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Pine Weevil Abundance on Clear-cuttings of Different Ages: A 6-year Study using Pitfall Traps

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Patterns of seasonal and yearly variation in the abundance of the pine weevil, *Hylobius abietis* (L.) (Coleoptera: Curculionidae), were determined on clear-cuttings of various age in southern Sweden. New clear-cuttings were established during each of five consecutive years, and the numbers of weevils caught in pitfall traps baited with α-pinene and ethanol were recorded weekly during the season for up to 6 yrs on these areas. In total, 74 281 weevils were trapped. On fresh clear-cuttings, the catches increased drastically once migrating weevils had arrived in spring. Catches peaked in May and July but were lower in June, when oviposition underground is most intense. The catches declined suddenly in the middle of August, coincident with the weevils becoming post-reproductive. On older clear-cuttings, most weevils were caught before migration in spring; thereafter the catches gradually decreased from June to September. Pine weevils were even abundant on 5-yr-old clear-cuttings. Relationships between trap catch and weevil-induced seedling mortality were examined on fresh clear-cuttings and on the same areas over the following 3 yrs. A significant relationship between these two variables existed only for the 2-yr-old clear-cuttings. Therefore, trapping data alone appear to be insufficient in forecasting seedling damage. *Key words: Abundance, forecasting, Hylobius abietis, monitoring, pest management, pine weevils, pitfall traps, reforestation, seedling damage.*

INTRODUCTION

Feeding by adult pine weevils (*Hylobius abietis* L.) on the bark of newly planted conifer seedlings is a well-known problem for foresters in Europe. In Scandinavia, and especially in the southern boreal forests, damage by pine weevils causes mortality that often exceeds 70% when planting is carried out on fresh, 1-yr-old or 2-yr-old clear-cuttings (von Sydow 1995, Örlander & Nilsson, unpubl.). A silvicultural system based on clear-cutting seems to provide near ideal conditions for pine weevils (e.g. Sylvén 1927, Bejer-Petersen et al. 1962). The larvae develop particularly well in the roots of sun-exposed, fresh conifer stumps, and flying adults can easily locate clear-cuttings. There is good reason to believe that the pine weevil problem will increase in the future because the conifer stands harvested generally will be more densely stocked (Lindroth 1995). Furthermore, owing to environmental concerns, the treatment of seedlings with insecticide will be prohibited by law in Sweden in the near future. Thus, alternative measures for protecting seedlings from pine weevils must be developed.

To use silvicultural strategies to protect seedlings from pine weevils, firm knowledge about the life history and temporal appearance of the weevil is essential. Fresh clear-cuttings are colonized by flying pine weevils in spring. The dispersal flight occurs only when the air temperature is above ca 16°C (Solbreck & Gyldberg 1979). These temperatures often occur by mid-May in southern Sweden, although the variation between years is considerable. According to calculations by Solbreck (1980), most weevils migrate more than 10 km, and some fly as far as 80 km. The migration often consists of repeated flights, and because the beetles fly mainly in the direction of the prevailing wind the dispersal track is difficult to predict (Solbreck 1980).

Flying weevils are attracted to freshly cut areas by the volatiles emanating from fresh conifer stumps. On the ground, weevils locate suitable roots for oviposition by olfactory orientation (Nordlander et al. 1986), and the eggs are laid in or adjacent to these roots (Nordenhem & Nordlander 1994). Adult weevils overwinter in the soil, and a considerable proportion may remain on the same site during the following season (Långström 1982, Nordenhem 1989). After hibernation, oviposition may be resumed on the same clear-cutting because some parts of the stump roots can still be used for breeding (Nordenhem 1989). However, most of the eggs are laid during the first summer after cutting.

In southern Scandinavia, adult weevils of the new generation emerge to a large extent in late summer the year after oviposition (Bejer-Petersen et al. 1962). These weevils feed for a month or two and then hibernate in the ground. Other weevils of the new generation remain in their pupal chambers until spring the second year after oviposition. Thus, the weevils of both categories appear on the clear-cutting in spring the second year, where they feed for about a month, while their flight muscles develop. Thereafter, they fly away to find suitable areas for breeding (Nordenhem 1989). Therefore, to help avoid severe damage by pine weevils, it has been a recommended practice to plant on clear-cuttings that are more than 2 yrs old.

There are various methods to assess the local abundance of resident adult pine weevils. Freshly cut billets of coniferous trees placed on the ground have frequently been used to arrest pine weevils. The billets can then be turned over and the weevils under them counted (e.g. Långström 1982, Wilson & Day 1994). However, the billet method has several disadvantages: For example, (1) natural host material can vary considerably in its attractivity to pine weevils; (2) weevils are arrested at the billets only temporarily; and (3) it is difficult to record the number of weevils arrested around the billets in a standardized way. These drawbacks are avoided with the monitoring method introduced by Nordlander (1987), based on covered pitfall traps baited with attractive volatile substances naturally present in host material (Tilles et al. 1986*a,b*). This method has been used in several studies of *H. abietis* in Europe (e.g. Nordlander 1987, 1990, Zumr & Stary 1992, 1993, 1994, Lindelöw et al. 1993, Malphettes et al. 1994, von Sydow 1995) and some closely related species in North America (e.g. Raffa & Hunt 1988, Hunt & Raffa 1989, Rieske & Raffa 1990*a,b*, 1991, 1993).

In this study we used baited pitfall traps to monitor pine weevil abundance on clear-cuttings of different ages throughout the season. However, the α-pinene-ethanol bait used has the limitation that the pre-reproductive weevils emerging in late summer are not attracted (Nordenhem & Eidmann 1991, Malphettes et al. 1994). Thus, the pre-reproductive weevils that feed for some time in the autumn can be assumed to have been recorded only to a negligible extent in the present study. This property of the bait has one advantage, however; namely, it should make it possible to follow the decline in activity of the parent weevil population without serious interference from newly emerged ones.

The aim of the present study was to describe general patterns of seasonal and yearly variation in pine weevil abundance in relation to clear-cutting age. Effects of between-year variation in weather conditions were possible to discern because new clear-cuttings were made during five consecutive years, and weevil abundance was monitored for up to 6 yrs on these clear-cuttings. We also assessed the effects of the amount of slash present on the ground on the local abundance of pine weevils. Moreover, the relationship between weevil catch and seedling mortality was examined in order to evaluate the potential for using trap-catch data to forecast seedling damage.

MATERIALS AND METHODS

Experimental design

The experiment was established over a 5-yr period at four sites in two different areas in southern Sweden (Fig. 1). Two of the sites are situated near the Asa Forest Research Station, about 40 km north of Växjö (57°10′ N, 14°47′ E), and the two other sites are near the Tönnersjöheden Forest Research Station, 25 km east of Halmstad (56°40′ N, 13°10′ E). The sites are representative of relatively fertile, south Swedish forests, and the original stands were dominated by Norway spruce (Table 1). The sites were chosen so as to represent a range of soil moisture and soil texture conditions. The two sites at Tönnersjöheden are dry and have coarse-texture soils, whereas the soils at Asa are mesic to wet and more fine textured (Table 1).

In 1988, five ca 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). In addition, one reference area of equal size was left uncut on each site. Each clear-cutting was divided into two parts of equal size; on one half the 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 ground.

On each clear-cutting, Norway spruce seedlings were planted in four blocks from the year of cutting until 1993. Two blocks were placed on the area where

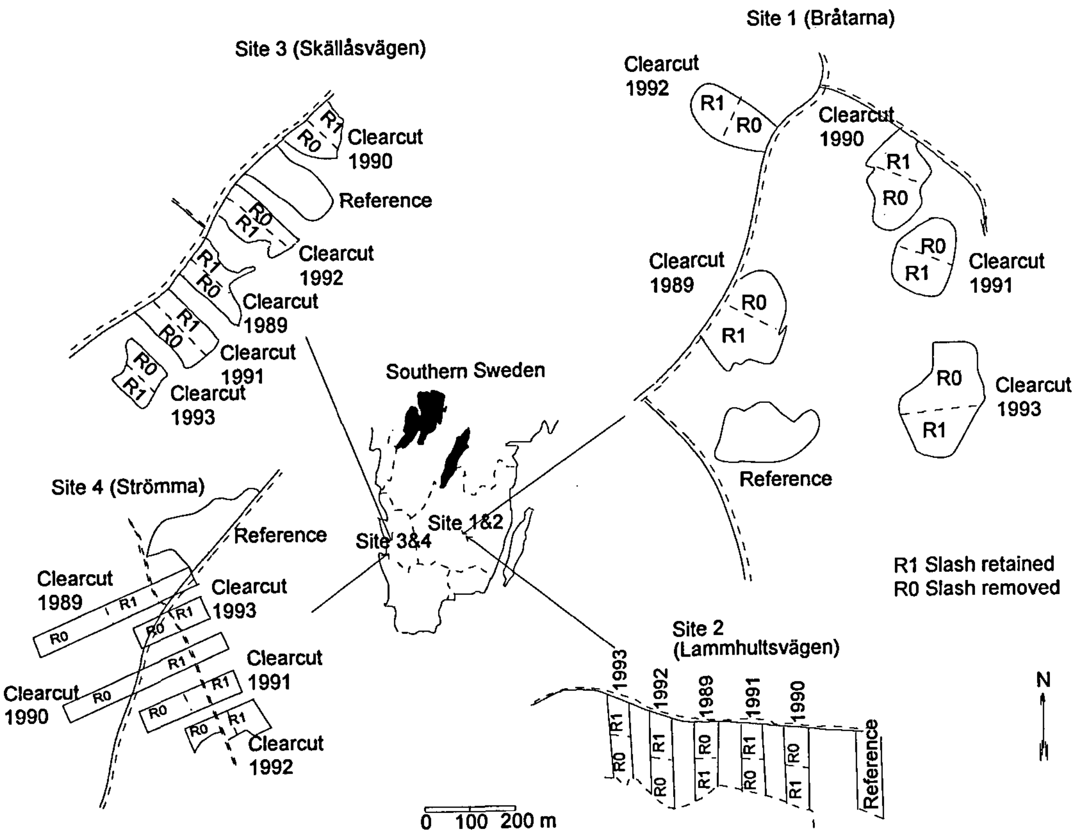


Fig. 1. Locations of the clear-cuttings and experimental layouts.

the slash had been retained, and the other two were located on the area where the slash had been removed. Each block contained eight treatments with 16 seedlings per plot. In this study only data from the control treatment (seedlings planted without site preparation and without insecticide treatment) were analysed.

Three-yr-old, bare rooted (1.5/1.5) and two-yr-old, containerized (Blockplanta 64) seedlings were

Table 1. *Description of study sites and stands before cutting*

Terminology after Hägglund and Lundmark (1977)

	Asa		Tönnersjöheden	
	Site 1	Site 2	Site 3	Site 4
Elevation (m)	245	175	85	60
Soil moisture	Mesic	Wet	Dry	Dry
Soil texture	Sand–fine sand	Sand	Gravel	Sand
Vegetation type	Blueberry	Blueberry	Grass	No field vegetation
Site index (at 100 yrs)				
m	28	28	31	31
m^2 ha^{-1} yr^{-1}	9	9	11	11
Species mixture[a]	43:57	50:50	1:99	1:99
Age in 1993 yrs	85	96	98	75
Vol. m^2 ha^{-1}	300	290	500	305
Stems ha^{-1}	590	360	470	380

[a] Shown as the volume (%) of *Pinus sylvestris*:*Picea abies*.

planted alternately along rows. All seed originated from the Maglehem seed orchard, and all seedlings were sown from the same seedlot. The seedlings were sorted before planting, with bare-rooted seedlings shorter than 25 cm and containerized seedlings shorter than 15 cm being discarded. In this report seedling mortality values are means for bare-rooted and containerized seedlings combined. Planting was carried out manually around the first of May each year. More details about the layout of the experiment are presented by Nilsson & Örlander (1995).

Measurements

Pine weevil abundance on the clear-cuttings was monitored with baited pitfall traps. Once a week from late April until the beginning of October the traps were emptied and the number of pine weevils recorded. Ten traps were placed on each clear-cutting, five on the part where slash had been retained and five on the part where slash had been removed. All traps were placed in undisturbed ground. The trap used was of the type described by Nordlander (1987). It was made from a capped, 1-L polypropylene jar with eight 1-cm-diameter holes equally spaced around the circumference, ca 2 cm below the rim. To allow walking weevils to enter, the traps were buried with their holes just above ground level, and they were filled with about 150 ml of water with a washing detergent added to drown the weevils. Inside each trap separate dispensers releasing α-pinene and ethanol were suspended (see Nordlander 1987).

Damage by pine weevils was assesed in October for all seedlings. The degree of damage was recorded using a 6-level scale, where 0 = undamaged and 5 = dead due to damage by pine weevils.

Precipitation was recorded with a rain gauge (Environmental Measurements Ltd., UK) on each site. The rain gauges were connected to Campbell CR10 dataloggers (Campbell Scientific Inc., USA), and total precipitation was recorded each day. Air temperature was measured at the clear-cuttings made in 1989, 1991, and 1993. Air temperatures were measured with Cu–Co thermocouples ($r = 0.05$ mm), which also were connected to the dataloggers. Measurements were taken every 10 min. In this study, a weekly mean of daily average maximum temperatures is presented. Soil temperatures in mounds were measured with thermistors inserted into small cylinders of brass. Soil temperatures were recorded 10 cm below ground in two mounds on each clear-cutting made in 1989, 1991, and 1993 and were recorded every 10 min.

Data on global radiation were only available for the sites at Asa, where radiation was registered every 10 min using a Licor 200Z pyranometer (Licor Inc., USA). We found that the difference between daily maximum and minimum soil temperatures in fresh mounds was correlated to global radiation using a linear model ($r^2 = 0.81$). Therefore, the soil temperature difference was used to estimate global radiation.

Calculations

The pine weevil catch is presented as an average value for each clear-cutting (10 traps) and each slash treatment (five traps). The general linear model (GLM) procedure for split-plot designs was used to perform the statistical tests (SAS Institute Inc.). One model was used for analysis of the effect of clear-cutting age. Effects of year of catch and slash removal were analysed with a second model (cf. Table 3). Differences among class means were evaluated with Tukey's honestly significant difference (HSD) mean separation test when clear-cutting age or year of catch was significant ($p = 0.05$) in the analysis of variance.

Relationships between the total trap catch on the fresh clear-cuttings and damage to seedlings planted during the same and subsequent years were analysed by log-linear regression. Because the proportion of seedlings available to be killed by the weevils decreases exponentially as the proportion of already killed seedlings increases, we used the following function for the regression:

$$y = 1 - ae^{-bx}$$

where x is the trap catch, y is the seedling mortality due to pine weevil damage, and a and b are constants (cf. Nordlander 1991).

RESULTS

Weather conditions

The weather varied considerably between years during the study period, but the general trends were the same for the different sites (Table 2). In 1990, precipitation was relatively evenly distributed throughout the summer, and air temperatures were high. In 1991, May and June were cold and precipitation was high, whereas late summer was dry with high air temperatures. The extremely dry and warm early summer of 1992 was followed by a wet and cold autumn. The

Table 2. *Monthly sums of precipitation (P) and average air temperature (T) during the growing seasons of 1989–1994 for sites 1 and 2 at Asa and sites 3 and 4 at Tönnersjöheden and, for comparison, the 30-yr-average (1960–1990) precipitation (mm) and air temperature (°C) at nearby climatic stations*

Data are missing for Tönnersjöheden in 1989, because the climatic stations at the sites were not operational at that time

		1989		1990		1991		1992		1993		1994		30-yr average	
Site	Month	*P*	*T*	*P*	*T*	*P*	*T*	*P*	*T*	*P*	*T*	*P*	*T*	*P*	*T*
Asa	May	26	10.4	22	10.7	49	7.6	17	11.9	48	11.3	15	8.7	48	10.8
	June	53	13.8	90	14.4	142	10.1	1	16.3	66	12.6	35	12.2	55	14.9
	July	92	15.8	69	14.9	25	17.1	55	16.5	115	13.2	16	19.6	75	15.9
	August	90	14.1	70	15.1	74	15.4	147	14.2	48	11.5	109	15.7	57	15.2
	September	43	11.4	83	10.2	118	10.3	53	8.5	49	8.5	157	10.8	71	11.2
Tönnersjöheden	May	–	–	45	11.2	39	8.6	52	12.5	35	12.8	22	10.4	57	10.3
	June	–	–	61	14.8	166	11.1	2	17.0	77	13.1	108	12.2	75	14.1
	July	–	–	86	15.1	61	17.2	66	16.8	205	13.4	8	19.4	98	15.1
	August	–	–	105	15.6	69	15.8	127	14.9	134	12.8	110	16.4	99	14.1
	September	–	–	198	10.4	138	11.4	75	10.0	44	9.2	194	11.7	110	11.2

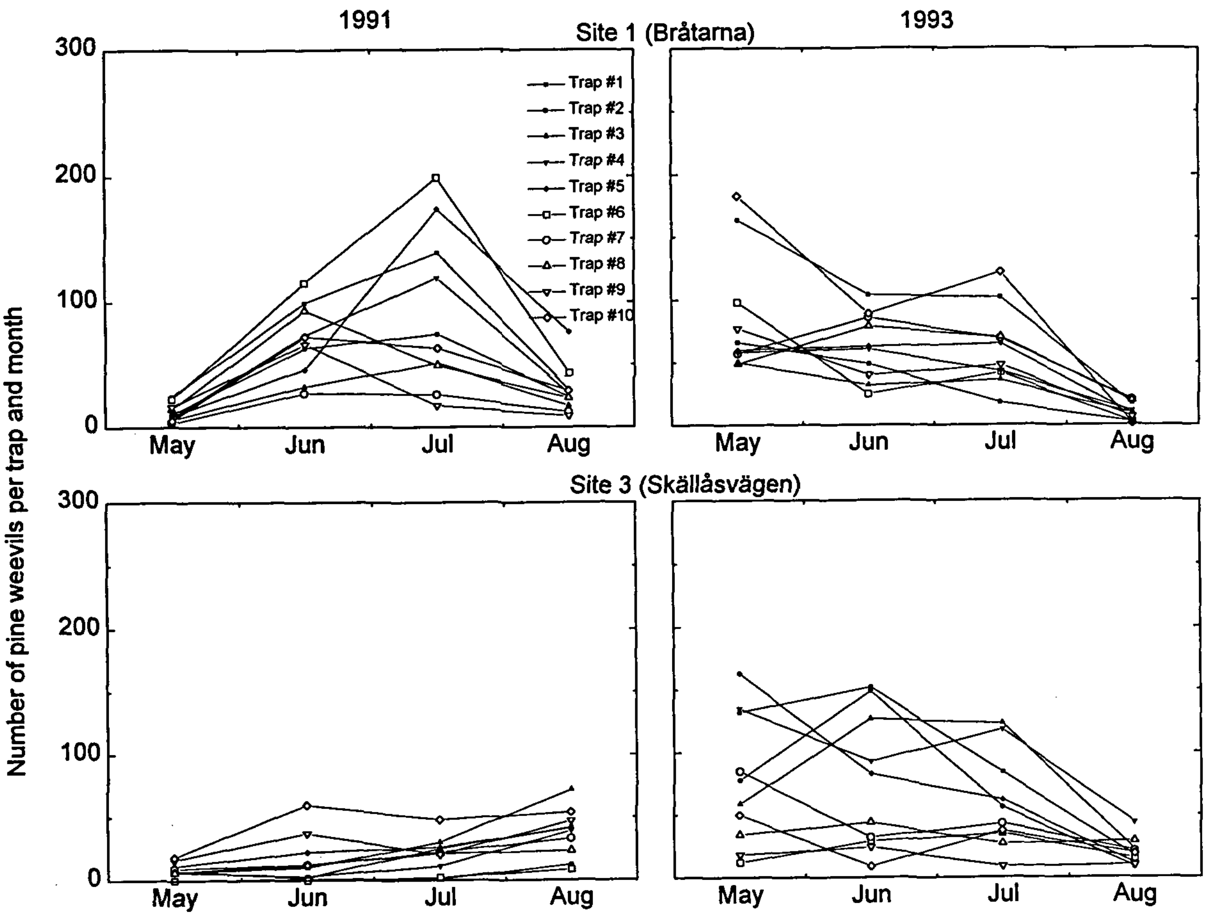
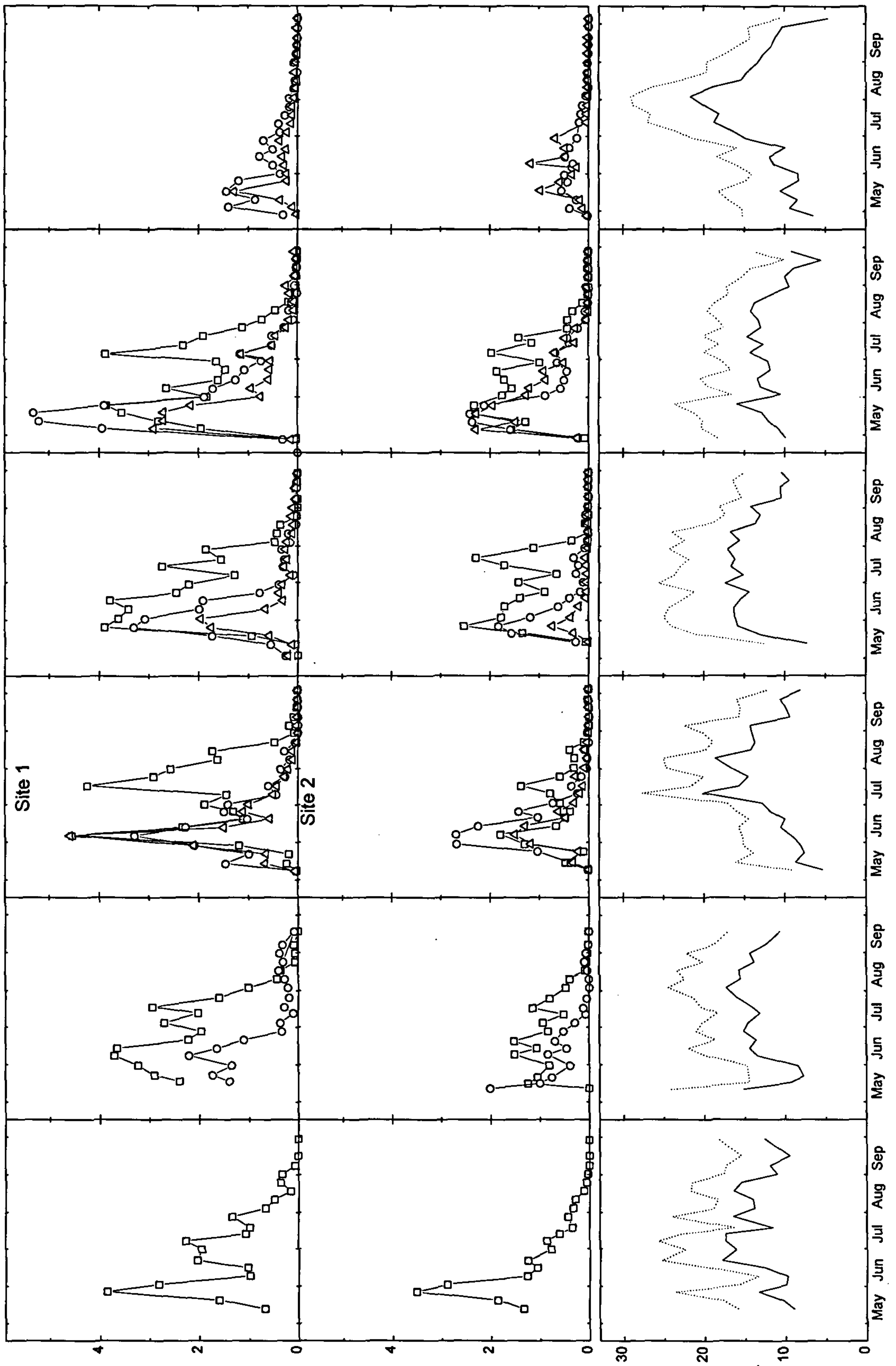


Fig. 2. Monthly catch of pine weevils in individual traps on fresh clear-cuttings on site 1 and 3 during the growing seasons of 1991 and 1993. Trap numbers 1–5 were placed on the part of the clear-cutting where the slash had been removed; traps 6–10 were located on sites where the slash had been retained.



1989
1990
1991
1992
1993
1994
Site 1
Site 2
Number of pine weevils per trap and day
Air temperature °C
May Jun Jul Aug Sep

Fig. 3.

spring of 1993 was warmer and drier than normal, whereas rainfall was abundant and air temperatures were lower than normal throughout the rest of the summer. In 1994, the early summer was dry and cold at Asa, whereas both precipitation and air temperature were more normal at Tönnersjöheden. July was warm and dry at both Asa and Tönnersjöheden, whereas late summer was wet.

Pine weevil trapping

In total, 74 281 specimens of *Hylobius* weevils were collected during the 6 yrs of trapping at the four localities. Species and sex were determined for a sample consisting of all specimens caught during six selected weeks distributed from early May to early October in 1994. In addition to *H. abietis*, a small proportion of the closely related species *H. pinastri* was present in the material. The mean proportion of *H. pinastri* for all localities was 0.7%, and the highest proportion, found at Strömma, was 2.4%. In our analyses, all weevils trapped were treated as belonging to a single species, *H. abietis*. Males were somewhat more common than females in early summer (58%), whereas in late summer the sex ratio was about equal (48% males).

The variation in pine weevil catch between individual traps on the same clear-cutting was considerable (Fig. 2). The maximum difference in monthly catch between such traps was about 150–200 pine weevils in May to July and about 50–100 weevils in August. In general, traps that caught many weevils in early summer also showed high catches in late summer (Fig. 2).

The number of pine weevils in the traps increased rapidly or was already high in early May, when trapping began (Figs. 3, 4). On fresh clear-cuttings the catches began to rise when the average air temperature exceeded about 10°C, corresponding roughly to a daily maximum of ca 20°C (Figs. 3, 4). Pine weevils appeared earlier on older clear-cuttings than on fresh ones (Fig. 5). In general, two peaks in pine weevil catch were found on fresh clear-cuttings, one in late May and the other in the middle of July (Fig. 5). On fresh clear-cuttings, the catch decreased drastically around the middle of August on all sites and during all years (Figs. 3–5), whereas on older clear-cuttings the catches usually decreased gradually from June to September.

The variation in pine weevil catch within each year was generally similar between sites; i.e. peaks and low values occurred at approximately the same time on the different sites (Figs. 3, 4). The catch on fresh clear-cuttings in the beginning of the growing season was lower at the two sites at Tönnersjöheden (sites 3 and 4) than at Asa (sites 1 and 2), whereas catches in late July and in August were clearly higher at Tönnersjöheden than at Asa (Fig. 5). On 1-yr-old clear-cuttings most pine weevils were caught in May and June. However, there was also a noticeable increase in catch in late summer (July–August) on sites at Tönnersjöheden. On 2-yr-old and older clear-cuttings, pine weevils were caught mainly in early summer (May–June) (Fig. 5). Thereafter, the catches decreased rapidly and remained low throughout the rest of the summer. Even on 5-yr-old clear-cuttings the catches were relatively high.

The yearly total catch of pine weevils on fresh clear-cuttings was relatively constant within sites over the years, and the differences were not significant (Table 3). The only exception was one extremely high value that was recorded at site 3 in 1989 (Fig. 6). On 1-yr-old and 2-yr-old clear-cuttings the differences in catch between years were statistically significant (Table 3). However, general trends in common for all sites are difficult to discern.

The variation in total catch between clear-cuttings of different age was analysed for the years 1991–1993. Analysis of variance showed that the effect of clear-cutting age was statistically significant in 1992 ($p < 0.001$) and 1993 ($p < 0.001$) but not in 1991 ($p = 0.27$). In 1992, the catch on fresh clear-cuttings was significantly higher than the catch on clear-cuttings of any other age, whereas in 1993 the catch on fresh clear-cuttings was significantly higher than the catches on 3-yr-old and 4-yr-old clear-cuttings.

For fresh, 1-yr-old, and 2-yr-old clear-cuttings, pine weevil catches were significantly larger on areas where the slash had been removed than on areas where the slash had been retained (Tables 3, 4). On older clear-cuttings, slash removal had no significant effect.

Fig. 3. Catches of pine weevils during the growing seasons of 1989–1994 on fresh (—□—), 1-yr-old (—○—) and 2-yr-old (—△—) clear-cuttings at sites 1 and 2 . The traps were emptied weekly, and values shown are the mean daily catches of ten traps. Weekly means of average (——) and maximum (· · ·) air temperature are given in the bottom panel. All values are means for the preceding period.

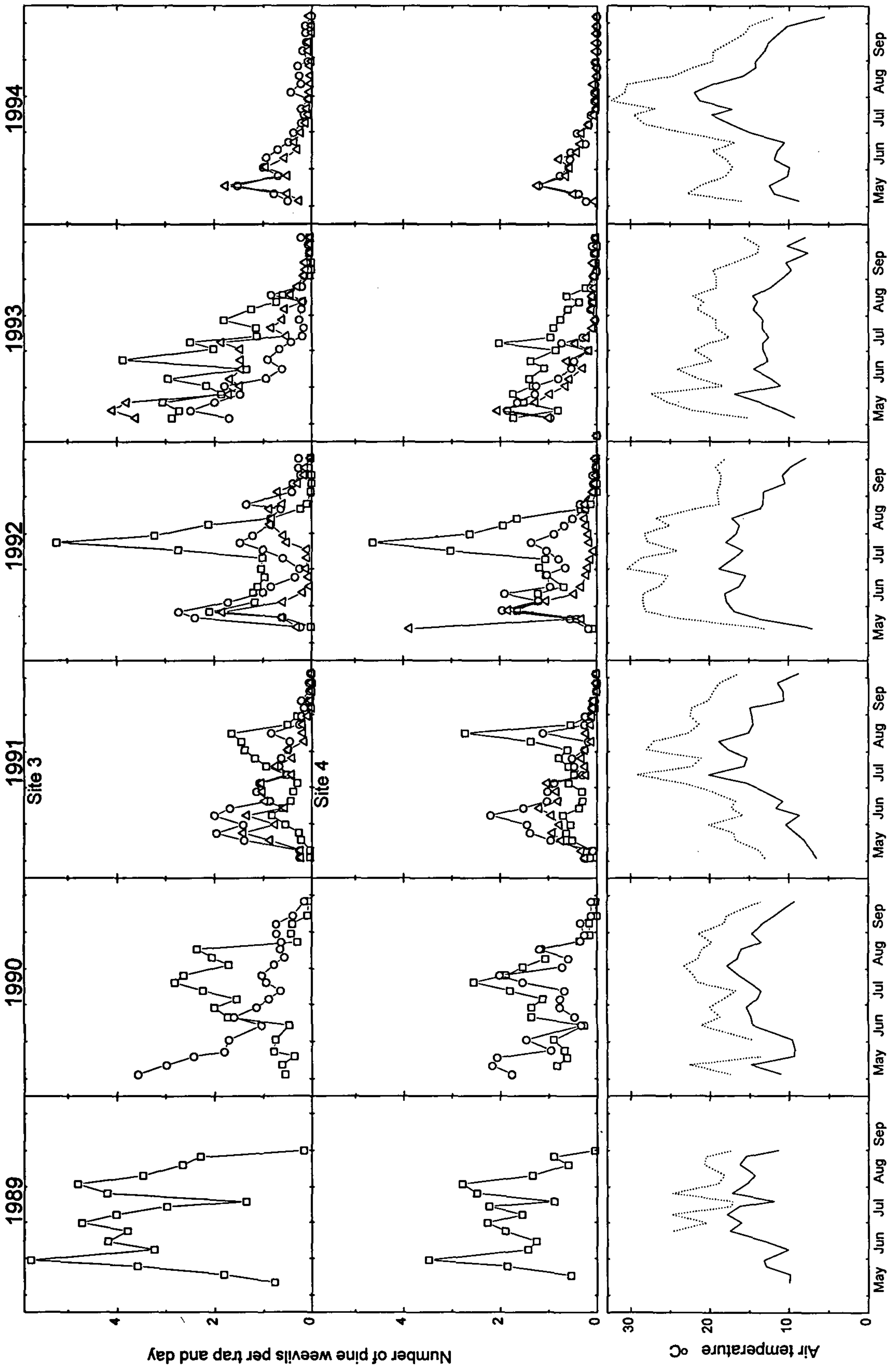

1989
1990
1991
1992
1993
1994
Site 3
Site 4
Number of pine weevils per trap and day
Air temperature °C
May Jun Jul Aug Sep

Fig. 4.

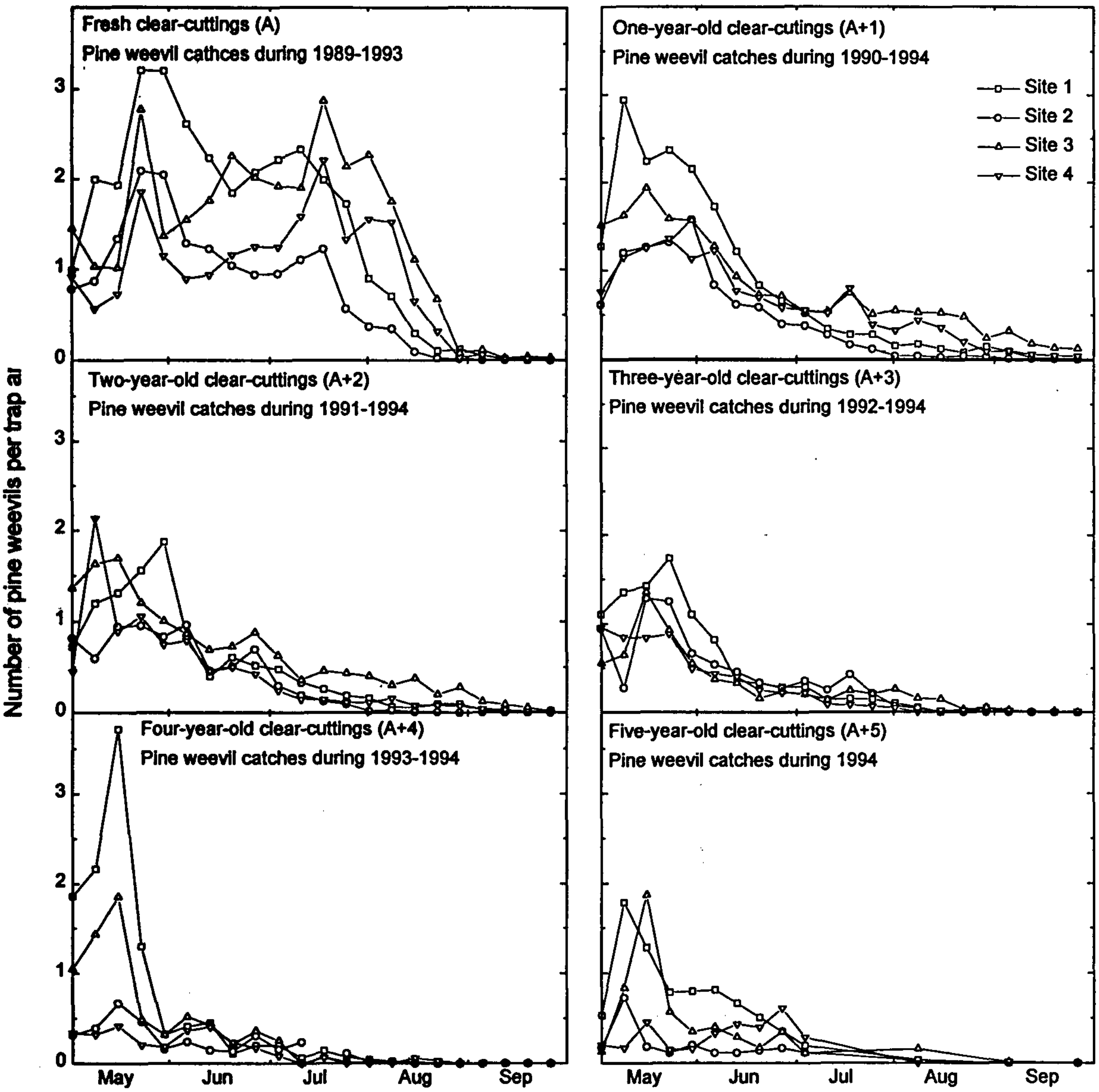


Fig. 5. Mean daily catches of pine weevils for all sites on clear-cuttings of different age. Values are weekly averages during the growing seasons of 1989–1993 for fresh clear-cuttings (A), 1990–1994 for 1-yr-old clear-cuttings (A + 1), 1991–1994 for 2-yr-old clear-cuttings (A + 2), etc.

Global radiation and pine weevil catches

Global radiation seemed to explain some of the daily variation in pine weevil catches. As an indirect estimate of global radiation we used the difference between daily maximum and minimum soil temperatures in fresh mounds. During sunny days the temperature difference was 8–9°C, corresponding to a global radiation of 22–25 MJ m^{-2} day^{-1}. During some years (e.g. 1993), high catches were recorded during periods when the difference between minimum and maximum soil temperatures was high (i.e. high global radiation), whereas the catches were less well correlated with global radiation during other years (e.g. 1991) (Fig. 7).

Fig. 4. Catches of pine weevils during the growing seasons of 1989–1994 on fresh (—□—), 1-yr-old (—O—) and 2-yr-old (—Δ—) clear-cuttings at sites 3 and 4. The traps were emptied weekly, and values shown are the mean daily catches of ten traps. Weekly means of average and maximum air temperature are given in the bottom panel. All values are means for the preceding period.

Table 3. *Split-plot analysis of variance table for yearly accumulated pine weevil catch depending on four levels of site, two to five levels of year of catch (year) and two levels of slash treatments (slash)*

Separate analyses were made for clear-cuttings of different ages (fresh to 4 yrs old)

Age		DF	MS	F	p
A	Site	3	25 087	3.46	0.0511
	Year	4	11 238	1.55	0.2501
	Error A[a]	12	7 240		
	Slash	1	20 065	14.72	0.0007
	Model	20	11 364	8.34	0.0001
	Error B[b]	19	1 363		
A + 1	Site	3	8 469	4.68	0.0218
	Year	4	6 788	3.75	0.0333
	Error A[a]	12	1 808		
	Slash	1	7 599	10.41	0.0045
	Model	20	4 093	5.6	0.0002
	Error B[b]	19	730		
A + 2	Site	3	3 244	1.94	0.1941
	Year	3	10 550	6.3	0.0136
	Error A[a]	9	1 674		
	Slash	1	3 894	6.74	0.0202
	Model	16	3 772	6.54	0.0004
	Error B[b]	15	577		
A + 3	Site	3	540	0.83	0.5239
	Year	2	908	1.39	0.3179
	Error A[a]	6	650		
	Slash	1	259	1.35	0.2707
	Model	12	633	3.29	0.0289
	Error B[b]	11	192		
A + 4	Site	3	2 292	1.49	0.3755
	Year	1	1 788	1.16	0.3599
	Error A[a]	3	1 538		
	Slash	1	213	0.87	0.3813
	Model	8	1 686	6.89	0.0098
	Error B[b]	7	244		

[a] Denominator for the site and year effect.
[b] Denominator for the slash effect.

Pine weevil catches and seedling damage

There was generally a poor correlation between the total catch of pine weevils in the year when the clear-cuttings were fresh and seedling damage in subsequent years (Fig. 8). Because plantings were made during five consecutive years after clear-cutting it was possible to evaluate each planting year separately. A relationship between mortality caused by pine weevils and catches on fresh clear-cuttings was discernible only in cases where plantings had been made on 2-yr-old clear-cuttings. The log-linear regression resulted in an r^2 of 0.49 for the function $y = 1 - ae^{-bx}$ ($a = 2.13$ and $b = 0.013$) when one outlier was discarded. This outlier consisted of the extremely high trap catch on site 3, year 1989.

DISCUSSION

Seasonal activity

The strong increase in the pine weevil catch on fresh clear-cuttings in spring can be ascribed mainly to the fact that most of the weevils are immigrants arriving by flight. That the catch increased once the maximum air temperature had reached around 20°C is well in line with data on pine weevil dispersal flight presented by Solbreck & Gyldberg (1979). They found that pine weevils start flying when day temperatures exceed 16–20°C. This corresponds with a daily average temperature of ca 10°C if the weather is sunny. Pine weevils on older clear-cuttings become active once the temperature has reached about 5°C, i.e. around mid-April in the study area. Because we did not begin trapping until the end of April, it was not possible to determine when the activity period began on older clear-cuttings.

During most years, two peaks in pine weevil catch were found on the fresh clear-cuttings, one in May and one around mid-July. Oviposition is normally at its most intense phase during June (personal observation). Thus, the lower trap catch in June may have been due to the fact that weevils were spending somewhat less time moving around on the surface of the ground. In the middle of August during all years, the pine weevil catch suddenly declined on all the fresh clear-cuttings. This decline in trap catch appears to coincide with ceased reproduction (Nordenhem 1989). Two lines of evidence suggest that this activity decline is induced by decreasing daylength; i.e. there is no general drop in temperature in mid-August, and pine weevils oviposit for 4–5 months under an 18-h light/6-h dark regime in the laboratory (Nordlander unpubl.). The August decrease in trap catch may not be due only to reduced activity on the ground surface. The response to baited traps might also change when the weevils become post-reproductive. Such a behavioural change could explain why considerable numbers of pine weevils can be collected under pine billets until the middle of September (Nordenhem 1989). However, the study by Nordenhem & Eidmann (1991) indicates that the combination of α-pinene and ethanol attracts post-reproductive weevils

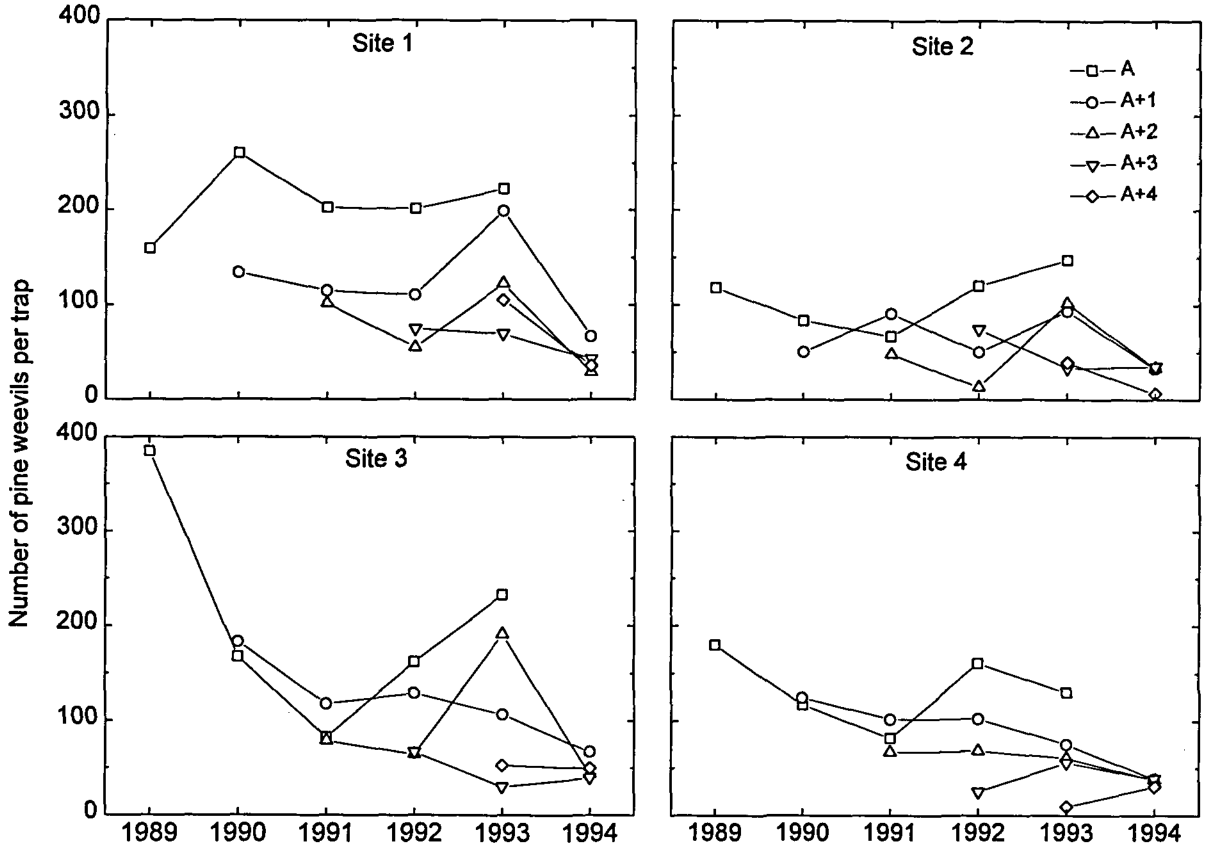


Fig. 6. Yearly catches of pine weevils on the four sites during the growing seasons of 1989–1993 for fresh clear-cuttings (A), 1990–1994 for 1-yr-old clear-cuttings (A + 1), 1991–1994 for 2-yr-old clear-cuttings (A + 2), etc.

about as well as pieces of pine stems do. Thus, it appears likely that the post-repoductive weevils start preparing for hibernation in the soil around mid-August.

Effect of clear-cutting age

Although weevils were most abundant during the first three seasons after cutting, considerable numbers were still found on 4- and 5-yr-old clear-cuttings.

Table 4. *Effect of slash removal on mean pine weevil catches (number per trap yr^{-1}) on clear-cuttings of various ages*

Values are averaged for all sites and the years: 1989–1993 for fresh clear-cuttings (A), 1990–1994 for 1-yr-old clear-cuttings (A + 1), 1991–1994 for 2-yr-old clear-cuttings (A + 2), etc. Standard error of the means is shown in parentheses

Age of clear-cutting	Slash treatment	Site 1	Site 2	Site 3	Site 4
A	Retained	193.2 (39.1)	92.2 (39.7)	173.8 (110)	147.3 (97.8)
	Removed	230.4 (39.5)	146.0 (22.2)	237.7 (133)	173.3 (76.2)
A + 1	Retained	104.1 (58.6)	61.0 (33.3)	132.5 (51.9)	72.0 (14.3)
	Removed	177.2 (29.8)	81.9 (19.2)	139.1 (27.5)	114.1 (19.0)
A + 2	Retained	71.9 (45.3)	45.1 (25.2)	95.4 (43.4)	55.1 (7.16)
	Removed	113.4 (24.4)	63.7 (64.7)	135.9 (114)	76.0 (4.82)
A + 3	Retained	54.5 (1.54)	56.2 (22.9)	57.7 (34.6)	37.8 (18.4)
	Removed	89.6 (5.71)	51.7 (34.9)	39.4 (17.2)	42.9 (25.0)
A + 4	Retained	92.4	45.0	70.6	13.8
	Removed	117.5	34.1	35.2	5.2

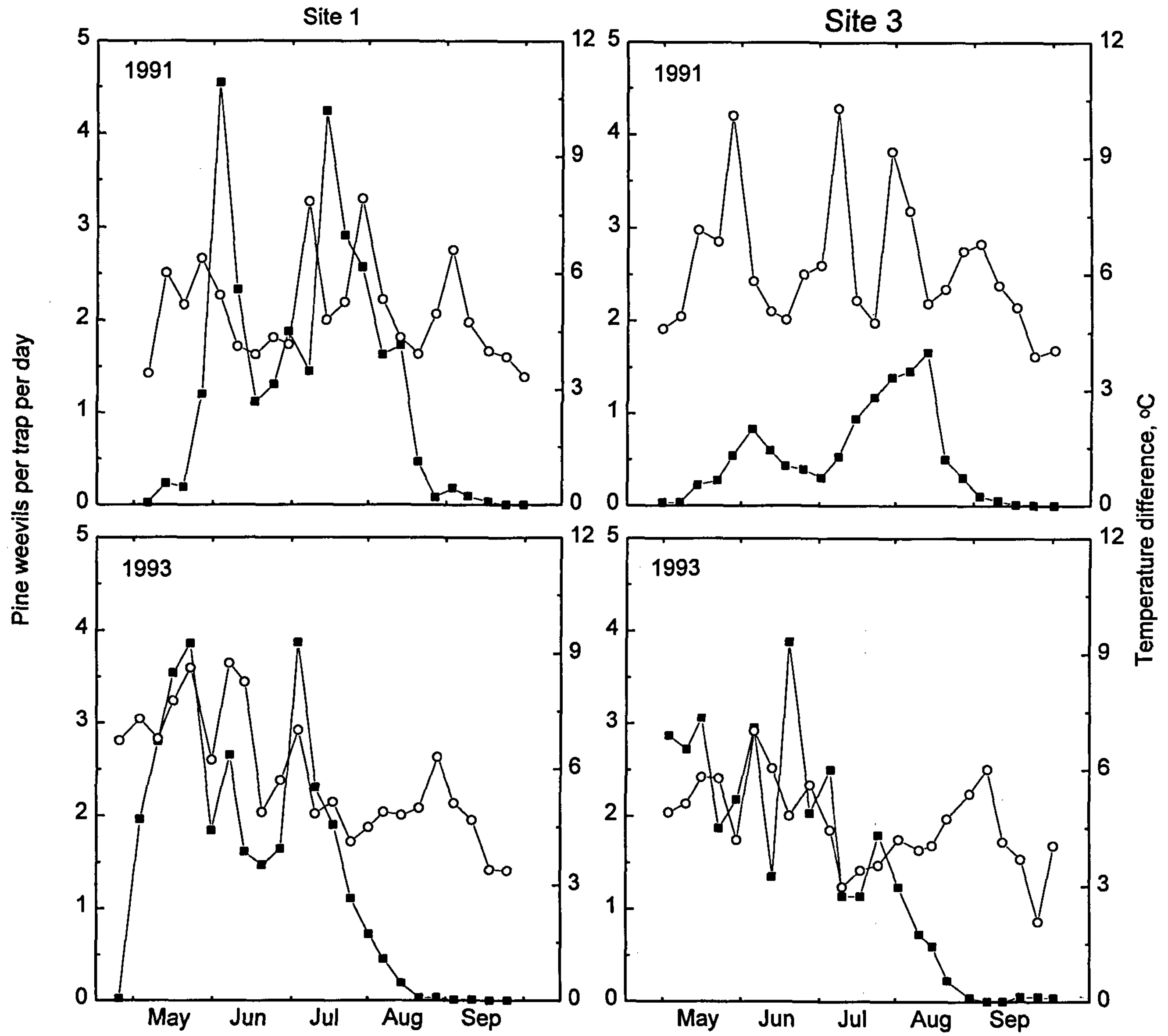


Fig. 7. Mean weekly catches of pine weevils (—■—) and global radiation on fresh clear-cuttings at sites 1 and 3 in 1991 and 1993. The global radiation was estimated using the difference in daily maximum and minimum temperatures in mounds (—○—), where high differences correspond to high levels of global radiation.

This is in agreement with the results of another recent Swedish study (von Sydow 1995). This late occurrence could be due to the fact that some of the weevils born at the site originate from eggs laid on 1-yr-old clear-cuttings (Nordlander 1987, Nordenhem 1989) and to the prolongation of development resulting from unfavourable microclimatic conditions (Bakke & Lekander 1965, Bejer-Petersen 1975).

The catch of pine weevils was high throughout the summer on fresh clear-cuttings, whereas on older clear-cuttings most weevils were caught during spring and early summer. This difference can be attributed to the tendency of weevils of the new generation to fly away during spring (Nordenhem 1989). On 1-yr-old clear-cuttings, catches increased slightly in the autumn. This increase coincided with the expected emergence of the new generation in late summer (Bejer-Petersen et al. 1962). However, newly emerged weevils in autumn are attracted only weakly by the α-pinene-ethanol bait used in our traps (Nordenhem & Eidmann 1991, Malphettes et al. 1994). That trapping at this time of year underestimated weevil activity is indicated by results showing that the damage by pine weevils on the 1-yr-old clear-cut-

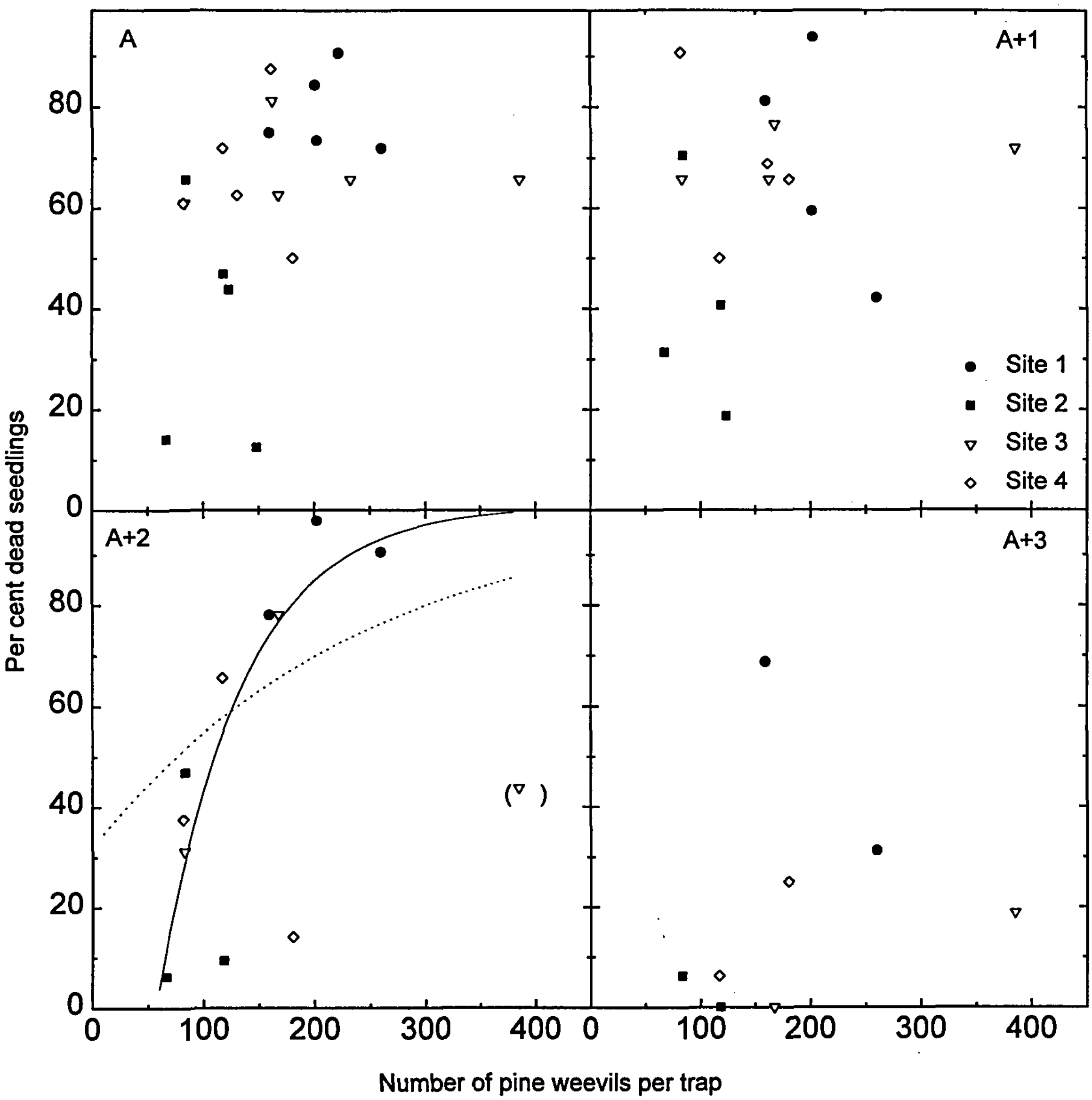


Fig. 8. Correlation between the yearly pine weevil catch on fresh clear-cuttings and mortality caused by pine weevils on seedlings planted during the same year and the following 3 yrs, i.e. year A, A + 1, A + 2, and A + 3. Norway spruce seedlings were planted in the beginning of each season, and seedling mortality was recorded 3 yrs after planting. Log-linear regressions (see Materials and Methods) including all data (· · ·), $r^2 = 0.04$ as well as regressions excluding one outlier (——), $r^2 = 0.49$ are shown for the seedlings planted year A + 2.

tings was very high in late summer (Örlander & Nilsson, unpubl.).

Effects of site and distance between clear-cuttings

As expected, there was considerable variation in catches between localities. Several investigations have shown that pine weevils are most abundant on dry sites (e.g. Sylvén 1927, Långström 1982). This may explain the low catches on the wet site at Asa. On the other hand, we cannot explain the considerable difference in catch between sites 3 and 4 based on differences in soil moisture. Instead, the location in the landscape may have been of importance: site 4 bordered on farmland to the west, which might have reduced the number of incoming pine weevils, especially as the prevailing winds in the region are from west to south-west.

The design of the experiment made it necessary to place the clear-cuttings within a limited area at each site. Even though the distance between two neighbouring clear-cuttings always exceeded 50 m, immigration from neighbouring clear-cuttings could have increased the size of the local pine weevil population as the experiment went on (cf. Eidmann 1979). However, pine weevil catches did not show any tendency to increase with time. This indicates that a "barrier" consisting of a strip undisturbed forest of about 50 m width is wide enough to prevent large-scale immigration by walking weevils and that most of the pine weevils originated from clear-cuttings located outside the experimental area. Immigration from distant clear-cuttings should be expected considering that pine weevils can fly several kilometres if wind conditions are favourable (Solbreck 1980).

Effects of weather

The weather in a broad sense probably explains most of the variation in pine weevil catch between years. The cold and wet early summer in 1991 resulted in low pine weevil catches on all sites except site 1, probably because the dispersal flight was largely hindered by weather conditions. In 1993, the dispersal flight occurred early in the spring, owing to warm weather, and the catch was of normal size on fresh clear-cuttings. The cold, rainy weather that followed in June and July probably reduced the reproductive success and may explain the low catches on one-year-old and two-year-old clear-cuttings in 1994. In June 1992, it was extremely warm and dry, and the pine weevil catches were low. When it started to rain in the beginning of July, catches increased dramatically, indicating that pine weevil activity can be negatively affected by drought and high temperatures (cf. Christiansen & Bakke 1971).

Effect of slash removal

On fresh, 1-yr-old, and 2-yr-old clear-cuttings, the catches of pine weevils were higher on the part of the clear-cutting where the slash had been removed than on the part were it had been retained. However, there was little difference between the two slash treatments in the amount of damage to seedlings caused by pine weevils (Örlander & Nilsson, unpubl.). We therefore suggest that the higher trap catch on areas lacking slash was due to the enhanced weevil mobility in these areas rather than to a higher abundance of weevils. The slash is probably of limited use as a food source for the weevils because it largely dries out early during the first season.

Aspects of pitfall trap data

There was considerable variation in monthly catch between traps. This variation should be attributable to variation in pine weevil abundance between different types of microsites. There was no indication that trapping affected the local abundance of weevils because, in general, traps with high catch rates in early spring also caught many weevils in late summer. This is in agreement with previous observations that walking weevils move over large areas and that they are attracted to a trap only once they happen to come close to it (Nordlander 1987).

Air temperature and humidity strongly affect pine weevil activity (Christiansen & Bakke 1968, 1971, Havukkala & Selander 1976, Pohris 1983) and thereby influence the probability of their entering the area of attraction that surrounds each trap. For this reason, high catch rates during periods of favourable weather do not necessarily indicate high population levels. Thus, if catches at different times are to be compared, catch data must be corrected for differences in weather (Nordlander 1987). In this study we had access to detailed weather data but only weekly observations of pine weevil catches, which made it difficult to correlate weather and catches. However, catch was related to global radiation during some years, indicating that temperature was a major limiting factor. The catch of pine weevils is probably determined by a complex combination of interacting variables such as air humidity, precipitation, reproductive phase of the weevils, site factors (ground vegetation, soil moisture, etc.), and the density of the pine weevil population.

Catch–damage correlation

A good correlation between trap catch and damage the same year was found by Nordlander (1987) in a situation where trap catch levels were low but not in situations with consistently high trap catches. In this study, with generally high trap catch levels, the relationships indicated by log-linear regressions were mostly weak. However, a positive relationship appeared to exist between trap catches on fresh clear-cuttings and the mortality caused by weevils among seedlings planted 2 yrs later. This relationship can be attributed mainly to the fact that damage on 2-yr-old clear-cuttings is caused largely by the progeny of the weevil population sampled when these clear-cuttings were fresh.

The lack of correlation between catch and damage for the other years may be due partly to the large variation in the amount of feeding needed to kill a seedling. A single weevil can kill a seedling by making a relatively small feeding scar which girdles the seedling at the base. On the other hand, a vigorous seedling can survive in spite of a large amount of feeding damage caused by many weevils, as long as it is not girdled. Furthermore, other stresses to the seedlings may interact with damage by pine weevils; e.g. drought will probably result in increased mortality in combination with pine weevil damage (Selander & Immonen 1992).

Our results regarding catch-damage correlations indicate that trap-catch data alone are not sufficient to be generally useful for forecasting seedling damage. Still, it may be possible to develop a reliable forecasting system that combines trapping data with various site-specific characteristics, like the system described by Pendrel (1990) for *Hylobius congener* in North America. Weather data and information on regional damage hazard could also be included.

In southern Sweden, it is likely that during most years pine weevil populations will be large enough to cause unacceptable damage on most clear-cuttings. Thus, there should be little need for forecasting damage risks. By contrast, in northern Scandinavia, population levels are generally lower but can vary greatly between localities. Under such conditions, the forecasting of damage risks could help considerably in deciding on silvicultural actions to be taken when planting a specific area.

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