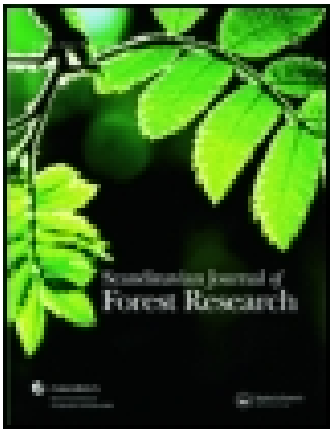

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A method for trapping hylobius abietis (L.) with a standardized bait and its potential for forecasting seedling damage

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A Method for Trapping *Hylobius abietis* (L.) with a Standardized Bait and Its Potential for Forecasting Seedling Damage

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A method for trapping walking *Hylobius abietis* (L.) (Coleoptera: Curculionidae) was developed and evaluated. Synergism between α-pinene and ethanol in attracting *H. abietis* was confirmed. The effects of varying release rates of these substances and of adding other host terpenes were studied. A simple bait was developed containing α-pinene and ethanol released from separate vials. The correlation between trap catch and seedling damage was estimated during May, June, and August on 1-, 2-, and 3-year-old clear-cuttings. In May and June, population levels were relatively high on all clear-cuttings and no significant correlations were found. The August experiment showed a strong positive correlation between catch and damage. The percentage damaged seedlings per captured weevil was considerably higher in August than in May or June. Possibilities for developing a system for forecasting seedling damage using this trapping method are discussed. *Key words: Hylobius abietis, pine weevils, α-pinene, ethanol, pitfall trap, trapping method, forecast, seedling damage, reforestation, Sweden.*

INTRODUCTION

Damage to conifer seedlings by adult weevils of the genus *Hylobius* Germar is of considerable economic importance in reforestation areas in the Holarctic region. In Europe, *H. abietis* (L.) is the most destructive species (e.g. Eidmann, 1974) while *H. pales* (Herbst) and *H. congener* Dalla Torre, Schenkling & Marshall are important species in various parts of North America (Lynch, 1984; Welty & Houseweart, 1985).

Freshly cut billets or logs of coniferous trees have previously been used in attempts at trapping out these weevils (e.g. Peirson, 1921; Escherich, 1923). This trapping method has also been employed in various ways to estimate relative population sizes over time or at different locations, e.g. *H. abietis* (Butovitsch, 1931; Swaine, 1951; Långström, 1982), *H. pales* (Bullard & Fox, 1969; Taylor & Franklin, 1970; Fox & Hill, 1973), *H. congener* (Welty & Houseweart, 1985).

Trapping methods using natural host material are difficult to standardize for several reasons: (1) Individual trees of the same species can differ considerably in their monoterpene composition (Thorin & Nömmik, 1974; Yazdani & Nilsson, 1986), thereby affecting the attractiveness of billets (Löyttyniemi & Hiltunen, 1976). (2) Cut billets change continuously in their chemical composition; production of ethanol during decomposition should be of particular importance in the attraction of pine weevils (Tilles et al., 1986*b*). (3) As billets dry out their attractiveness is reduced (Långström, 1982). (4) Release rates of volatiles from billets are almost impossible to standardize and are difficult to measure. (5) When weevils have access to host material in the trap their feeding increases the release of host volatiles, thereby increasing the attractiveness of the trap (Tilles et al., 1986*a*). (6)

Billet traps have not usually been designed to effectively prevent weevils from leaving the trap; thus the number of weevils recorded is both a function of movements to and from the trap.

The first goal of this study was to avoid the drawbacks associated with the use of natural host material for estimating pine weevil population levels. We have previously found that walking *H. abietis* are attracted to several host terpenens and to ethanol in the laboratory (Nordlander et al., 1986) and that α-pinene and ethanol act synergistically in the field (Tilles et al., 1986*b*). Additional tests were therefore conducted with a bait consisting of these two relatively inexpensive substances. This bait was placed in a covered pitfall trap with entrance holes in its wall at ground level (modified after Tilles et al., 1986*a*).

The second goal of this study was to establish whether the number of weevils collected with this trapping method is positively correlated with conifer seedling damage. If a sufficient correlation exists, then it might be possible to further develop a trapping system for forecasting risks of seedling damage in reforestation areas. Such information would be useful to forest managers who must decide when to plant (year and time of year) and whether seedling protection measures are necessary.

MATERIALS AND METHODS

Traps

A pitfall trap designed to selectively catch pine weevils was developed and used in experiments during 1982 and 1983 (Tilles et al., 1986*a*, 1986*b*). This trap was constructed from 20-cm lengths of 11 cm diam., 2 mm thick, grey PVC plastic drainpipes. Both ends of the tube were covered with white polyethylene caps. Eight 1 cm diam. holes were drilled around the circumference of the trap, 3 cm below the top. In experiments presented in this study a layer of water covered the bottom of each trap to drown responding weevils.

In 1982 two tests regarding the application of this trap were performed at two clear-cuttings ca. 20 km E of Uppsala, Sweden. These clear-cuttings had been harvested during the preceding winter and Scots pine, *Pinus sylvestris* L., was the dominating tree species in the experimental areas. Pieces of pine stem were used as baits in the 1982 tests since an artificial bait had not yet been developed.

The first of these tests compared the catch of traps having their entrance holes just above the ground with that of traps placed with their holes ca. 2 cm below ground level. This comparison was made because it was thought that placing the traps with their holes below ground might increase selectivity of the traps. Three treatments were compared by using 15 sets of three traps, one of each treatment in a set. Two traps in each set were baited with one half of a split piece of young Scots pine stem (length 7 cm, ca. 4 cm diam.). One of these traps was placed with its holes above ground and the other with holes below ground. The third trap was left unbaited and placed with its holes above ground. The pieces of pine were cut immediately before loading the traps, and they were suspended in the trap centre with an iron wire attached to the lid. The three traps in a set were placed in random order 2 m from each other, forming the apices of an equilateral triangle. Trap sets were placed ca. 15 m apart along a line across the clear-cutting. The test lasted 6 weeks (5 July–16 August). Every 7th day the traps were emptied and the water and pine baits were renewed.

The second test aimed to determine whether a visual cue resembling a small stump can increase catches of weevils in traps releasing host odours. All traps were baited with pieces of pine, similar to those used in the previous experiment, and placed with their holes above ground. A 20 cm high and 11 cm wide grey PVC tube with a white lid was placed directly over 50% of the traps. Eight traps representing each of the two treatments

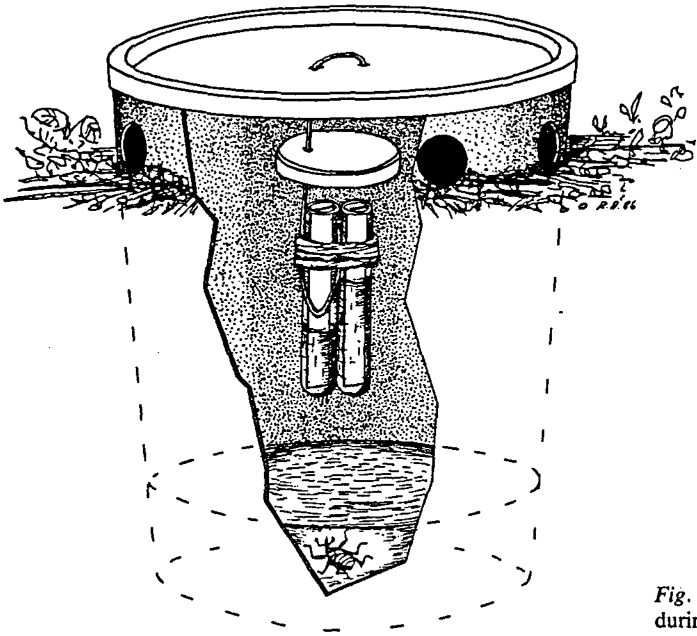

Fig. 1. Trap with dispenser used during 1984 and 1985.

were placed in blocks with 2 m spacing between traps. Five such blocks, separated by at least 30 m, were placed in a row on the clear-cutting. The test was run for 4 weeks (24 June–22 July) and traps were serviced weekly as described above.

A smaller, more convenient trap was used to test synthetic baits during 1984 and 1985 and to study plant damage in relation to trap catch in 1985 (described below). This trap was made from a transparent polypropylene jar with a white polyethylene cap (height 121 mm, upper diam. 116 mm, lower diam. 95 mm). Eight 1 cm diam. holes were equally spaced around the circumference of the jar, 2 cm below its rim. Traps were always placed with their holes just above ground level and were filled with 0.15 l of water (Fig.1).

Baits

The development of a simple synthetic attractant for *H. abietis* initiated in 1983 by Tilles et al. (1986*b*) was continued in 1984 and 1985. Primarily, combinations of α-pinene and ethanol were tested. However, in one test pine was also included (split stem section: length 7 cm, 4 cm diam.) to determine the effects of additional host volatiles.

In the 1984 tests four treatments were compared in each test. Sets of four traps were arranged in squares with 2 m sides and with the four treatments randomly assigned to the traps in each set. Fifteen sets of traps were placed ca. 25 m apart in a row on the clear-cutting. Two fresh clear-cuttings, situated 20 km N of Uppsala, were used for these tests, which were performed during the period 20 June–13 July.

In 1985 traps baited with either α-pinene alone or with α-pinene and ethanol were compared both before and after swarming (24–29 May and 27 June–2 July). The test in May was made on a 2-year-old clear-cutting with newly emerged weevils present while the second test was made at a fresh clear-cutting on which migrating weevils had settled. Fifteen sets of two traps, one of each treatment spaced 1 m apart, were placed in a row across the clear-cuttings with ca. 20 m between sets. The experimental areas were located ca. 20 km NE of Uppsala.

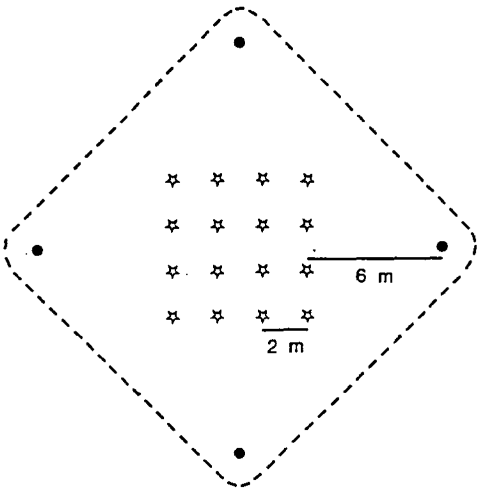

Fig. 2. Arrangement of seedlings (*) and traps (●) at the study sites. Slash removed from the area enclosed by the broken line.

In these tests as well as in the experiment described below the dispensers consisted of test tubes (depth 54 mm, inner diam. 8.5 mm) supplied with a strip of filter paper (50×8 mm, Munktell no. 3) reaching to about 1 mm from the opening of the tube (and 3 mm from the rounded bottom of the tube). These dispensers were filled with either 1 ml of (1S)-(−)-α-pinene (97% purity according to GC-analysis; supplied by Fluka AG, CH-9470 Buchs) or 2 ml of 70% ethanol. The amounts released were varied by adding more dispensers. About half the amount of α-pinene and ethanol in the tubes was released during a 5-day period in the field. The dispensers were held together with a rubber band and suspended by an iron wire; their openings were about 2 cm below the centre of the trap lid. A small polyethylene cap (37 mm diam.) was thread onto the wire 1 cm above the dispensers to protect them from the condensation that can form inside the lid of the traps (Fig. 1).

Catch–damage correlation

The relationship between trap catch and seedling damage was investigated in 1985. Nine clear-cuttings were chosen for this experiment in a forested area about 25 km NNE of Uppsala. The longest distance between outermost clear-cuttings was 12 km and the shortest distance between clear-cuttings was 0.5 km. Clear-cuttings 1–3 had been harvested during spring 1982, 4–6 during spring 1983, and 7–9 during spring 1984. Thus the clear-cuttings were 3-, 2-, and 1-year-old counted from the year that they were first accessible for oviposition by *H. abietis*.

Four study sites were chosen on each one of the nine clear-cuttings. These sites were situated at least 50 m from each other (usually >100 m) and at least 50 m from the edge of the clear-cutting (25 m at clear-cutting 8). At each site 16 containerized Scots pine seedlings were planted in a 4×4 pattern with a 2 m spacing. Four traps baited with α-pinene (1 ml) and ethanol (2 ml) (see Traps and Baits above) were also placed at each site. The arrangement is shown in Fig. 2.

All sites with plants and traps were located on comparatively flat areas without any large blocks of stone. Slash which could affect walking directions of weevils was removed from the area between and immediately around the traps (Fig. 2). Furrows created during soil scarification on clear-cuttings 1–3 were also refilled in the area between the traps. These three clear-cuttings were planted by the forest owner in spring 1985, however, the study sites were left unplanted. Clear-cuttings 4–9 were not scarified or planted.

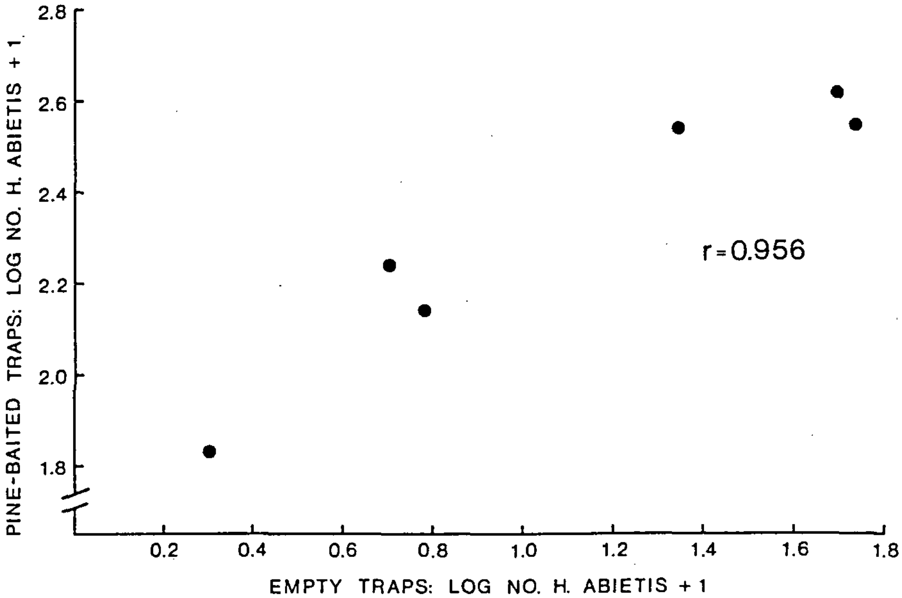

Fig. 3. Correlation between trap catches in pine-baited and empty pitfall traps. Dots represent one week's total catch in 15 traps for each treatment; traps with holes above ground level. Data from this experiment further treated in Table 1.

The experiment was conducted during each of three periods: before the flight period in May, after the flight period in June, and towards the end of the oviposition period in August, by which time a new generation of weevils had begun emerging. Seedlings were planted at the beginning of each period (9 May, 13 June, and 15 August) and were planted at the same sites on each occasion. The seedlings were cold-stored until a few days before planting in May and June. Those planted in August were from the same lot but were kept in a greenhouse from June until planting. Seedling damage was recorded 11 and 21 days after planting during each period. Traps were set out one day after planting and reloaded with attractant and water after 5 days. Trap catch was recorded for two 5-day periods: days 2–7, and 7–11.

Statistics

The efficiency of traps with holes above ground compared with that of traps with holes below ground and the comparisons of various baits were tested statistically using two nonparametric methods based on ranks. Friedman's test followed by a multiple comparison (Zar, 1984: 230) was employed when more than two treatments were included, and a two-tailed Wilcoxon paired-sample test was used when only two treatments were compared. The effect of a visual cue above the traps was tested with a two-tailed paired t-test using the summed catch of the eight traps representing the same treatment in each block.

Correlation coefficients (r) were calculated on square root transformed trap catch data and arcsine transformed percentage data on seedling damage. Since these r values were very similar to r values calcultated on untransformed data, only the latter are presented in Fig. 4.

The level of association between trap catch and site over time was analyzed using a nonparametric rank test. The trap catches at the four sites on each clear-cutting were ranked (1–4) for each period, and the squared differences in ranks between the two periods were summed (Spearman's statistic D, see Lehmann (1975)). Since the trap catches are numbers, and thus observations of a discrete random variable, there is a risk for tied values. To overcome this problem, the ranks were assigned at random within each tie. As four sites are too small a sample, the values of D were summed for the nine clear-cuttings, and the sum S was used as the statistic for testing the hypothesis of no association. The cumulative distribution function of S for $n=9$ was calculated by repeated use of the convolution formula (see Feller 1968: 266).

RESULTS

Traps

Traps with their holes resting at ground level caught about twice as many weevils as traps with holes below ground, and this difference was significant for both males and females (Table 1). The catch in empty traps with holes above ground was about 10% of the catch in corresponding pine-baited traps. The catches of both males and females in empty traps differed significantly from the catches in pine-baited traps with holes either above or below ground. There was a slight but significant difference in the response of the sexes to the three treatments (3×2 contingency table, df=2, $\chi^2=6.904$, $p<0.05$). However, the sex ratio also varied somewhat over time in all treatments, and the differences in sex ratio were not consistent; during 2 of 6 weeks the female/male ratio was higher in traps with holes below ground than in those with holes above ground.

The weekly catches during this 6-week experiment varied due to weather conditions and time of the season (Table 1). However, the trap catches in pine-baited and empty traps were well correlated ($p<0.001$) (Fig. 3).

Traps with holes both below and above ground caught pine weevils selectively considering the variety of animals that could be expected to fall into an ordinary pitfall trap (open jar). *Formica* spp. (Formicidae) were the only other animals that were occasionally abundant in the traps with holes above ground. The traps with holes below ground often contained large amounts of soil, making the counting of weevils more difficult.

A visual cue, in the form of a stump-like tube on top of the traps, did not increase trap catch. In total, traps with a "stump" caught 824 weevils (62% ♀) while traps without a "stump" caught 1003 weevils (59% ♀), but this difference was not significant (two-tailed paired t-test, df=4, $t=1.575$). There was no significant difference between the sexes in their response to these two kinds of traps (2×2 contingency table, $\chi^2_c=1.672$).

Table 1. *Comparative trapping efficiency of traps with entrance holes above and just below the ground surface*

15 sets of three traps, one of each treatment in every set. Fresh clear-cutting, near Uppsala, 1982

	No. *H. abietis*[a]								
Bait, trap position	5–12.7	12–19.7	19–26.7	26.7–2.8	2–9.8	9–16.8	♂ total	♀ total	% ♀
Pine, holes below ground	103	204	174	83	85	33	319 a	363 a	53
Pine, holes above ground	351	412	342	138	173	67	617 b	866 b	58
Empty, holes above ground	53	48	21	5	4	1	65 c	67 c	51

[a] Column figures for total catches of each sex followed by the same letter are not significantly different at the 5% level (Friedman's test ($p<0.001$) followed by a multiple comparison).

Table 2. *Catch of H. abietis in baited pitfall traps*

Four treatments compared in each of three tests. Each test comprises the summed catch of two consecutive trapping periods.[a] 15 sets of four traps. Fresh clear-cutting near Uppsala, 1984

		No. *H. abietis*[b]			
Test	Baits	Period 1	Period 2	Total	% ♀
I	α-Pinene 1 ml	34	20	54 a	57
	Ethanol 2 ml	16	17	33 a	45
	α-Pinene 1 ml + ethanol 2 ml	183	144	327 b	53
	Empty trap	6	7	13 a	61
II	Pine	51	74	125 a	58
	Pine + ethanol 2 ml	82	152	234 ab	55
	α-Pinene 1 ml + ethanol 2 ml	113	204	317 bc	54
	Pine + α-pinene 1 ml + ethanol 2 ml	170	309	479 c	58
III	1 × α-pinene 1 ml + 1 × ethanol 2 ml	222	201	423 a	57
	2 × α-pinene 1 ml + 1 × ethanol 2 ml	170	160	330 a	53
	1 × α-pinene 1 ml + 2 × ethanol 2 ml	137	137	274 a	61
	2 × α-pinene 1 ml + 2 × ethanol 2 ml	178	138	316 a	55

[a] Test I: 20–27.6, 27.6–3.7. Test II: 27.6–3.7, 3–9.7. Test III: 3–9.7, 9–13.7.
[b] Column figures followed by the same letter are not significantly different at the 5% level (Friedman's test ($p<0.001$ in Tests I and II) followed by a multiple comparison).

Baits

The combination of α-pinene and ethanol caught about six times more weevils than α-pinene alone, ten times more than ethanol alone, and 25 times more than empty traps (Table 2). These differences were significant but the α-pinene, ethanol, and control treatments did not differ significantly from each other. There were no significant differences between the sexes in their response to the treatments in this test or in the two other tests presented in Table 2 (4×2 contingency tables, df=3, χ^2=1.536, 1.230, and 3.942).

Combinations of α-pinene and ethanol were also compared with α-pinene alone on other

Table 3. *Catch of H. abietis in pitfall traps baited with α-pinene and ethanol in relation to traps baited with α-pinene alone*

Year	Test period	Age of clear-cutting	Ratio: catch with α-pinene + ethanol/ α-pinene	No. *H. abietis* with α-pinene + ethanol
1983[a]	20–22.7	Fresh	3.5	67
1983[a]	29–31.7	Fresh	8.0	40
1984[b]	20–27.6	Fresh	5.4	183
1984[b]	27.6–3.7	Fresh	7.2	144
1985[c]	24–29.5	2-year	4.6	785
1985[d]	27.6–2.7	Fresh	6.0	180

[a] Data from Tilles et al. (1986*b*). α-Pinene 20 μl, ethanol 0.5 ml. 10 sets of traps.
[b] Data from Table 2. α-Pinene 1 ml, ethanol 2 ml. 15 sets of traps.
[c] Unpublished data. α-Pinene 1 ml, ethanol 2 ml. 13 sets of traps. Treatments significantly different (Wilcoxon paired-sample test, $p<0.001$).
[d] As above but 15 sets of traps.

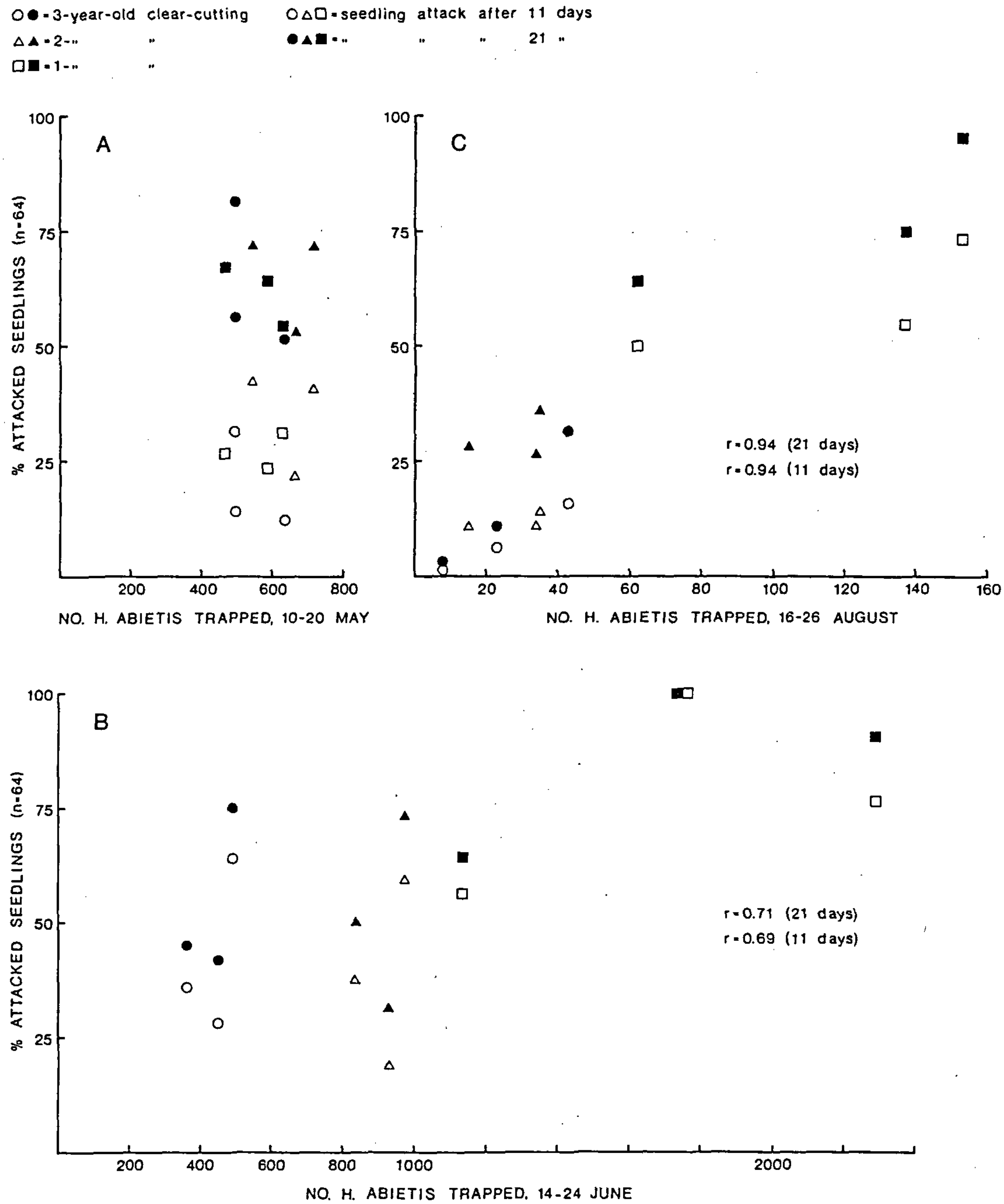

Fig. 4. Correlation between trap catch and seedling damage on nine clear-cuttings during the sampling periods in (A) May, (B) June, and (C) August.

occasions. Traps baited with α-pinene-plus-ethanol consistently caught four to eight times as many weevils as the α-pinene-baited traps (Table 3).

In the combinations of pine, α-pinene, and ethanol, each of these components appeared to add to the attractiveness, although the pine-plus-ethanol treatment was not significantly different from pine alone, and pine-plus-α-pinene-plus-ethanol was not significantly different from α-pinene-plus-ethanol (Table 2). However, pine-plus-α-pinene-plus-ethanol differed significantly from both pine-plus-ethanol and pine alone.

A two-fold increase in either α-pinene or ethanol or both did not increase trap catches (Table 2). Although the total catch varied between treatments the ranked data showed no clear tendencies of preference; i.e. there were no significant differences between treatments.

Catch—damage correlation

During the test period in May, weevil catch and seedling damage were at roughly similar levels on all nine clear-cuttings; thus no correlation between these measures was discernible (Fig. 4 A).

In June there was a pronounced difference in catch between clear-cuttings of different age; catch increased with decreasing age (Fig. 4 B). The correlation between catch and damage was not significant but the two clear-cuttings with the highest catches also showed the highest levels of seedling damage.

Considerably fewer weevils were caught in August than during the two previous periods (Fig. 4 C). The catch on 1-year-old clear-cuttings was distinctly higher than on 2- and 3-year-old clear-cuttings. The correlation between catch and damage was highly significant for this period ($p<0.001$). The damage/catch ratio was much higher during August than during May and June.

Seedling damage was recorded after 11 and 21 days; during the second of these periods no trapping was conducted. Although the overall percentage of damaged seedlings increased from day 11 to day 21 the relative amount of damage between clear-cuttings remained about the same (Fig. 4).

There was a good correlation between the trap catches at each site during the two consecutive 5-day sampling periods, which is best illustrated for the June experiment (Fig. 5). A strong positive association between catches during the consecutive sampling periods was also evident in an analysis of the ranked catch data of the four sites on each clear-cutting (Table 4). Moreover, the ranked total catches for May and June and for June and August were positively associated while the data for May and August did not show any significant association. Thus the ranks of the trap catches at the four sites on each clear-cutting were usually similar between adjacent trapping periods but approached independence with increasing time between sampling periods.

Table 4. *Association between the ranked trap catches for various trapping periods*

Expected value of S is 90 (n=9) when there is no relationship between periods. S<90 indicates a positive association

Compared trapping periods	S	Level of significance[a]
May: period 1–period 2	42	**
June: period 1–period 2	30	***
August: period 1–period 2	20	***
May–June	50	*
June–August	52	*
May–August	70	NS

[a] * $p<0.05$, ** $p<0.01$, *** $p<0.001$, NS = no significance.

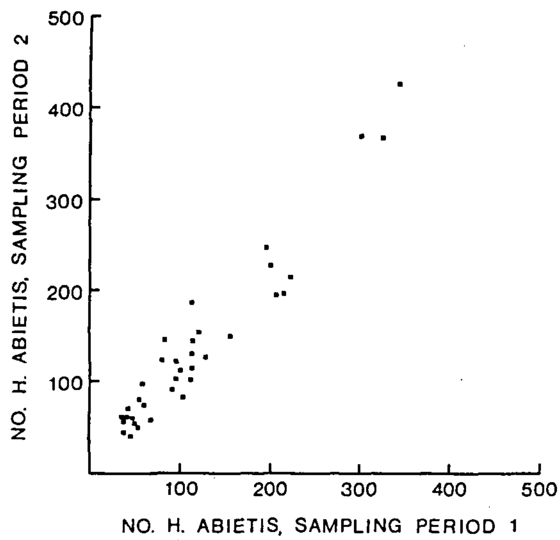

Fig. 5. Correlation between trap catches at each site during the first and second 5-day sampling period in June (n=36).

DISCUSSION

This study confirmed that a combination of α-pinene and ethanol is an effective synthetic attractant for *H. abietis*. Used in combination with a trap designed for capturing walking pine weevils, this attractant proved useful for monitoring relative population levels. A strong correlation was also found between trap catch and seedling damage in one experiment, implying that the trapping method is potentially suitable for use in forecasting pine weevil damage on conifer seedlings.

Traps

Covered pitfall traps of the kinds used in this study should be placed with their entrance holes just above ground level. Placement of the holes below ground decreased trap catch and did not considerably improve trap selectivity. Trapping efficiency was not enhanced by supplying traps with a tube resembling a small stump. Since *H. abietis* is able to locate host material hidden underground (Nordlander et al., 1986), visual orientation is probably not important for walking weevils at this stage of the host selection process.

The trap used in this study is suitable for experimental trapping of pine weevils. However, for practical use a trap without water, standing on the ground surface would be more convenient to set out. It may not be necessary to use water or other killing agents since captured weevils do not apparently affect the attractivity of the baited trap (Nordlander et al., 1986; Tilles et al., 1986*a*).

Baits

Synergism between α-pinene and ethanol as attractants for walking *H. abietis* was first demonstrated by Tilles et al. (1986*b*). This synergistic effect was corroborated by the present study. In addition, it was found that weevils show similar responses to the combination of α-pinene and ethanol before and after the flight period. Synergism between terpenes and ethanol in attracting flying weevils of the related species *Hylobius pales* and *Pachylobius picivorus* (Germar) was reported by Fatzinger (1985). However, the capture data for these two species were not presented separately; therefore it remains to be shown whether synergistic attraction occurs in each of these species.

Synergistic attraction to terpenes and ethanol appears to be common among species of scolytid and cerambycid beetles breeding in recently killed or dying trees (e.g. Bauer & Vité, 1975; Fatzinger, 1985; Ikeda et al., 1980; Kohnle, 1985). Species searching primarily for weakened, living trees may only be responsive to small amounts of ethanol released along with host terpenes (Klimetzek et al., 1986). Ethanol can be produced by fermentation processes in the phloem (Cade et al., 1970; Moeck, 1970) but also in living trees under various kinds of stress, not necessarily related to restricted oxygen availability (Kimmerer & Kozlowski, 1982).

H. abietis was strongly attracted to the high concentrations of α-pinene and ethanol in this study. A two-fold change in the release rate of these two substances did not significantly affect the trap catch at these high levels of release. Since *H. abietis* feeds on fresh conifer phloem containing high amounts of α-pinene it is not suprising that this species tolerates and is attracted to high concentrations of this monoterpene. The ethanol concentration in the traps, however, was probably far higher than that released by their host material (cf. Ikeda et al., 1980; Tilles et al., 1986*a*). This suggests that weevils do not avoid potential host material of high ethanol content nor do they discriminate against even higher ethanol concentrations which they normally do not encounter in nature.

For trapping, high release rates are advantageous: the risk for release rates decreasing below the detection threshold at low temperatures is diminished and the area around the trap within which weevils can discover the odour source should be increased. Thomas & Hertel (1979) concluded that the maximum range at which *H. pales* can detect and respond to a strong odour source is about 6 m. A directed response towards the odour source at distances exceeding a few decimeters is unlikely (Kennedy, 1977) but various kinetic reactions may lead to the arrestment of a walking insect at somewhat larger distances. Both klinokinetic and orthokinetic reactions to humidity stimuli occur in *H. abietis* (Havukkala, 1980).

In a laboratory bioassay Nordlander et al. (1986) found that several fractions of a pine condensate were attractive; among these was one containing 98% α-pinene. However, none of the fractions was as attractive as the complete condensate (which did not contain traceable amounts of ethanol), suggesting that a terpene mixture together with ethanol might be more attractive than only α-pinene and ethanol. The present study showed, however, that there was no dramatic effect of additional terpenes released by a fresh pine stem on trap catch. Moreover, additional terpenes would add cost to the bait and require a more complicated dispenser since the relative release rates among the substances should be kept constant. Therefore I have refrained from further attempts to optimize the attractivity of the bait by adding other terpenes.

Catch–damage correlation

A main objective of this study was to determine whether the trapping method is potentially useful in predicting risks for seedling damage. There was a strong correlation between trap catch and seedling damage in the August experiment. However, no significant correlations were found during May or June; at least for the May experiment, this could be due to insufficient variation in weevil populations between clear-cuttings.

The overall high population levels in May and June were somewhat unexpected. To maximize variation among the sampled areas, they had been chosen so as to represent clear-cuttings that were 1, 2, and 3-years old (the time between harvest and the following vegetation period not included). In the Uppsala area most of the pine weevils emerge in spring (April–May) 2 years after the eggs from which they developed were laid. Part of this generation, however, emerges after only one year in late summer (August–September) and hibernates in the ground after a period of feeding (Bejer-Petersen et al., 1962). These weevils leave their hibernation sites the following spring at about the same time as the majority of this generation is emerging from their pupal chambers. After a period of feeding, all the weevils of the new generation are ready to migrate to fresh clear-cuttings (May–June). According to this pattern of development there should not be any weevils emerging the third year. However, part of the population may undergo a year's delay in response to unfavourable microclimatic conditions (Bakke & Lekander, 1965; Bejer-Petersen, 1975) or when breeding material cut during late summer is utilized (Butovitsch & Heqvist, 1961; Lekander et al., 1985). In addition, *H. abietis* found in spring of the third year may represent the offspring of weevils that had hibernated on the clear-cutting and had again oviposited in the stumps the year after they had invaded the clear-cutting. That many weevils do indeed hibernate is reflected by the large populations recorded in this study in May and June on 1-year-old clear-cuttings. These populations should, at least before the flight period, consist entirely of hibernated weevils that arrived at the clear-cutting the previous year. Långström (1982) also reported that a large proportion of *H. abietis* in Finland hibernates after their first breeding season.

Much more plant damage per captured weevil was recorded in August than during May and June; i.e., weevils either fed more per individual on the seedlings in August or they were less attracted to the baited traps at this time. To compare feeding behaviour during various periods one has to consider both the amount and types of food they eat. For instance, during the breeding period, stump roots may constitute an important food source. The attractivity of the bait could be tested by comparisons with unbaited traps. However, the willingness to enter holes may also vary somewhat between periods. In a laboratory experiment, weevils walking on a smooth sand surface actively investigated holes they encountered (Nordlander et al., 1986).

Although the degree of damage to each seedling was recorded in the field, it was found that the percentage damaged seedlings was a more simple and appropriate parameter to use for this study. Daily inspections of the seedlings at certain sites showed that once a seedling had been found and wounded by a weevil it was nearly always heavily attacked within a day or two. The amount of subsequent damage due only to the initially attacking weevil was not investigated but two or more weevils were frequently observed on attacked seedlings. Hertel (1970) and Thomas & Hertel (1979) found that *H. pales* is not able to detect the presence of uninjured plants at a distance of about 20 cm (the figure calculated from their description of the experiment). The pattern of attack that I observed appears to confirm that uninjured seedlings are found by random movements; however, as soon as a seedling is damaged, volatiles emanating from the wound probably attract weevils (cf. Tilles et al., 1986*a*).

The rankings of sites on the same clear-cutting according to trap catch were similar during consecutive sampling periods. This consistency is important because if the trapping method is to be useful for monitoring or forecasting purposes, the relative size of catches between sites should not vary from week to week within the main periods. Also there were positive associations between May and June and between June and August catches. This was not true for May and August, probably because of the great change in the vegetation that occurs between these periods and because the origins of the sampled populations are largely different. Thus early May trapping appears useful for predicting relative pine weevil abundance in May and June but not in August the same year. However, trapping during summer on fresh clear-cuttings might be useful in predicting the size of the next generation appearing partly in August the following year and in spring the second year.

The pine weevil abundance on fresh clear-cuttings may vary between years and between clear-cuttings in an area due to weather conditions during the potential migration period. Migration is largely hindered by wind speeds above 4 m/s and temperatures below 18–19°C (Solbreck & Gyldberg, 1979). In certain years only a few days during late May and June are suitable for sustained flight. Despite the good dispersal capacity of *H. abietis* (Solbreck, 1980), not all weevils may successfully migrate such years, and the distribution of arriving weevils at available clear-cuttings will depend on their location relative to wind direction during the days of migration and relative to sources of migrating weevils.

Forecasting

In the previous sections I have pointed out some of the possibilities and restrictions of the trapping method when used for monitoring or forecasting purposes. The need for a standardized trapping method for monitoring populations of various *Hylobius* species has previously been stressed, e.g. by Thomas & Hertel (1979) and Welty & Houseweart (1985). Långström (1980, 1985) presented data from Finland showing that certain sites and regions were more heavily attacked by *H. abietis*. However, he also emphasized the great need of a more accurate method for predicting pine weevil damage (Långström, 1980).

Szmidt & Korczyński (1981, 1983) developed a forecasting method based on the amount of feeding observed on pine billets set out on clear-cuttings. Aside from the drawbacks of using natural host material pointed out in the introduction, this method also seems to be very timeconsuming and therefore probably too costly for use in Scandinavia. However, if the method can be simplified and better standardized it might be useful since seedling damage can be expected to be well correlated with the amount of feeding on billets. A similar method has also been proposed as an early warning system for damage caused by the carrot weevil (Stevenson, 1985). Lynch & Hedden (1984) found a close relationship between early- and late-season seedling mortality caused by *H. pales* and *P. picivorus*, and they also established a damage threshold above which chemical control is recommended. This method is of less applicability to northern European conditions where the most important damage by *H. abietis* usually occurs soon after planting. Thus control decisions generally must be made prior to planting.

Additional large-scale studies are needed to determine whether pine weevil damage on planted seedlings can be predicted with sufficient accuracy to make the trapping method useful in practical forestry. The relationship between catch and damage must be established for the important periods (May and August) and also for clear-cuttings and seedlings of different types. The catch–damage relationship on fresh clear-cuttings may differ from that on older ones because of the large amounts of available host material on the former. On fresh clear-cuttings it may be worthwhile to catch weevils in the middle of the summer to roughly predict damage risks during the following years (see above). To establish thresholds it will probably be necessary to modify the catch figures using a correction factor related to the temperature during the sampling period. However, the trapping method should still be useful even if thresholds in terms of absolute numbers of captured weevils cannot be established.

A relative estimation of damage risks can also be valuable. For example, if a forest owner traps weevils for one week in early spring on all clear-cuttings considered for planting within a region subjected to similar weather conditions, he should have a better basis for deciding which clear-cuttings to plant that spring and where to postpone planting. Similar decisions regarding planting in autumn should be aided by catching weevils in August. In this way, the time of planting could be better adapted to the local conditions on the clear-cuttings. Conceivably, many clear-cuttings could be planted earlier than during spring of the third year, which is commonly practiced in Sweden today, while the planting of others would be postponed until autumn of the third year. Forecasting should also help to evaluate the need for using seedlings protected with insecticides or with various mechanical devices (see Eidmann & Sydow, 1984; Lindström et al., 1986).

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