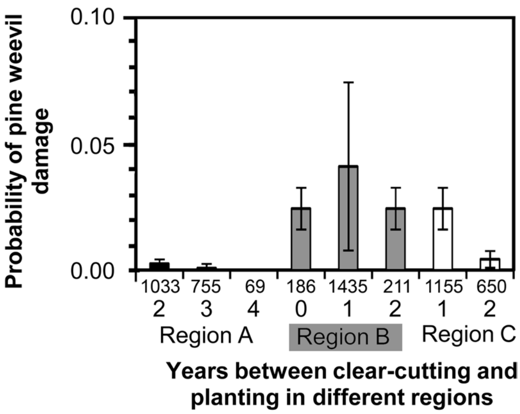

Fig. 2. Probability of pine weevil damage in regions A, B and C after an interval of 0–4 years between clear-cutting and planting. The numbers below the bars indicate the number of seedlings in each interval for each region. The vertical bars are the standard error of means (SE).

Table 4. Probability (±SE) of seedling damage caused by pine weevils for different soil classes, tree species (only for region C in 2008), soil and site types, stoniness and soil preparation methods. The letters after the numbers indicate statistically significant ($p<0.05$) differences among the soil and stoniness classes or soil preparation methods. N indicates the total number of seedlings included in the GLIMMIX.

	Probability of pine weevil damage	N
Soil class		
Peatland	0.02±0.004a	3620
Mineral soil	0.01±0.003b	1874
p-value	0.045	
Tree species		
Scots pine	0.01±0.008	267
Norway spruce	0.02±0.02	626
p-value	*0.161*	
Soil type		
Coarse	0	12
Medium coarse	0.01±0.003	904
Fine	0.01±0.003	1034
Peat	0.02±0.004	3544
p-value	*0.168*	
Site type		
Mesic	0.02±0.01	461
Sub-mesic	0.01±0.002	4312
Sub-xeric	0.02±0.01	721
p-value	*0.209*	
Stoniness		
No stones	0.01±0.003ab	3998
Normal stoniness	0.01±0.004b	1141
Very stony	0.03±0.01b	355
p-value	*0.042*	
Soil preparation method		
Patching	0.04±0.03ab	113
Inverting	0.002±0.007a	1583
Mounding with inverted humus	0.001±0.004ab	1656
Mounding with ditching	0.01±0.003b	2107
p-value	*0.042*	

3.3 Other Damage

Vole damage was observed in 40% of the regeneration areas planted in 2008, but there was much regional variation. The most damage was observed in region C (18% of seedlings), but in regions A (1%) and B (3%) only a few seedlings were damaged by voles. Thus, the occurrence of vole damage and the effect of different factors were analyzed only for regeneration areas of region C. The probability of vole damage did not differ between peatland and mineral soil sites, between tree species or among the surface materials surrounding the seedlings (Table 5). Less vole damage was observed when the soil type was medium coarse than when it was fine soil or peat (Table 5). The probability of vole damage to seedlings planted in mounds was less than the probability for those planted in patching, but the differences were not statistically significant (Table 5).

The other agents causing damage, such as frost and drought or damage by fowl and moose that had trampled the seedlings, weakened a total of 17% of seedlings. Three percent of seedlings had broken shoots. The occurrence of other damage was random and was not analyzed separately. When combined, soil class ($p=0.080$), preparation method ($p=0.148$), site type ($p=0.252$), soil type ($p=0.171$), stoniness (0.061), years between clear-cutting and planting ($p=0.132$) or the surface type around a seedling ($p=0.218$) did not affect the probability of these other damage types. However, there was significantly more damage ($p<0.001$) in the planting year 2008 (0.22) than in the planting year 2009 (0.04).

Table 5. Probability (±SE) of seedling damage caused by voles for different soil classes, tree species, soil types, preparation methods and types of surface material surrounding the seedlings in region C in 2008. The letters after the numbers indicate statistically significant ($p<0.05$) differences among the soil types or preparation methods. N indicates the total number of seedlings included in the GLIMMIX.

	Probability of vole damage	N
Soil class		
Peatland	0.06±0.05	737
Mineral soil	0.17±0.24	156
p-value	*0.526*	
Tree species		
Scots pine	0.30±0.25	267
Norway spruce	0.04±0.03	626
p-value	*0.161*	
Soil type		
Medium coarse	0.07±0.02a	77
Fine	0.10±0.08b	152
Peat	0.09±0.06b	664
p-value	*0.009*	
Surface type		
Unprepared peat	0.10±0.12	25
Unprepared humus	0.02±0.01	18
Prepared peat		0
Prepared peat	0.13±0.09	234
Prepared mineral soil	0.05±0.07	616
p-value	*0.071*	
Soil preparation method		
Patching	0.22±0.15	99
Mounding with inverted humus	0.09±0.06	162
Mounding with ditching	0.07±0.05	632
p-value	*0.063*	

4 Discussion

In this study, the seedlings' risk for pine weevil damage was slightly higher on peatland than on mineral soil sites. Independent of soil class, a prepared surface around a seedling reduced the risk for pine weevil damage. Our results also showed that a prepared mineral soil surface was more efficient in preventing pine weevil feeding than a prepared peat surface. Especially on peatlands with a thick layer of peat, it may be difficult to achieve a mineral soil surface. Luoranen et al. (2011) showed that although most mounds in machine-planted peatlands were peat-covered, it was also possible to cover mounds with mineral soil or a mixture of mineral soil and peat, even on drained peatlands with a thick (>30 cm) layer of peat. Thus, in order to reduce pine weevil feeding on peatland sites, we recommend that seedlings should be surrounded with mineral soil whenever possible.

According to our results, the risks for pine weevil damage were similar in different site types and soil types in the case of both Scots pine and Norway spruce seedlings. These results differ from Långström's (1982) observations that pine weevil damage is more frequent in Scots pine than in Norway spruce, and more frequent in dry sites dominated by Scots pine than in more fertile sites where Norway spruce dominates. Our study included only three regeneration areas where Scots pine seedlings had been planted, and some of the seedlings were damaged by voles. This may have caused underestimation of pine weevil damage within those areas.

A longer interval between clear-cutting and planting decreases seedlings' risk for pine weevil damage (von Sydow 1997, Örlander and Nilsson 1999). In this study, the number of years in between clear-cutting and planting had no effect on seedling mortality since most damage caused by pine weevil feeding was slight. In the regions studied, the regeneration operations varied and it could not be estimated how much the interval between clear-cutting and planting and how much, e.g. the soil preparation method – which also differed among the regions – affected the results. In addition, when planting a year after clear-cutting was compared to planting in unprepared soil, the latter increased the risk for pine weevil damage more. When there is a longer interval between planting after clear-cutting, the negative effects of competing vegetation increase, especially on peatland sites where the growth of field vegetation after clear-cutting is rapid (Moilanen et al. 1995). Field vegetation reduces seedling growth (Löf et al. 2006) and increases both mortality (Nilsson and Örlander 1995) and vole damage (Teivainen et al. 1986).

Stoniness had a slight influence on the occurrence of pine weevil or other damage. The damage that occurred in very stony sites was more serious and the mortality of seedlings was higher in very stony sites than in less stony sites. When the stoniness increases, the quality of soil preparation and planting decreases (Arnkil and Hämäläinen 1995, Luoranen et al. 2011) and the risk of drought-induced damage increases at the same time (Luoranen et al. 2011). If the seedlings suffer from other stress factors, e.g. drought, in addition to pine weevil feeding, their recovery from pine weevil damage is weakened and even slight feeding may cause fatal damage.

We inspected pine weevil damage only one growing season after planting. However, pine weevil damage increases one to three years after clear-cutting (Långström 1982). The observed 1% level of pine weevil damage one growing season after planting contradicts the observations of Heiskanen and Viiri (2005) in Central Finland. According to them and Saksa (2011), most pine weevil damage is usually observed the second and third growing seasons after planting. Hånell (1993) and von Sydow (1997) observed that a heavy pine weevil attack on peatlands could continue for at least three years, and according to Ozols et al. (1989), a pine weevil attack may last longer on drained peatlands than on mineral soil sites. When pine weevil damage was inventoried a year after planting, chemical control against pine weevil still protected the seedlings. The protection given by chemical control disappears from seedlings during the first growing season after planting (Viiri et al. 2007). Similarly, the damage-suppressing effect of soil preparation decreases over time due to in-growth of vegetation (Örlander and Nordlander 2003). Pine weevil damage should thus be followed for three years in order to determine the total risk for pine weevil damage. However, it is more difficult to determine the final cause of death or damage to seedlings in later years. Therefore we did our survey after one feeding summer and assume that our observations apply better to comparison of soil classes.

More seedlings planted in the year 2008 were damaged and the damage then was more serious in comparison to seedlings planted in 2009. Although all of the inspected seedlings spent a growing season in the forests, seedlings planted in 2008 had also spent one winter in the forests. In autumn 2008, frosts occurred in Central Finland (see Ilmastokatsaus September 2008), damaging seedlings in region B and causing the upper part of shoots to dry. In addition, damage caused by fowl (Seiskari 1962) generally occurs during winter. The planting year did not affect pine weevil damage, but seedlings planted in 2008 and damaged by pine weevil died during their first winter. If the seedling is weak already in autumn, it will weaken more during winter and the following spring. In this study, however, the agent causing the most important damage during winter was the vole.

Various factors affected the seedlings' risk for damage by voles, but as the number of regeneration areas was low, we cannot make very far-reaching conclusions. All ten regeneration areas with vole damage were located in region C, with a maximum distance of 70 km between them; in most cases the distance from each other was 20 km. There can be great local variation in vole damage (Henttonen et al. 1995, Huitu et al. 2009), and this may have influenced the results.

More vole damage was found in fine and peat soils than in medium coarse soils, but the differences were most probably caused by soil fertility, not soil texture. In fertile soils, both on mineral soil sites and especially on peatlands, vegetation develops quickly after clear-cutting (Moilanen et al. 1995) and the amount of vegetation is known to increase the risk for vole damage (Teivainen et al. 1986). We observed that mounding slightly reduced the risk for vole damage compared to patching. Similarly, Löf et al. (2006) found more vole damage among seedlings planted in unprepared soil than among seedlings planted in mounds.

In conclusion, the probability of pine weevil damage was slightly higher for peatland than for mineral soil sites. The most important factor in preventing pine weevil damage was soil preparation. Especially important was the surface material around a seedling: mineral soil reduced the risk of pine weevil damage. Mounding also decreased vole damage. Thus, soil preparation should be done so that seedlings can be planted in prepared soil on both mineral soil and peatland sites. On drained peatland sites, mounds or patches should be covered by mineral soil whenever possible. The inspection of damage on the same sites three years after planting will give more information about trends in occurrence of pine weevil damage on peatland and on mineral soil sites.

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