Scandinavian Journal of Forest Research

ISSN: 0282-7581 (Print) 1651-1891 (Online) Journal homepage: https://www.tandfonline.com/loi/sfor20

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To cite this article: Göran örlander & Urban Nilsson (1999) Effect of Reforestation Methods on Pine Weevil (Hylobius abietis) Damage and Seedling Survival, Scandinavian Journal of Forest Research, 14:4, 341-354, DOI: 10.1080/02827589950152665

To link to this article: https://doi.org/10.1080/02827589950152665

Published online: 05 Nov 2010.

Scand. J. For. Res. 14: 341–354, 1999

Effect of Reforestation Methods on Pine Weevil (*Hylobius abietis*) Damage and Seedling Survival

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Scandinavian Journal of Forest Research

Örlander, G.[1] and Nilsson, U.[2] ([1]Swedish University of Agricultural Sciences, The Southern Swedish Forest Research Centre, Asa Forest Research Station, S-360 30 Lammhult, Sweden and [2]Swedish University of Agricultural Sciences, The Southern Swedish Forest Research Centre, Box 49, S-230 53 Alnarp, Sweden). *Effect of reforestation methods on pine weevil (Hylobius abietis) damage and seedling survival.* Received Feb. 16, 1998. Accepted Sept. 15, 1998. Scand. J. For. Res. 14: 341–354, 1999.

Damage to Norway spruce (*Picea abies* (L.) Karst.) seedlings by the large pine weevil, *Hylobius abietis* (L.) (Coleoptera: Curculionidae), was monitored in relation to clear-cutting age and silvicultural treatments in southern Sweden. New clear-cuttings were established on four sites during five consecutive years, and seedlings were planted on them from 1989 through 1993. In total, 31 774 seedlings were planted on 20 clear-cuttings. The measures evaluated were seedling insecticide treatment, application of herbicide to ground vegetation, scarification (mound) and planting late in the season. In addition, the effects of slash removal and seedling type were studied.

The pine weevil was, by far, the dominant damaging agent. Planting without insecticide or soil treatment on fresh, one- or two-year-old clear-cuttings resulted in a mean level of weevil-caused mortality exceeding 60%. The results indicate that the risk of serious damage by pine weevils remains high until the clear-cuttings reach four or five years of age. Killing the vegetation with herbicide had no effect on pine weevil damage. Slash removal decreased damage on older clear-cuttings, but the effect was small. Scarification (mounding) strongly reduced damage. On fresh clear-cuttings the mean mortality caused by pine weevils in mounded plots was 13%, whereas it was 77% in the controls. The mounding effect varied between sites and clear-cuttings of different ages. Late planting (10 June instead of 1 May) reduced damage on two- and three-year-old clear-cuttings. Three-year-old, bare-rooted seedlings were not damaged as seriously as two-year-old, containerized ones, but the effect was probably due to the larger size of the bare-rooted seedlings. Non-lethal injury resulted in reduced seedling growth. Damage by pine weevils varied between years and within growing seasons. However, on fresh, one- and two-year-old clear-cuttings, damage was severe enough to cause high mortality during all studied years. *Key words: Hylobius abietis, mounds, Picea abies, pine weevils, reforestation, scarification, seedling damage, slash removal, vegetation.*

INTRODUCTION

In southern Scandinavia, pine weevil *(Hylobius abietis* (L.) (Coleoptera: Curculionidae)) population levels are generally high enough to cause unacceptable damage to conifer seedlings on most clear-cuttings (Lindström et al. 1986, Eidmann & von Sydow, 1989, Hagner & Jonsson, 1995, Eidmann et al. 1996, von Sydow, 1997). By using insecticides, e.g. permethrin preparations, it is possible to reduce pine weevil damage to acceptable levels at a relatively small cost (e.g. von Sydow, 1997). However, the use of insecticides for treating seedlings will probably be prohibited in Sweden in the near future. Thus, there is a need to develop alternative measures for protecting seedlings from pine weevil.

Many silvicultural methods affect the risk of pine weevil attack on seedlings. One way to overcome the problem is to delay planting until the weevils have left the clear-cutting. Studies from southern Scandinavia show that the generation time for pine weevils is two years; i.e. the new generation of pine weevils emerges from two-year-old clear-cuttings (Beijer-Petersen et al. 1962, Långström, 1982). Based on those studies, planting on three-year-old clear-cuttings has been recommended for practical forestry (Anon, 1978). Recent studies (von Sydow, 1997, Örlander et al. 1997) have confirmed that weevils are most abundant during the first three seasons after cutting, but considerable numbers are also found on older clear-cuttings. Thus, the effectiveness of using a three-year fallow period to avoid pine weevil damage can be questioned. Planting on old clear-cuttings can also result in problems with competition from ground vegetation (Nilsson & Örlander, 1995, Örlander et al. 1996). Furthermore, from an economic point of view, rapid replanting is desirable.

In addition to the "wait and plant method", there are several other silvicultural options available for reducing problems with pine weevils. However, none of these alternative methods are free from problems. There is clearly a need to develop a method for predicting attack rates after cutting (Wilson et al. 1996) and to learn more about the relation between clear-cutting age and pine weevil occurrence (e.g. Nordenhem, 1989, Örlander et al. 1997).

The size, structure and distribution of clear-cuttings are important factors influencing the risk of damage. Thus, Wilson et al. (1996) found that damage decreased with the size of a clear-cutting and that the risk of damage increased if the clear-cuttings were aggregated. Damage by weevils can be considerably reduced by leaving shelter trees (Sundkvist, 1994, von Sydow & Örlander, 1994) or by planting close to north-facing forest edges (Löfting, 1949). However, in practice, the forest manager has very little leeway when it comes to determining the layout of a clear-cutting.

Since pine weevils avoid exposed mineral soil, mechanical soil scarification reduces the frequency of attack (e.g. Söderström et al. 1978, Lindström et al. 1986, Örlander et al. 1991). Results obtained by von Sydow (1997) suggested that the effect of scarification might differ depending on the age of the clear-cutting. The presence of vegetation close to the seedling might increase the risk of damage (Lekander & Söderström, 1969). On the other hand, a Russian investigation described by Wilson & Day (1996) showed a negative correlation between the density of herbaceous vegetation and weevil damage. Thus, there is a need to study how weevil behaviour and seedling damage is affected by the microenvironment around the seedling.

It is likely that slash removal affects both pine weevil numbers and seedling damage (Selander, 1993, Örlander et al. 1997), since slash provides a food source during the first spring after clearfelling and also affects important environmental factors such as soil temperature, air humidity, and temperature close to the ground. Large amounts of nutrients are released from the slash following clear-cutting. (Selander & Immonen, 1991, 1992) have shown that high N levels in seedlings increase the risk of pine weevil feeding, indicating that there might be an interference with slash treatment.

It is well known that damage to seedlings varies greatly depending on their type and size. Large seedlings survive pine weevil attacks better than smaller ones (Lekander & Söderström, 1969, Selander et al. 1990, Selander, 1993). Seedlings that suffer from water stress after outplanting seem to be especially sensitive to pine weevil feeding (Selander & Immonen, 1992). Since pine weevil activity varies seasonally (Långström, 1982, Nordenhem, 1989, Örlander et al. 1997), it is likely that the date of planting affects the damage risk.

In this study results are presented from the "clear-cut age experiment". The experiment was established in southern Sweden between 1989 and 1993 in order to study the effects of the age of the clear-cutting on damage by pine weevils and competing vegetation. In a previous report (Örlander et al. 1997) our focus was on factors influencing pine weevil abundance. This report focuses on seedling damage caused by pine weevils.

The objective of the study was to ascertain how pine weevil damage is influenced by age of the clear-cutting, slash removal, scarification and vegetation treatment, seedling type and size, and planting date. Moreover, the experiment allowed between-year variation in pine weevil damage to be analysed.

MATERIAL AND METHODS

Description of the sites

The experiment was established over a five-year period at four sites in two different areas in southern Sweden (Fig. 1). Two of the sites were situated near Asa Forest Research Station, about 40 km north of Växjö (57°10′ N, 14°47′ E), and the two other sites were near Tönnersjöheden Forest Research Station, 25 km east of Halmstad (56°40′ N, 13°10′ E). The sites were representative of relatively fertile, south Swedish forests, and the original stands were dominated by Norway spruce. The sites represent a range of soil moisture and texture conditions. The two sites at Tönnersjöheden are dry and have coarse-texture soils, whereas the soils at Asa are mesic to moist and more fine-textured. More details about the stands are given in Örlander et al. (1997).

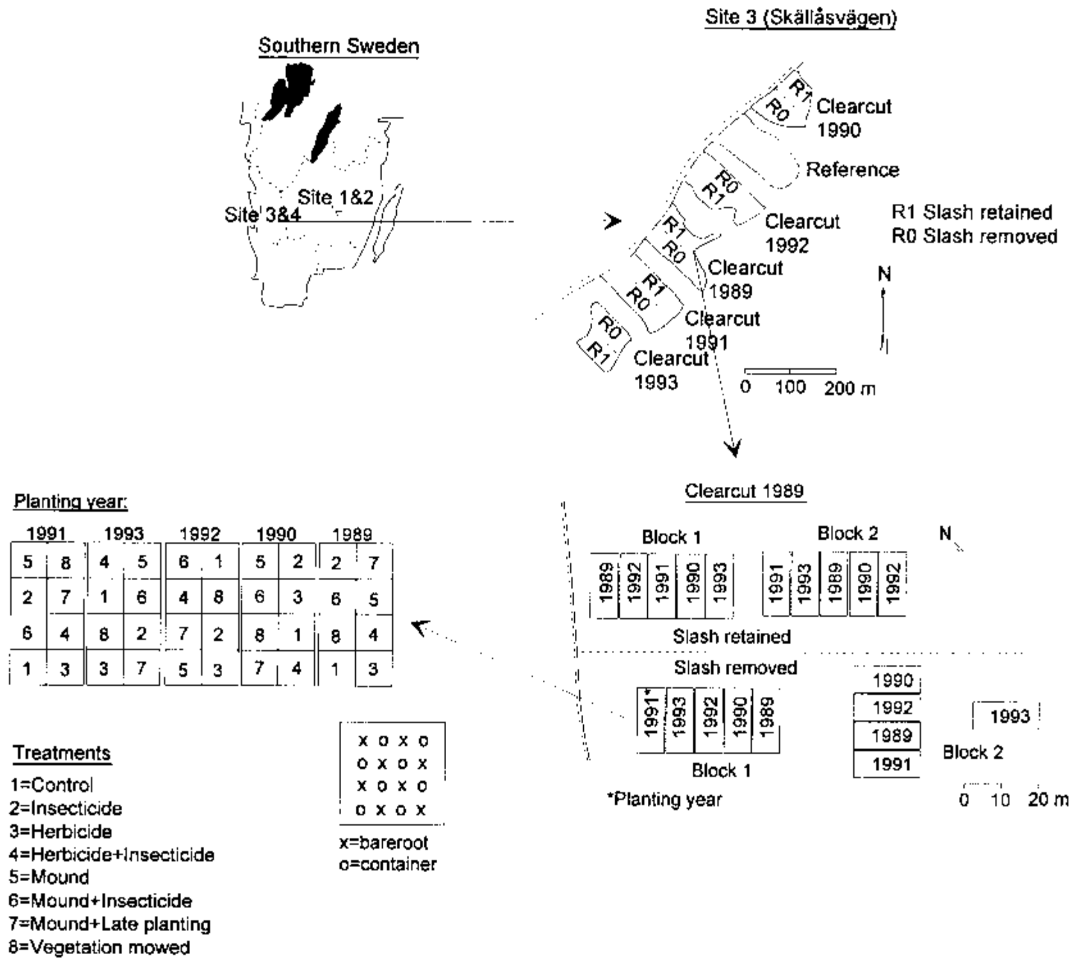

Fig. 1. Location and layout of the experimental plots.

Design of the experiment

In 1988, five 1–4 ha areas were chosen for future clear-cutting at each site. After randomization, one area was cut each year from 1989 until 1993 (Fig. 1). To avoid edge effects, at least 10 m was left unplanted along the forest edges. Each clear-cutting was divided into two parts of equal size; on one half slash was removed, while on the other half the slash was retained (Fig. 1). After removal of the slash, about 20% of its total weight still remained on the site.

The experimental design was randomized blocks with subplots (split–split–split–split–plot). On each clear-cutting, Norway spruce seedlings were planted in four blocks from the year of cutting until 1993. Thus, in 1989 only fresh clear-cuttings (A) were planted; in 1990 fresh (A) and one-year-old clear-cuttings (A + 1) were planted, and so on. Two blocks were placed on the area where slash had been retained, and the other two were located on the area where slash had been removed (Fig. 1).

Within a block, the area planted each year consisted of eight treatment plots, with 16 seedlings in each plot (Fig. 1). There were eight treatments in all: control, insecticide, herbicide, herbicide + insecticide, scarification (mound), mound + insecticide, mound + late planting, and vegetation mowed (cf. Fig. 1). In total, 31 774 seedlings were planted in the experiment, including all sites and planting years.

Insecticide-treated seedlings were dipped before planting in a permethrin emulsion consisting of 1% active ingredient (a.i.). The seedlings were then resprayed with permethrin (0.5% a.i.) each autumn (August) and each spring (April/May), including the spring when the clear-cuttings were of age A + 3. The herbicide treatment consisted of two applications of glyphosate emulsion (12% a.i.) per growing season or whenever necessary. The herbicide was applied directly to the leaves of the ground vegetation. All ground vegetation on the herbicide-treated plots was treated, except within an area of about 0.1 m^2 nearest to the seedlings, which was manually weeded. Mounding was carried out in early April in the year of planting. Each mound, about 5 dm in diameter and 10–20 cm in height, consisted of about 20 dm^3 of mineral soil. The mounds were carefully compressed in order to get rid of any air pockets, etc. On all sites except site 2, which was wet, the mounds were placed on mineral soil after patch scarification. On site 2 the mounds were placed on upturned humus. Planting was carried out manually around 1 May each year, except for the "late planting" treatment, in which case planting was delayed until about 10 June.

All seed was produced at the Maglehem seed orchard, and all seedlings originated from the same seedlot. The seedlings were sorted before planting, during which bare-rooted seedlings shorter than 25 cm and containerized seedlings shorter than 15 cm were rejected. Three-year-old bare-rooted (1.5/1.5) and two-year-old containerized (Blockplanta 64) seedlings were planted alternately along rows (Fig. 1) except in 1991, when only bare-rooted seedlings were planted.

Weevil damage analyses were made for treatments that did not include insecticide application (treatments 1, 3, 5 and 7 in Fig. 1). Survival and growth of the seedlings were analysed for all treatments except the mowing treatment (treatment 8).

Measurements

Damage caused by pine weevils, competing vegetation, and the other most important damage-causing agents was recorded in early July for seedlings planted the same year and in October for all seedlings. In the assessment of pine weevil damage, current-year damage to the main stem excluding the current-year shoot was recorded. Damage was recorded using a 6-level scale where 0 = undamaged, 1 = slightly damaged … 4 = severely damaged and 5 = dead. Feeding by pine weevils was also recorded as the percentage of the stem that was debarked, where 0 = no feeding, 1 = 1–10% debarked, 2 = 11–20%, 3 = 21–40%, 4 = 41–60%, and 5 = 61–100% debarked. In addition, the vertical position of the debarked area on the stem was scored where 0 = attacks at stem base, 1 = attacks at a mean level of 1/10 of the seedling height, 2 = attacks at a mean level of 2/10 of the seedling height, etc. Roots of dead seedlings were examined to determine whether mortality was due to attacks by root-feeding insects such as *Hylastes* spp.

Height and diameter at stem base were recorded for newly planted seedlings directly after planting. Seedling height and current leader length were recorded for all seedlings after the end of the growing season (October–November) each year. Stem base diameter was recorded for two-, four- and five-year-old seedlings on the same occasion.

Weather data, including air and soil temperatures, precipitation, etc., were recorded at all locations throughout the studied period. Details concerning these measurements are given by Örlander et al. 1997.

Calculations and statistical analysis

The mean percentage of debarked stem area and the mean vertical position of the removed bark were calculated using class means. When calculating the position, only seedlings severely damaged by pine weevil (class $\geqslant 3$) were included. The frequency of damaged seedlings in each plot was determined before calculating treatment means. Seedlings that died immediately after planting because they were of poor quality were excluded from the analyses. Before each test, frequencies were transformed according to Bartlett (1937), after which all frequencies were arcsine square-root transformed (Zar, 1984). Stem volume was derived using the formula for a cone.

The general linear model (GLM) procedure of SAS for split-plot designs was used to perform the statistical tests. In the first model, effects of site, age of the clear-cutting, slash removal, treatment, and seedling type on seedling mortality caused by pine weevils were analysed (cf. Table 1). In the second model, which was similar to model 1, effects of site, planting year, slash removal, and treatment on seedling volume were analysed. Differences among class means were evaluated with Tukey's honestly significant difference (HSD) mean separation test when treatment effects were significant ($p = 0.05$) in the analysis of variance.

RESULTS

Insecticide treatment

The intensive insecticide treatment effectively protected seedlings from severe attacks by pine weevils. On average over all sites and years, about 1% of the insecticide-treated seedlings died as a result of pine weevil damage. In this study attacks by pine weevils were, by far, the most important cause of mortality. Thus, insecticide-protected seedlings survived relatively well independent of the treatment. The only significant difference in the survival of insecticide-treated seedlings was found between scarification methods.

The mortality of untreated seedlings caused by pine weevil attacks stabilized within three years after planting. Thus, in the following discussion, accumulated mortality caused by pine weevils during the first three years after planting will be presented for treatments that did not include insecticide applications.

Age of the clear-cutting

Pine weevil damage was severe on young clear-cuttings (≤ 2 years old). The mortality for fresh clear-cuttings (mean value three years after planting over all sites and planting years) was 77% for the controls, but variation between sites was considerable (Fig. 2). Although mortality decreased with increasing clear-cutting age, it was still almost 30% among seedlings planted on three-year-old clear-cuttings (Fig. 2). The effect of the clear-cutting age was significant for seedlings planted

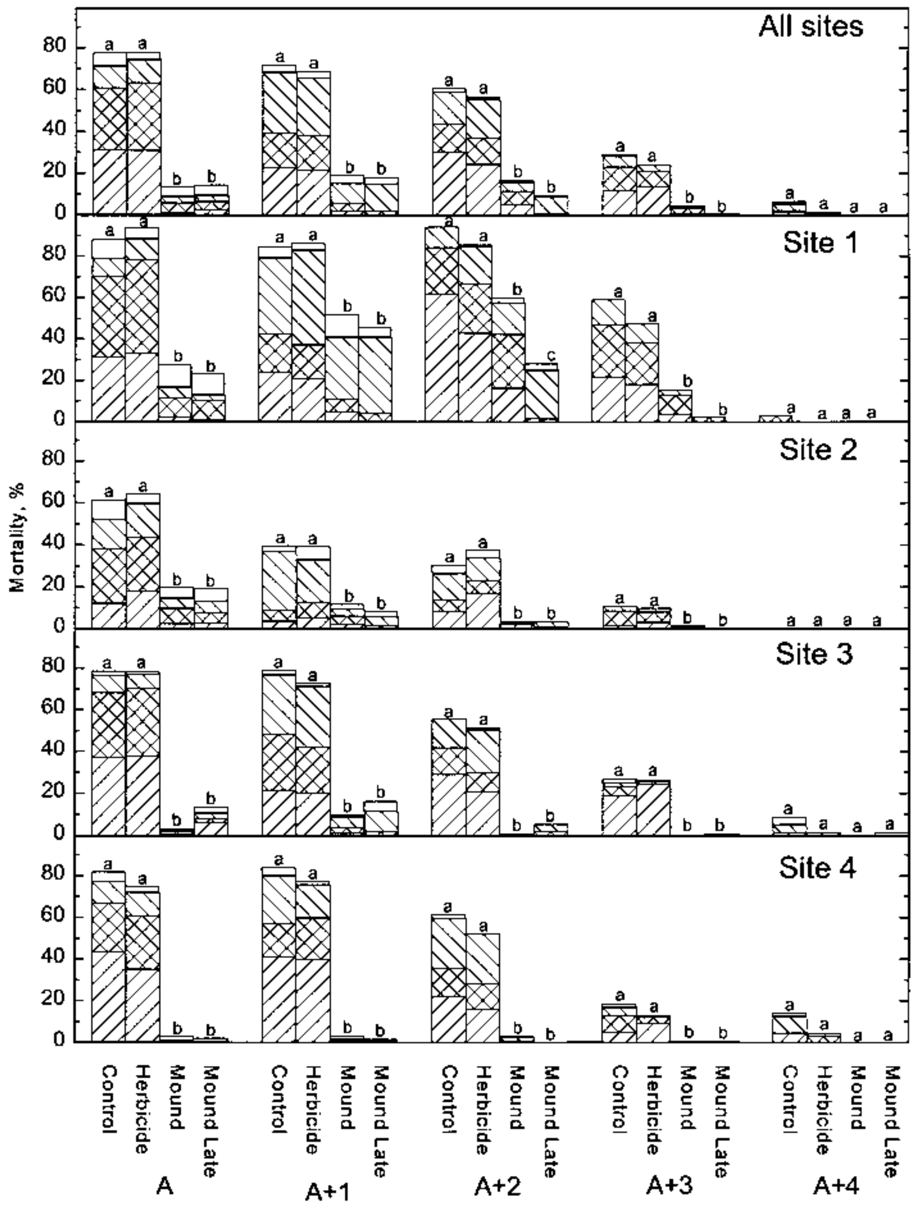

Fig. 2. Effect of some treatments (application of herbicide to ground vegetation, scarification by mounding, and planting late in the season) on mortality due to pine weevils during the three growing seasons following planting. ▨ = First summer. ▩ = First autumn. ▧ = Second autumn. □ = Third autumn. Norway spruce seedlings were planted on clear-cuttings of different ages (fresh = A, … four-year-old = A + 4). Average values for all sites are shown at the top, and values for each of the four sites are given below. Columns within each clear-cut age with different letters are statistically significantly different ($p < 0.05$). Mean values for all planting years (except 1991), sites, slash treatments and seedling types.

Table 1. *Results of split plot analyses of variance in mortality caused by pine weevils after three years*

A separate analysis of variance was conducted for each planting-year group of seedlings (1990–1993)

Parameters	Planted 1990				Planted 1991				Planted 1992				Planted 1993			
	df	Mean square	*F*-value	*p*-value	df	Mean square	*F*-value	*p*-value	df	Mean square	*F*-value	*p*-value	df	Mean square	*F*-value	*p*-value
Site	3	1502	1.91	0.3042	3	997	1.77	0.2523	3	5707	16.9	0.0005	3	5235	5.89	0.0103
Age	1	1023	1.3	0.3368	2	792	1.41	0.3155	3	6502	19.3	0.0003	4	10593	11.9	0.0004
Error A[a]	3	786			6	563			9	336			12	887		
Slash	1	95	0.34	0.5797	1	196	2.02	0.1884	1	5.45	0.01	0.9086	1	826	4.73	0.0461
Age × slash	1	6.16	0.02	0.8867	2	193	2.01	0.1909	3	250	0.63	0.6083	4	72.5	0.42	0.7953
Error B[b]	6	278			9	97			12	396			15	174		
Treatment	3	17346	128	0.0001	3	6486	79.8	0.0001	3	21591	98.1	0.0001	3	14846	99.9	0.0001
Age × treatment	3	369	2.73	0.0566	6	102	1.26	0.2907	9	357	1.62	0.1222	12	1417	9.54	0.0001
Slash × treatment	3	2.55	0.02	0.9964	3	27.8	0.34	0.7948	3	101	0.46	0.7092	3	16.3	0.11	0.9539
Error C[c]	39	135			60	81.2			81	220			81	149		
Seedling type	1	1737	35.1	0.0001					1	143	2.04	0.1554	1	4800	100	0.0001
Age × seedling type	1	335	6.78	0.0117					3	117	1.68	0.1744	4	537	11.2	0.0001
Slash × seedling type	1	5.23	0.11	0.7462					1	4.16	0.06	0.8079	1	23.9	0.49	0.481
Treatment × seedling type	3	73.95	1.49	0.2254					3	144	2.04	0.1109	3	581	12.1	0.0001
Model	69	1019	20.62	0.0001	35	845	10.4	0.0001	135	979	13.9	0.0001	168	940	19.6	0.0001
Error D[d]	58	49.5			60	81.2			120	70.1			151	48.0		

[a] Denominator for the site and age effect.
[b] Denominator for the slash and age × slash effects.
[c] Denominator for the treatment, age × treatment, and slash × treatment effects.
[d] Denominator for the seedling type, age × seedling type, slash × seedling type, and treatment × seedling type effects.

Table 2. *Mean (SE) percentage of area debarked by pine weevils, and average position of the feeding scars (in per cent of stem height)*

Bare-rooted Norway spruce seedlings planted during 1991–1993 on clear-cuttings of different ages (A–A+2). No seedlings were treated with insecticide. Debarked stem area includes current-year gnaw. Calculations based on data from the second autumn after planting were only made for seedlings that survived the first year. In the calculations of average position only seedlings with damage classes ⩾ 3 were included

Age of clear-cutting when planting	Date of inventory	Debarked stem area (%)			Average position of debarked stem area		
		Control	Herbicide	Mound	Control	Herbicide	Mound
Fresh (A)	First summer	17.4 (0.67)	14.8 (0.68)	2.5 (0.21)	18.9 (0.81)	17.2 (0.81)	13.4 (0.89)
	First autumn	21.5 (0.78)	19.3 (0.78)	3.4 (0.23)	22.3 (0.74)	20.3 (0.74)	15.0 (0.97)
	Second autumn	8.1 (0.65)	7.7 (0.64)	7.7 (0.49)	22.7 (1.39)	24.4 (1.40)	39.1 (2.06)
One-year-old (A+1)	First summer	7.2 (0.52)	7.8 (0.52)	1.8 (0.24)	15.2 (1.01)	14.3 (1.01)	17.1 (2.02)
	First autumn	21.7 (0.91)	21.8 (0.82)	6.4 (0.40)	24.8 (0.63)	23.2 (0.64)	23.0 (1.15)
	Second autumn	9.1 (0.80)	7.0 (0.66)	7.9 (0.57)	15.9 (1.10)	17.2 (1.25)	25.8 (1.67)
Two-year-old (A+2)	First summer	14.9 (0.91)	14.2 (0.88)	4.2 (0.47)	20.3 (0.86)	19.1 (0.82)	22.4 (1.23)
	First autumn	19.6 (0.93)	18.6 (0.93)	5.9 (0.60)	21.6 (0.75)	19.8 (0.73)	23.5 (1.22)
	Second autumn	3.3 (0.39)	3.0 (0.37)	1.5 (0.24)	8.9 (1.25)	9.0 (1.23)	7.6 (2.43)

in 1992 and 1993 (Table 1), during which years planting was done on clear-cuttings of at least four different ages. The mortality on three- and four-year-old clear-cuttings was significantly lower than that on fresh- and one-year-old clear-cuttings.

Pine weevils debarked the stems relatively close to the ground. The average vertical position of the debarked area during the first autumn after planting was at 15–25% of the height of the stem. However, on the one-year-old clear-cuttings the mean position was considerably higher in the autumn compared with in the summer (Table 2). Low positions were recorded for seedlings the second autumn following planting on two-year-old clear-cuttings.

Mounding

Mounding clearly reduced mortality due to pine weevils, the reduction being significant on all sites (Fig. 2). Seedlings planted in mounds on one-year-old clear-cuttings suffered somewhat higher mortality than comparable seedlings on clear-cuttings of other ages. Furthermore, most of the mortality among seedlings planted in mounds on one-year-old clear-cuttings was registered during the second growing season, whereas most of the mortality occurred during the first growing season among seedlings planted on clear-cuttings of other ages (Fig. 2).

The effect of mounding varied between sites (Fig. 2). On sites 3 and 4 the three-year accumulated mortality for seedlings planted in mounds was lower than 10% for clear-cuttings of all ages. On site 1, mounding reduced mortality, but the effect was not as strong as on other sites. The weaker effect of mounding was especially evident on one- and two-year-old clear-cuttings on that site (Fig. 2). The percentage of debarked stem area was strongly reduced the first year following planting on seedlings planted in mounds compared with the controls (Table 2). Mounding seemed to reduce the amount of feeding on the seedlings, especially on fresh clear-cuttings. During the second year after planting mounding had no significant effect on pine weevil feeding (Table 2).

Compared with controls, the position of the gnawed bark during the year of planting on seedlings planted in mounds was lower on fresh clear-cuttings, but not on older clear-cuttings (Table 2).

Mounding increased survival considerably compared with controls (Table 3). The mean survival rate was 80% for unprotected seedlings (bare-rooted + containerized) planted in mounds, whereas it was only 34% for controls. The lowest survival among seedlings planted in mounds was registered on one-year-old clear-cuttings (mean = 72%, bare-rooted + containerized). The highest survival was found when mounding and insecticide treatments were combined (92–97%, Table 3).

Removal of slash

Slash removal had only a minor effect on pine weevil damage (Fig. 3). However, for seedlings planted in

Table 3. *Mean survival (SE) of bare-rooted and containerized seedlings planted after various treatments*

The seedlings were planted on clear-cuttings of different ages (fresh = A, … three-year-old = A + 3). Mean values for all planting years except 1991

	Control	Herbicide	Insecticide	Herbicide and insecticide	Mound	Mound and late planting	Mound and insecticide
Bare-rooted							
A	26.8 (3.3)	26.4 (3.6)	84.5 (2.5)	88.1 (1.9)	86.9 (2.4)	75.4 (3.9)	94.7 (1.2)
A + 1	28.8 (4.0)	32.0 (4.2)	87.2 (2.5)	88.5 (1.9)	77.1 (3.7)	64.1 (4.5)	95.8 (1.0)
A + 2	38.7 (6.1)	43.0 (6.1)	80.8 (4.3)	94.0 (3.1)	77.3 (5.4)	68.0 (6.1)	94.1 (1.9)
A + 3	62.9 (6.2)	68.0 (5.9)	76.9 (5.2)	76.9 (5.0)	89.8 (2.4)	83.9 (5.0)	93.0 (2.6)
Containerized							
A	9.3 (1.8)	7.7 (1.7)	86.1 (2.0)	77.5 (2.7)	75.8 (3.2)	72.1 (3.3)	95.8 (1.0)
A + 1	17.6 (3.6)	20.2 (3.7)	83.0 (2.8)	85.7 (2.2)	67.9 (4.4)	69.6 (4.2)	92.5 (1.6)
A + 2	34.1 (5.8)	35.1 (5.7)	83.9 (3.6)	81.6 (3.9)	78.4 (5.2)	76.7 (4.8)	96.0 (1.7)
A + 3	57.6 (5.7)	61.5 (6.2)	77.3 (4.8)	74.9 (4.5)	90.4 (2.5)	87.2 (3.3)	97.4 (1.0)

1993 slash removal significantly reduced mortality ($p = 0.046$) (Table 1), the effect being most evident on older clear-cuttings. The interaction between slash removal and age of the clear-cutting was not significant because of high variation between sites.

There were only small and non-significant differences in the percentage of stem area debarked and position of the gnawing between slash treatments, and there was no significant difference in survival between the slash treatments (data not shown).

Vegetation control

Vegetation removal by herbicide treatment did not significantly affect mortality due to pine weevils (Fig. 2). Moreover, neither the percentage of stem area debarked nor the position of the gnawing differed between herbicide and control treatments. Herbicide treatment had no significant effect on the survival of any of the seedling types (Table 3).

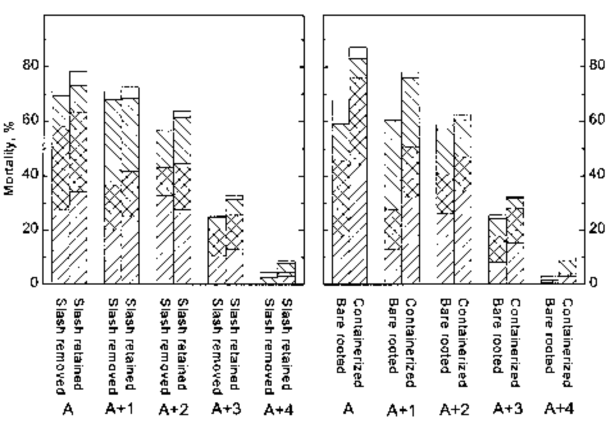

Fig. 3. Effect of slash treatment (left) and seedling type (right) on mortality caused by pine weevils during the three growing seasons following planting. ▨ = First summer. ▩ = First autumn. ▧ = Second autumn. □ = Third autumn. The seedlings were planted on clear-cuttings of different ages (fresh = A, … four-year-old = A + 4). Mean values for all planting years (except 1991), sites, slash treatments and seedling types.

Seedling type and size

Pine weevil-caused mortality was lower among bare-rooted seedlings than among containerized ones. This difference was significant for seedlings planted in 1990 and 1993 (Fig. 3, Table 1), during which years there was also a significant interaction between seedling type and clear-cutting age. The difference in mortality between seedling types was greater on fresh and one-year-old clear-cuttings than on older clear-cuttings, and was already discernible after the first summer (Fig. 3).

Mortality due to pine weevils after three years correlated with the initial stem base diameter of the seedlings (Fig. 4). Mortality decreased with seedling size, and this effect was stronger on older clear-cuttings. Bare-rooted and containerized seedlings of the same initial stem base diameter showed about the same mortality rate on fresh and one-year-old clear-cuttings, whereas on older clear-cuttings mortality was higher for bare-rooted seedlings than for containerized seedlings of equal size (Fig. 4).

There were only small differences in survival between seedling types. However, the survival of bare-rooted seedlings was lower for those planted in June (late planting) than for those planted in May. No corresponding difference was evident for containerized seedlings (Table 3). Among seedlings that were

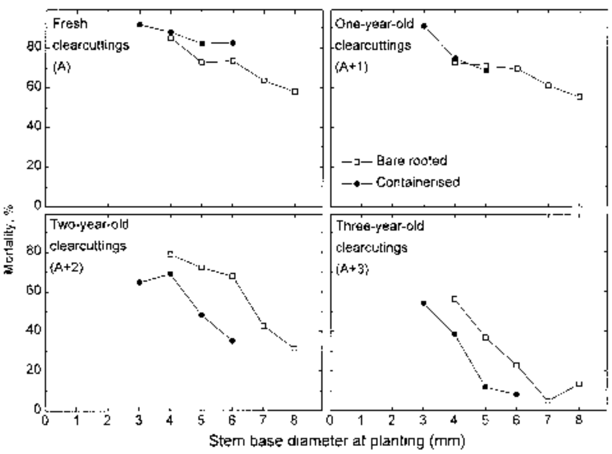

Fig. 4. Relation between seedling stem base diameter at planting and mortality caused by pine weevils. Mean value for bare-rooted and containerized Norway spruce seedlings that were planted in 1992 on clear-cuttings of different ages (fresh = A, ... three-year-old = A + 3). Mean values for all sites.

not treated with insecticides on young clear-cuttings, bare-rooted seedlings survived better than containerized ones, but even the former showed low survival.

Planting date

Late planting (10 June) only marginally affected seedling mortality due to pine weevils on fresh and one-year-old clear-cuttings (Fig. 2). On older clear-cuttings, late planting reduced lethal pine weevil damage somewhat (average over all sites). However, this difference was only significant for two-year-old clear-cuttings at site 1. The proportion of bark area consumed by weevils during the first summer averaged only 2.0% for seedlings planted late on two-year-old clear-cuttings, whereas it was 5.9% for seedlings planted on 1 May.

Between-year variation

During the studied period, from 1989 to 1995, there was considerable variation in climatic conditions (Örlander et al. 1997). For instance, in 1992, spring and early summer were extremely dry, whereas in 1991 the corresponding period was wet. The wet summer/autumn of 1993 and the warm summer of 1994 were also noticeably different.

The variation in pine weevil damage between years was quite high (Fig. 5). The variation seemed to be larger on older (≥ 2 years old) than on younger clear-cuttings. On two-year-old clear-cuttings, debarking the first year following planting varied from 14% in 1991 to 28% in 1992. There was a tendency for more severe attacks by pine weevils during the dry summer of 1992, but the pattern differed depending on the age of the clear-cuttings.

The accumulated mortality caused by pine weevils also varied considerably between planting years. Mortality was significantly lower for seedlings planted in 1993 than for those planted in 1992. For seedlings planted on older clear-cuttings (A + 2 and A + 3) there was larger variation in mortality between years, and the most severe damage was registered for seedlings planted in 1992.

Seasonal variation

On fresh clear-cuttings, most of the damage occurred before early July (Fig. 6). Most years, considerably less damage was recorded during May–July for seedlings planted on the one-year-old clear-cuttings. However, pine weevil attacks in the autumn on the one-year-old clear-cuttings were generally severe (Fig. 6). On older clear-cuttings most of the damage was caused by attacks in May–June. The distribution of pine weevil damage over the season varied considerably between years. In 1992, severe damage occurred on the one-year-old clear-cuttings during the spring and early summer, but damage was even more severe on the fresh clear-cuttings. The high level of damage coincided with the extremely warm and dry weather in May and June that year.

The effect of similar damage varied between years. For example, many seedlings that sustained large feeding scars in 1991 survived that damage, whereas most seedlings with similar damage died in 1992 (Fig. 6).

After planting on fresh and one-year-old clear-cuttings, many of the seedlings were attacked several times. This resulted in increased accumulated pine weevil-induced mortality for at least three years (Fig. 6).

Seedling growth

On fresh- and one- year-old clear-cuttings, insecticide-treated seedlings grew considerably better than untreated ones (Fig. 7). Among the untreated seedlings, those planted on mounds showed higher volume growth than those planted in undisturbed ground. Insecticide treatment also increased the growth of seedlings planted in mounds. For seedlings planted on two- and three-year-old clear-cuttings, insecticide treatment had no effect on volume growth, whereas mounding had a significant positive effect.

DISCUSSION

Pine weevil damage was, by far, the most common cause of mortality. Intensive insecticide treatment protected the seedlings from severe damage. Thus, it was possible to separate insect damage from damage caused by other agents. Drought caused mortality in 1992, especially among bare-rooted seedlings planted on unscarified soil (cf. Nilsson & Örlander 1995). Browsing by large herbivores and summer frost also contributed to mortality. However, for a large proportion of the seedlings that were damaged by agents other than pine weevils, it was not possible to determine the cause. Some other insect damage (mainly *Hylastes* spp.) was also registered, but it was never severe. The high survival rates of insecticide treated seedlings found on young clear-cuttings should be interpreted with care, since our insecticide treatment was much more intensive than that used in practical forestry.

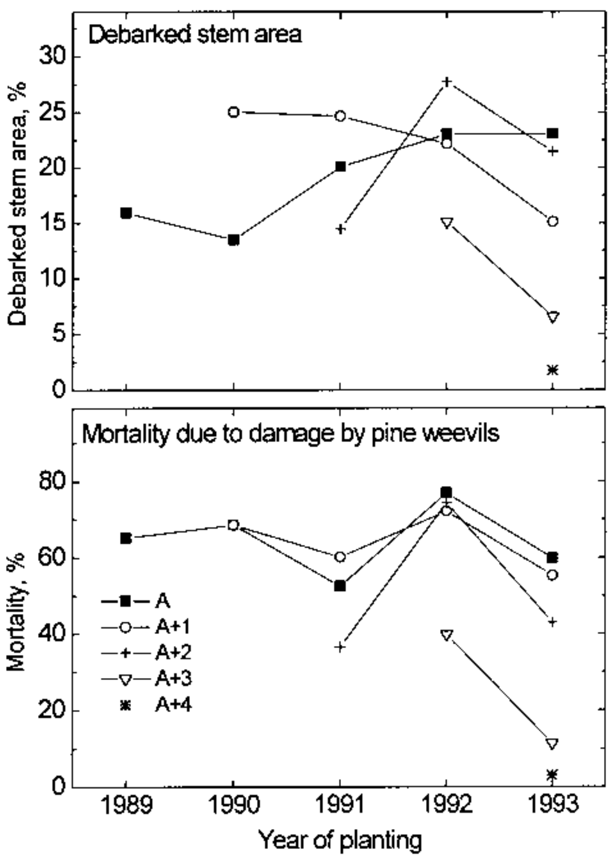

Fig. 5. Between-year variation in pine weevil damage for seedlings planted on clear-cuttings of different ages (fresh = A, … four-year-old = A + 4). Bare-rooted Norway spruce seedlings that had not been treated with insecticide were planted on unscarified soil during 1989–1993. Measurements of debarked stem area were made in the first autumn following planting. Mortality due to pine weevils was measured three years after planting. Mean values for all sites.

Age of the clear-cutting

The severe attacks by pine weevils on fresh, one- and two-year-old clear-cuttings were well in line with the results of previous investigations (e.g. Beijer-Petersen et al. 1962, Bakke & Lekander, 1965, von Sydow, 1997). The relatively severe attacks on three-year-old clear-cuttings were somewhat unexpected, since the insect is expected to have a development cycle of two years in southern Sweden (Beijer-Petersen et al. 1962). The seedling damage levels recorded are well in line with previously presented data on the occurrence of pine weevils on the same clear-cuttings (Örlander et al. 1997). The occurrence on older clear-cuttings might have been due to delayed development of the new generation, or to the fact that some roots were still suitable breeding substrate on the one-year-old clear-cuttings. Nordenhem (1989) suggested that such material could be used for producing a second generation.

Our data support the results from many other studies (e.g. Lindström et al. 1986, Eidmann & von Sydow, 1989, Hagner & Jonsson, 1995, Eidmann et al. 1996, von Sydow, 1997) showing that pine weevils cause unacceptable damage to unprotected conifer seedlings planted on young (< two-year-old) clear-cuttings. The large between-year variation in attacks on older clear-cuttings suggests that climatic factors (e.g. temperature and solar radiation) influence the weevil population and thereby the risk of damage. Current Swedish regeneration practices and guidelines (Anon, 1978) state that damage by pine weevils can be avoided by planting on three-year-old clear-cuttings. Our findings indicate that clear-cuttings must be four to five-years-old before planted seedlings can escape serious weevil damage.

Mounding

Mounding significantly reduced mortality due to pine weevils, in accordance with the findings of other studies (Söderström et al. 1978, Lindström et al. 1986, Örlander et al. 1991). The difference in damage between the control and mounded plots was large at all locations and in all studied years, proving that mounding is an effective way of reducing damage. The protective effect of scarification in this study was considerably better than that normally achieved in practice. One reason for this may simply be that the site preparation practices applied in our study differed from conventional methods. Söderström et al. (1978)

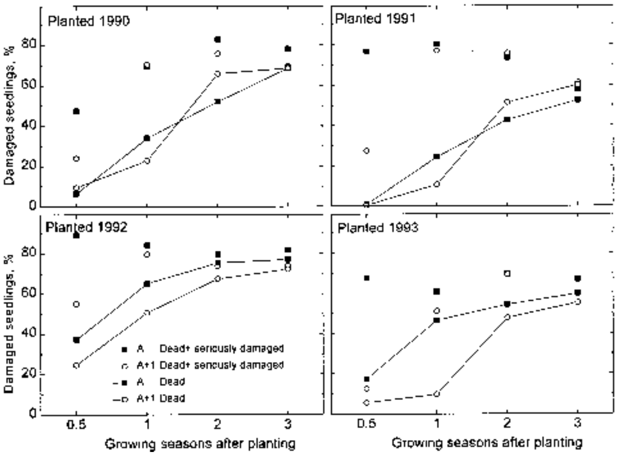

Fig. 6. Increase in the mean accumulated percentage of serious and lethal damage caused by pine weevils to seedlings planted on fresh (A) and one-year-old (A + 1) clear-cuttings. Bare-rooted Norway spruce seedlings that had not been treated with insecticide were planted on unscarified soil from 1990–1993.

found that mounding was more effective than disc trenching or patch scarification. The protective effect of site preparation is assumed to be due to the pine weevils' tendency to avoid exposed, dry and warm soil (Lekander & Söderström, 1969, Christiansen & Bakke, 1971). Mounding is probably an ideal scarification method where the aim is to create a warm, dry soil

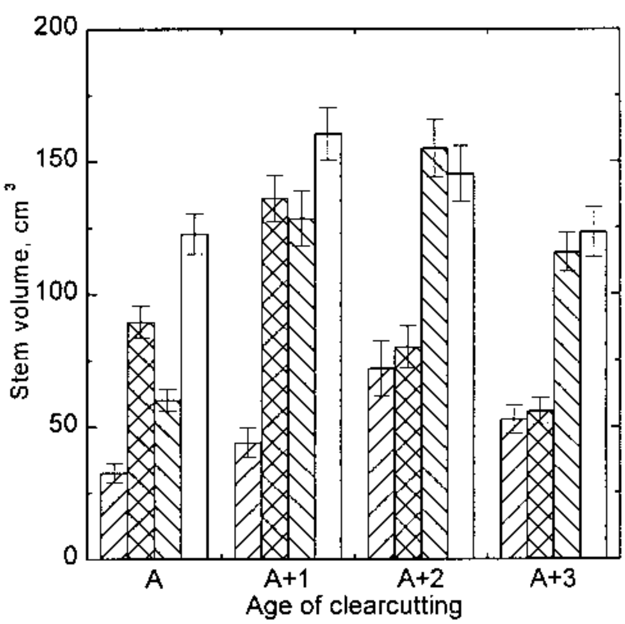

Fig. 7. Effect of insecticide treatment and soil scarification on stem volume (cm^3) after four growing seasons. Norway spruce seedlings were planted in 1992 on clear-cuttings of different ages (fresh = A, … three-year-old = A + 3). Mean values ± SE for all sites, slash treatments and seedling types. ▨ = Control. ▩ = Insecticide. ▧ = Mound. □ = Mound + insecticide.

surface, whereas disc trenching or patch scarification results in a smaller increase in soil-surface temperature because micro-sites are less elevated (e.g. Örlander et al. 1990).

The large difference between site 1 at Asa and sites 3 and 4 at Tönnersjöheden in the ability of mounding to prevent damage was unexpected. We suggest that the composition of the mounds is important for damage control, and that it differed between sites. The mounds at Tönnersjöheden had a higher content of mineral soil, whereas at Asa, more humus was mixed into the mounds. If the humus is mixed with mineral soil, damage by pine weevils will increase (Örlander et al. 1991). Furthermore, at Tönnersjöheden, seedlings could be planted 2–3 dm from the humus edges, whereas at Asa, the seedlings were occasionally planted close to the humus edge, which is assumed to increase damage (Lindström et al. 1986).

Mounding promotes the establishment and growth of seedlings during the first year after planting. Such larger, more vital seedlings are better able to resist and recover from pine weevil attacks during the subsequent years. The initial growth of the seedlings was considerably better at sites 3 and 4 (data not presented), which was probably an important factor determining the final outcome.

The reduction of pine weevil feeding caused by mounding was only evident the first year after planting (Table 2). It seems likely that with increasing age, the growth of vegetation on the mounds reduces their protective effect. However, this ageing effect was evident even on mounds prepared on fresh clear-cuttings, despite the small amounts of vegetation on these sites. Therefore, the reason why old mounds (free from vegetation) have a lower protective effect remains to be determined.

During most years, mortality caused by pine weevils among seedlings planted on mounds was higher on one-year-old clear-cuttings than on fresh or two-year-old clear-cuttings. On one-year-old clear-cuttings, the major part of pine weevil damage was caused during the autumn by weevils of the new generation. At that time it is likely that mounding has a somewhat lower protective effect (because of the ageing effect) compared with the situation on fresh clear-cuttings, where the seedlings are attacked earlier in the summer. Furthermore, on one-year-old clear-cuttings, feeding occurs in late summer when the weather is normally wetter, and incoming radiation is lower compared with early summer. If the surface temperature and moisture are important determinants of the scarification effect, this might explain the difference in response.

A third explanation could be that newly emerged weevils do not respond to the environment in the same way as the parental generation. Newly emerged pine weevils, which probably cause much of the damage in late summer on one-year-old clear-cuttings, are not as sensitive as the more mature individuals to the warm, dry conditions (Havukkala & Selander, 1976).

In summary, scarification, particularly mounding, offers an effective way of reducing pine weevil damage, but the factors responsible for the scarification effect are still not completely understood.

The difference in survival between insecticide-treated seedlings planted on mounds and those planted on unscarified soil indicated that agents other than pine weevils were responsible for the lower survival if the soil was not scarified. However, the agent responsible for the mortality of the latter seedlings could not be determined at the time of registration. One to three per cent of the insecticide-treated seedlings planted on unscarified soil died each year for unknown reasons. One explanation could be that such seedlings have more problems (with e.g. water uptake) during the establishment phase compared with those planted in scarified soil.

Removal of slash

The finding that slash removal did not increase pine weevil damage is not in accordance with the results of Selander (1993). Axelsson (1987) found that removal of slash increased damage the first year after planting fresh clear-cuttings, but had no effect the second year. Slash might serve as food for the pine weevils during the first weeks after planting and thereby decrease feeding pressure on seedlings. However, the slash dries out relatively early in the season, after which the bark is not attractive as food. Our results indicate that the positive effect of slash as an alternative food resource for pine weevils is not significant.

The small positive effect of slash removal that we observed on older clear-cuttings may have been partly an indirect effect of the microclimate. Slash decreases the soil temperature during the growing season. This probably slows down the development of weevils (Christiansen, 1971, Bakke & Lekander, 1965), which might result in more insects on older clear-cuttings.

However, on the older clear-cuttings, the proportion of stem area debarked was no greater for the seedlings on the plots where slash had been retained, despite the significantly higher mortality on these plots. In addition, trap data did not indicate any difference in pine weevil population between slash treatments (Örlander et al. 1997).

Seedlings planted in slash normally have a higher N content than those planted in areas where slash has been removed (cf. Bergquist & Örlander, 1998). The fact that seedlings with a higher N content are more likely to be attacked by pine weevils (Selander & Immonen, 1991, 1992) might explain the difference between slash treatments.

In summary, slash removal had only a limited effect on pine weevil damage, and the effect was only evident on older clear-cuttings.

Vegetation control

Our results suggest that the presence of ground vegetation does not influence the risk of pine weevil damage on unprotected seedlings. This suggestion is not in accordance with the findings of Lekander & Söderström, (1969), who observed higher attack rates in grassy vegetation than on moss-covered ground. Wilson & Day (1996) reported a negative correlation between the density of herbaceous vegetation and weevil damage. We suggest that factors other than the vegetation itself were important damage determinants in those studies. The effect of vegetation can be studied most easily by simply removing it, but we do not know of any other study where herbicide-treated and untreated plots have been compared. Our finding that damage was very high on fresh clear-cuttings, where almost no vegetation was present, suggests that the major site factor determining the risk of pine weevil attack is the presence of humus close to the seedlings.

Seedling type and size

Mortality caused by pine weevils was significantly lower for bare-rooted seedlings than for containerized ones. This result agrees with the findings of Eidmann (1969), Selander et al. (1990) and von Sydow (1997). However, the difference in mortality between the two seedling types was relatively small. The influence of the seedling stem base diameter on mortality due to pine weevils was evident for both seedling types. This indicates that the main reason why mortality was lower for bare-rooted seedlings than for containerized ones is that the former are initially larger in size. Small seedlings are less able to tolerate pine weevil damage than larger ones.

On old clear-cuttings mortality was higher for bare-rooted seedlings than for containerized seedlings of roughly equivalent size. On older clear-cuttings with competing vegetation, bare-rooted seedlings have been found to suffer more from water stress compared with containerized ones (Nilsson & Örlander 1995). Water stress is one important factor that could decrease the capacity of seedlings to tolerate pine weevil damage (Selander & Immonen, 1992), and might thus explain why bare-rooted seedlings suffered more from pine weevil damage than containerized seedlings did. In conclusion, our results suggest that the seedlings have to be very large (>10 mm diameter) if they are to survive pine weevil attack.

Planting date

Compared with planting at the normal time (1 May), late planting (10 June) reduced pine weevil damage, but only on older clear-cuttings. By 10 June, most adult pine weevils have left the older clear-cuttings; therefore most feeding occurs before that date. On fresh clear-cuttings, damage occurs throughout the summer (Nordenhem, 1989, Örlander et al. 1997), and these seedlings are further damaged in subsequent years. Thus, our results suggest that although pine weevil damage can be reduced by late planting on two- and three-year-old clear-cuttings, the effect is limited. Late planting is associated with an increased risk that the newly planted seedlings will be exposed to water stress because of dry weather, and to increased competition from ground vegetation (Nilsson & Örlander 1995). Late planting resulted in lower survival due to these factors in the present study (Table 3). Therefore, late planting should only be done on clear-cuttings where competition from ground vegetation is low or can be controlled by site preparation, and where the risk of desiccation is low.

Between-year variation

The variation between years in mortality due to pine weevils on young clear-cuttings ($\leq$ two-year-old) was noticeable. Dry weather in the early summer seemed to increase the damage. Studies on the numbers of pine weevils did not reveal any clear correlation between population size and damage (Örlander et al. 1997). However, it is plausible that weevil activity was higher and caused more damage during warm periods. The lower mortality for seedlings planted in 1991 and 1993, when rainfall in spring and early summer was high, can also be attributed to the fact that conditions were more conducive for seedling establishment during those years.

Even during wet years pine weevil damage was considerable. Thus, in southern Sweden, the pine weevil will probably cause unacceptable damage to unprotected seedlings every year on clear-cuttings up to two years of age.

The between-year variation in attack rates seems to have been greater on older clear-cuttings. The number of pine weevils on older clear-cuttings depends on several factors, many of which are influenced strongly by weather.

Seasonal variation

Attacks on fresh clear-cuttings increased dramatically after the migrating weevils had arrived, and continued until mid-August. This is in accordance with recent findings concerning weevil abundance on fresh clear-cuttings (Örlander et al. 1997). On one-year-old clear-cuttings, most damage occurred during the autumn, whereas attacks were moderate during spring and summer. This shows that weevils emerging in August/September after a 1.5-year generation cycle (Nordenhem, 1989) did much of the damage.

Attacks made in the autumn on one-year-old clear-cuttings were more widely distributed over the stem compared with attacks made on clear-cuttings of other ages, where the feeding scars were concentrated closer to the stem base (Table 2). It is likely that in order to protect themselves from desiccation, the pine weevils fed closer to the ground during warm, dry periods, as is normally the case when they are feeding on fresh clear-cuttings.

Seedling growth

As expected, seedling growth was negatively influenced by pine weevil damage (cf. Örlander et al. 1991). This was especially evident for seedlings planted on unscarified soil on fresh and one-year-old clear-cuttings. Although most of the seedlings planted in mounds on fresh clear-cuttings survived pine weevil attack, the growth of attacked seedlings was considerably reduced. This growth reduction can be ascribed to disturbances in the nutrient- and water-transport systems of the seedlings. Moreover, feeding scars produce large amounts of resin, which is another source of energy drain for the seedlings.

ACKNOWLEDGMENTS

This work was financially supported by the Swedish Council for Forestry and Agricultural Research and the Swedish National Forestry Board. We thank Morgan Erixon, Ola Langvall and Magnus Petersson for technical assistance and David Tilles for correcting the English.

REFERENCES

Anon. 1978. Om skydd mot insektsskador på skogsplantor

(Snytbaggeutredningen). National Board of Forestry, Jönköping, Sweden, 161 pp. (In Swedish.)

Axelsson, M. 1987. Direct planting: a possibility? Sveriges Skogsvårdsförbunds Tidskrift 85: 23–26. (In Swedish with English summary.)

Bakke, A. & Lekander, B. 1965. Studies on *Hylobius abietis*. II. The influence of exposure on the development and production of *Hylobius abietis*, illustrated through one Norwegian and one Swedish experiment. Rep. of the Norwegian For. Res. Inst. 20: 117–135.

Bartlett, M. S. 1937. Some examples of statistical methods of research in agriculture and applied biology. J. R. Stat. Soc. Suppl. 4: 137–170.

Beijer-Petersen, B., Juutinen, P., Kangas, E., Bakke, A., Butovitsch, V., Eidmann, H., Heqvist, K. J. & Lekander, B. 1962. Studies on *Hylobius abietis* (L.). I. Development and life cycle in the Nordic countries. Acta Entomol. Fenn. 17: 1–106.

Bergquist, J. & Örlander, G. 1998. Browsing damage by roe deer on Norway spruce seedlings planted on clear-cuts of different ages. I. Effect of slash, vegetation development, and roe deer density. For. Ecol. Manage. 105: 283–293.

Christiansen, E. & Bakke, A. 1971. Feeding activity of the pine weevil, *Hylobius abietis* L. (Col., Curculionidae), during a hot period. Norsk Entomol. Tidskr. 18: 109–111.

Christiansen, E. 1971. Laboratory study on factors influencing pre-imaginal development in *Hylobius abietis* L. (Col., Curculionidae). Norsk Entomol. Tidskr. 18: 1–8.

Eidmann, H. H. & von Sydow, F. 1989. Stocking for protection of containerised conifer seedlings against pine weevil (*Hylobius abietis* L.) damage. Scand. J. For. Res. 4: 537–547.

Eidmann, H. H. 1969. Russelkäferschäden an verschiedenen Nahrungspflanzen. Anz. Schädl. Pflanzenschutz 42: 22–26.

Eidmann, H. H., Nordenhem, H. & Weslien, J. 1996. Physical protection of conifer seedlings against pine weevil feeding. Scand. J. For. Res. 11: 68–75.

Hagner, M. & Jonsson, C. 1995. Survival after planting without soil preparation for pine and spruce seedlings protected from *Hylobius abietis* by physical and chemical shelters. Scand. J. For. Res. 10: 225–234.

Havukkala, I. & Selander, J. 1976. Reactions of the large pine weevil, *Hylobius abietis* L. (Col., Curculionidae), to various light and humidity stimuli during three stages of its life cycle. Ann. Entomol. Fenn. 2: 54–62.

Långström, B. 1982. Abundance and seasonal activity of adult *Hylobius*-weevils in reforestation areas during first years following final felling. Comm. Inst. For. Fenn. 106: 1–23.

Lekander, B. & Söderström, V. 1969. Studies on damage caused by *Hylobius abietis* on coniferous plants. Sveriges Skogsvårdsförbunds Tidskrift 67: 351–383. (In Swedish with English summary.)

Lindström, A., Hellqvist, C., Gyldberg, B., Långström, B. & Mattson, A. 1986. Field performance of a protective collar against damage by *Hylobius abietis*. Scand. J. For. Res. 1: 3–15.

Löfting, E. C. L. 1949. Problems of spruce reforestation in Danish heathland. Forstlige Forsogsvaesen i Danmark 18: 327–383. (In Danish with English summary.)

Nilsson, U. & Örlander, G. 1995. Effects of regeneration methods on drought damage to newly planted Norway spruce seedlings. Can. J. For. Res. 25: 790–802.

Nordenhem, H. 1989. Age, sexual development, and seasonal occurrence of the pine weevil *Hylobius abietis* (L.). J. Appl. Entomol. 108: 260–270.

Örlander, G., Nilsson, U., Hällgren, J. E. 1996. Competition for water and nutrients between ground vegetation and planted *Picea abies*. New Zeal. J. For. Sci. 26: 99–117.

Örlander, G., Gemmel, P. & Hunt, J. 1990. Site preparation. A Swedish Overview. FRDA Report 105: 1–61.

Örlander, G., Gemmel, P. & Wilhelmsson, C. 1991. Effect of scarification, planting depth and planting spot on seedling establishment in a low humidity area in southern Sweden. Swedish University of Agricultural Sciences, Department of Silviculture, Report 33: 92 pp. (In Swedish with English summary.)

Örlander, G., Nilsson, U. & Nordlander, G. 1997. Pine weevil abundance on clear-cuttings of different ages: a six-year study using pitfall traps. Scand. J. For. Res. 12: 225–240.

Selander, J. & Immonen, A. 1991. Effect of fertilization on the susceptibility of Scots pine seedlings to the large pine weevil, *Hylobius abietis* (Coleoptera, Curculionidae). Folia Forestalia 771: 1–18.

Selander, J. & Immonen, A. 1992. Effects of fertilization and watering of Scots pine seedlings on the feeding preference of the pine weevil (*Hylobius abietis* L.). Silva Fennica 26: 75–84.

Selander, J. 1993. Survival model for *Pinus sylvestris* seedlings at risk from *Hylobius abietis*. Scand. J. For. Res. 8: 66–72.

Selander, J., Immonen, A. & Raukko, P. 1990. Resistance of naturally regenerated and nursery-raised Scots pine seedlings to the large pine weevil *Hylobius abietis* (Coleoptera: Curculionidae). Folia Forestalia 766: 1–19.

Söderström, V., Bäcke, J., Byfalk, R. & Jonsson, C. 1978. Comparison between planting in mineral soil heaps and some other soil treatment methods. Swedish University of Agricultural Sciences, Department of Silviculture, Report 11: 177 pp. (In Swedish with English summary).

Sundkvist, H. 1994. Extent and causes of mortality in *Pinus sylvestris* advance growth in northern Sweden following overstory removal. Scand. J. For. Res. 9: 158–164.

von Sydow, F. & Örlander, G. 1994. The influence of shelterwood density on *Hylobius abietis* (L.) occurrence and feeding on planted conifers. Scand. J. For. Res. 9: 367–375.

von Sydow, F. 1997. Abundance of pine weevils (*Hylobius abietis*) and damage to conifer seedlings in relation to silvicultural practices. Scand. J. For. Res. 12: 157–167.

Wilson, W. L. & Day, K. R. 1996. Variation in the relative abundance of the large pine weevil among Sitka spruce plantation sites. Forestry 69: 177–179.

Wilson, W. L., Day, K. R. & Hart, E. A. 1996. Predicting the extent of damage to conifer seedlings by the pine weevil (*Hylobius abietis* L.): a preliminary risk model by multiple logistic regression. New For. 12: 203–222.

Zar, J. H. 1984. Biostatistical analysis. Prentice-Hall, Englewood Cliffs, NJ.