Taylor & Francis
Taylor & Francis Group

ORIGINAL ARTICLE

Within- and between-stand distribution of attacks by pine weevil [*Hylobius abietis* (L.)]

LARS WICHMANN HANSEN[1], HANS PETER RAVN[2] & JONAS GELDMANN[2]

[1]*Kaka Consult, Nexø, Denmark, and* [2]*Forest & Landscape, KVL, Hørsholm, Denmark*

Abstract
The pine weevil (*Hylobius abietis* L.) is considered one of the most damaging pests in reforestation areas in Scandinavia. The purpose of this study was to ascertain the within- and between-stand distribution of pine weevil attacks. Between-stand distribution was examined by assessing the frequency of attacks in all newly planted coniferous stands in relation to stands clear-cut at two state forest districts in North Zealand, Denmark. Within-stand distribution was examined by investigating the position and damage to individual seedlings in relation to the position of breeding material. The stand-level attack frequency did not seem to be higher for stands in areas with more clear-cuts. The within-stand distribution of attacks was not influenced by the position of breeding material.

Keywords: *Attack frequency, clear-cut intensity, Denmark, distance relations, spatial distribution.*

Introduction

The pine weevil (*Hylobius abietis* L.) is considered one of the most damaging pests in reforestation areas in Scandinavia (Bejer-Petersen et al., 1962; Bejer, 1982; von Sydow, 1997; Leather, Day, & Salisbury, 1999). Numerous studies have investigated the effects of planting under shelter, using different measures to protect seedlings physically and chemically, and applying different reforestation and soil preparation methods (Bejer-Petersen, 1975; von Sydow & Örlander, 1994; Eidmann, Nordenhem, & Weslien, 1996; von Sydow & Birgersson, 1997; Örlander & Nilsson, 1999; Hannerz, Thorsén, Mattson, & Weslien, 2002; Nordlander, Bylund, Örlander, & Wallertz, 2003*b*). The preferred method has, however, been chemical control, e.g. pyrethroids (Kudela, 1983, von Sydow & Birgersson, 1997; Watson, 1999). The interest in pine weevil has increased recently, because the chemical treatments are likely to be banned (Bichel-udvalget, 1998; Skogstyrelsen, 2003). Hence, there is a demand for development of silvicultural practices and measures that may aid in limiting the effects of pine weevil attacks, i.e. integrated pest management.

In brief, the adult beetles migrate in the late spring or early summer, and the females oviposit in or close to roots of dead or dying coniferous trees (Bejer-Petersen et al., 1962; Nordlander, Nordenhem, & Bylund, 1997; von Sydow, 1997; Salisbury, 1998), which clear-cuts provide in plenty. The larvae develop under the bark and emerge as adults after 1–3 years (Nordenhem, 1989; von Sydow, 1997). As the adults emerge they need to feed to develop their reproductive organs and flight muscles (Nordenhem, 1989; Örlander, Nordlander, Wallertz, & Nordenhem, 2000). Having developed their flight muscles the beetles migrate, and are able to travel significant distances, e.g. Solbreck (1980) found extreme travelling distances of up to 80 km. Newly planted seedlings on clear-cuts may provide the food the beetles need for both premigratory and postmigratory feeding, and are thus exposed to ringbarking or damage to the cambium around the root collar.

Most studies found less damage to seedlings when planted under shelter of an existing stand (e.g. Bejer-Petersen, 1975; Engberg, 1976; von Sydow & Örlander, 1994; Nordlander et al., 2003*b*; Petersson & Örlander, 2003). Studies of different site preparation methods found that intensive scarification also

---

decreases the severity of the attacks (von Sydow & Birgersson, 1997; Petersson & Örlander, 2003). Concerning microhabitat, it is well documented that the weevils respond to climatic variables, e.g. temperature (Bejer-Petersen, 1975; Kudela, 1983). Similarly, they respond to the availability of feeding material and cover, e.g. stump conditions, fallow period (von Sydow, 1995; Örlander & Nilsson, 1999) and the amount of slash (Wilson & Day, 1996; Örlander & Nilsson, 1999). What has not been addressed in detail earlier, except for Korczyski (1989), is a quantification of the spatial distribution of feeding damage in relation to distance to breeding material, i.e. stumps and slash.

Korczyski (1988) and Wilson and Day (1995) found a significant effect on trap catches in relation to trap position within stands. Likewise, Wilson and Day (1996) concluded that incoming migrating beetles are concentrated around the edges of newly planted stands. Örlander, Nordlander, and Wallertz (2001) remarked that incoming beetles arrive at, and feed in the surrounding stands of mature trees before losing their ability to fly, and they start feeding on seedlings instead. Logically, the probability of damage to seedlings decreases with distance from points of attraction, as also found by Korczyski (1989), e.g. the odour of food sources and breeding sites attract beetles and the concentration of beetles is likely to be higher in these areas. The first purpose of this study was to ascertain quantitative differences in feeding activity (damage to seedlings) in relation to distances to stumps, i.e. the spatial within-stand distribution. The following hypothesis was studied: seedlings closer to breeding material suffer a greater risk of attack by *H. abietis*.

According to Wilson and Day (1994, 1996), von Sydow (1997) and Örlander and Nilsson (1999), the size, structure and distribution of clear-cuts influence the risk of damage. Furthermore, Danish foresters have reported an increase in pine weevil problems after severe windthrows. Finally, Wilson and Day (1996) also found little damage in new plantations, indicating that isolated stands without readily available breeding material are much less susceptible to pine weevil damage. Logically, the larger the clear-cuts, the more breeding sites and the less other food sources available, thus, the more pronounced the feeding activity on planted seedlings. The size of clear-cuts in Denmark is small compared with the other Scandinavian countries, but larger areas or several connected stands in an area may be clear-felled, e.g. in the case of windthrow. Hence, the second purpose of this study was to ascertain the overall attack density on a stand level in relation to the abundance and area of nearby clear-cuts, i.e. the spatial between-stand distribution. The following hypothesis was studied: stands in areas with more and larger clear-cuts suffer a greater risk of attack by *H. abietis*.

Materials and methods

Materials

The data for the study of within-stand distribution of attacks were gathered by recording the position and damage to each individual seedling (a total of 1099 seedlings) in a newly planted stand. Similarly, the positions of stumps and slashpiles were recorded (a total of 427 stumps, and two elongated slashpiles stretching the entire length of the experiment). The experiment was located at Frederiksborg State Forest District, Department 830c (UTM 55.98° N, 12.29° E). The positions of seedlings, stumps and slash of the recent Norway spruce [*Picea abies* (L.) Karst] stand were measured using the Global Positioning System (GPS). The damage to each seedling was recorded by measuring the area of damaged cambium using a calliper for estimations of mean trunk diameter and a ruler for estimating the length of the trunk. The cambium area damaged was converted to percentage of total trunk area.

The data for the between-stand distribution study were collected at Kronborg (5769 ha) and Frederiksborg State Forest Districts (8889 ha), covering most of the forested areas in North Zealand, Denmark. All stands and management actions are recorded in the Geographical Information System (GIS)-based management system Proteus during normal forest management (Danish Forest and Nature Agency, 2004). Hence, the position and size of all stands that were clear-cut, and those replanted with conifers, in the period 1999–2002 were easily extracted from the existing record. A total of 99 clear-cut stands was recorded, of which 27 were replanted with conifers. The distances between clear-cut areas were calculated as the distance between their individual positions (centres), while the age of the clear-cut areas was not considered.

The attack density in each newly planted stand was estimated by two methods: the percentage of surviving trees with visible *H. abietis* damage, and the percentage of seedlings that had died from attack by *H. abietis*. According to Eidmann and Lindelöw (1997), the number of dead trees is proportional to the number of attacked trees. Both frequency estimates were attained by examining 100 seedlings in each stand, arranged in 10 batches of 10. The batches were selected to represent the entire stand by examining 10 different rows located across the stand. Within each row, 10 trees were sampled by selecting

the first tree in a haphazard manner and then examining the 10 following trees. The seedlings in the two methods were selected independently. In the damage frequency method the seedlings were scored binomially, being either damaged by *H. abietis* or not, disregarding missing or dead trees. In the mortality count each seedling was assessed to be living, dead from *H. abietis* or dead/missing for other reasons.

Within-stand distribution

The distance between each seedling and its nearest stump was calculated. Pairwise observations of seedling damage and distance to nearest stump were examined graphically (point plot) and by calculating their correlation. To analyse the overall effect of stump density (number), a stump index (*SI*) was defined as

$$SI_i = \sum_{j=1}^{n_j} \frac{1}{d_{ij}} \tag{1}$$

where d_{ij} was the distance from seedling i to stump j, and n_j is the total number of stumps in the stand. The correlation between seedling damage and stump index was calculated and the pairwise observations were plotted in a point plot.

The cumulated distributions of nearest stump distances were calculated for four damage classes based on the area of feeding scar (no feeding, 0–200 mm^2, 200–400 mm^2 and >400 mm^2). The distributions were plotted and tested for differences using a Kolmogorov–Smirnov test (de Groot, 1986).

To evaluate the spatial distribution of feeding activity (i.e. clustered, random or regular), Ripley's *K*-function was calculated along with the corresponding *L*-function (Ripley, 1976). This was done individually for the four damage classes as defined above (e.g. 0, 0–200, 200–400 and >400 mm^2). The 95% confidence limits for the *L*-functions under complete spatial randomness were estimated by a Monte Carlo sampling scheme (Cressie, 1993). That is, the measured scar areas were assigned to individual seedlings at random, this was iterated 100 times and the corresponding *L*-functions were estimated. To counter edge-effects the correction K_4 of Cressie (1993) was used, i.e.

$$K_4(h) \equiv \lambda^{-1} \sum_{i=1}^{N} \sum_{j=1, j \neq i}^{N} \frac{I(\|\mathbf{s}_i - \mathbf{s}_j\| \leq h)}{Nw(\mathbf{s}_i, \mathbf{s}_j)} \tag{2}$$

where N is the number of events, I is an indicator function ($I = 1$ if the condition is true, 0 otherwise), the weight ($w(\mathbf{s}_i, \mathbf{s}_j)$) is the proportion of the circumference of a circle centred at $\mathbf{s}_i$, passing through $\mathbf{s}_j$, that is inside the stand area, and λ is estimated as the stand average number of events per unit area ($\hat{\lambda} = \frac{N}{A}$). The *L*-function was defined as

$$L_4(h) = \sqrt{\frac{K_4(h)}{\pi}} \tag{3}$$

If the $L_4(h)$-function was less than the lower 95% confidence limit, the attacks were said to be regularly distributed, whereas if $L_4(h)$ was larger than the upper limit the attacks were cluster distributed (Cressie, 1993).

Between-stand distribution

Stand areas were calculated from the vertices making up the stand boundaries. The distances between stands were measured as the distance between their centres. The centre of a stand was calculated as the mean position of its boundary vertices.

Two measures of *H. abietis* intensity were examined: the percentage of surviving seedlings with visible *H. abietis* damage (HI_s), and the percentage of seedlings that died from *H. abietis* damage (HI_d).

Clear-cut intensity ($CC_{x,y}$) at a position (x, y), which was an indicator of the amount of clear-cuts in an area, was defined as:

$$CC_{x,y} = \sum_{i=1}^{n} w_i A_i \tag{4}$$

where n is the total number of stands, w_i is a weight and A_i is stand area, both for stand i. The weight (w_i) was calculated from stand position (x_i, y_i) as:

$$w_i = \min \left[1, \frac{c_1}{\sqrt{(x - x_i)^2 + (y - y_i)^2}} \right] \tag{5}$$

where c_1 is a constant. Hence, all stands within distance c_1 weight with their full area, while stands further away are weighted in reverse proportion to their distance from the point in question (i.e. (x, y)).

The choice of c_1 was investigated by calculating the correlation between *H. abietis* intensity and clear-cut intensity for different c_1-values. The 95% confidence level for each c_1-value was estimated by a Monte Carlo sampling scheme: (1) assigning random *H. abietis* intensity values to each stand, (2) calculating the correlation between *H. abietis* intensity and clear-cut intensity, (3) iterating the first two points 1000 times, and (4) estimating the 95% confidence limit as the 975th highest correlation (two-sided).
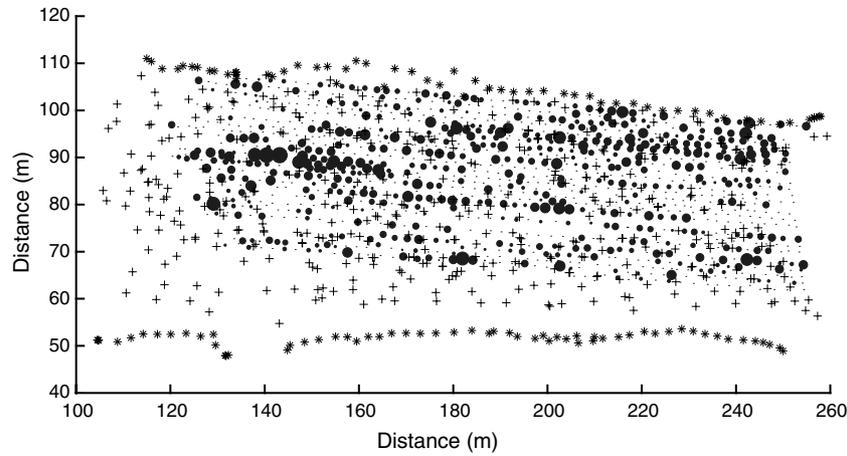
Figure 1. Map of the within-stand experiment. Dots denote seedlings and the size is proportional to area of feeding scar; $+$ = stumps; $\star$ = slash piles.

Results

Within-stand distribution

The position and damage to individual seedlings are shown in Figure 1.

There was no apparent relationship between distance to nearest stump and seedling damage (Figure 2). This was also evident from a relatively low correlation of 0.23. Furthermore, the cumulated distributions of nearest stump distance for the four damage classes were not significantly different.

From the L_4-functions for the four damage classes (along with 95% confidence limits) (Figure 3) it was evident that the seedlings with a scar area of 0–200 mm² were randomly distributed at all scales, while seedlings in the three other classes were clustered at scales larger than 2–3 m.

Between-stand distribution

The correlation between the two measures of *H. abietis* intensity was 0.80, indicating that both measures were equally good. Hence, only results using HI_s are reported.

The correlation between *H. abietis* intensity (HI_s) and clear-cut intensity (CC) as a function of c_1 is plotted in Figure 4. From this it is evident that the maximum correlation was attained for c_1-values from 2000 to 3000 m; however, the correlation was at maximum 0.27 and not significant (95% level).

Pairwise observations of *H. abietis* intensity and clear-cut intensity at the optimal c_1-value (3000 m) are plotted in Figure 5. From this it was evident that there were no correlations between the two. Pairwise observations of *H. abietis* intensity and stand area are plotted in Figure 6. From this it was evident that there were no correlations between the two.

Discussion

According to Zumr, Stary, and Dostálková (1994), the migratory behaviour of *H. abietis* depends on the availability of feeding material, and migration is
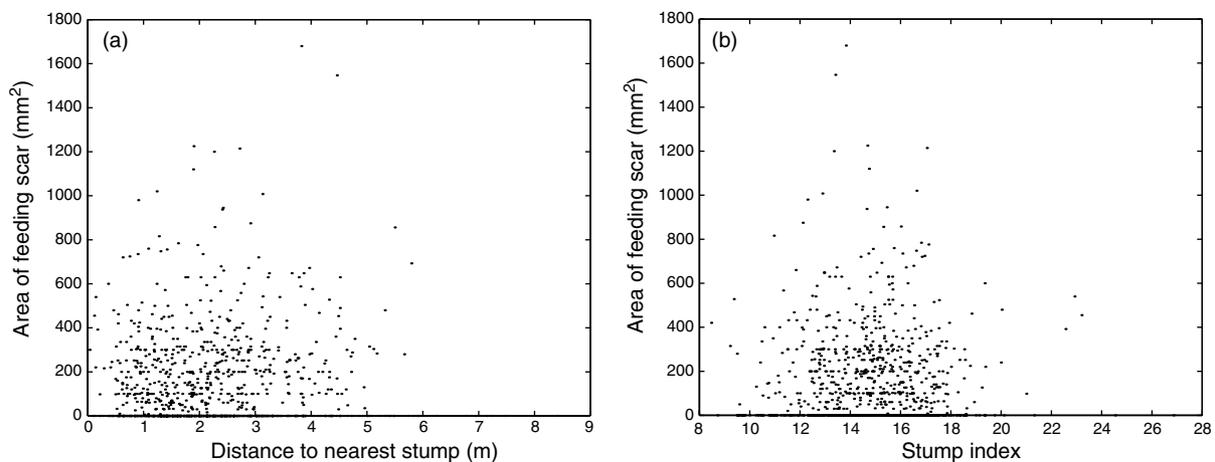

Figure 2. Pairwise observation of (a) distance to nearest stump and (b) stump index, and seedling damage (area of feeding scar).
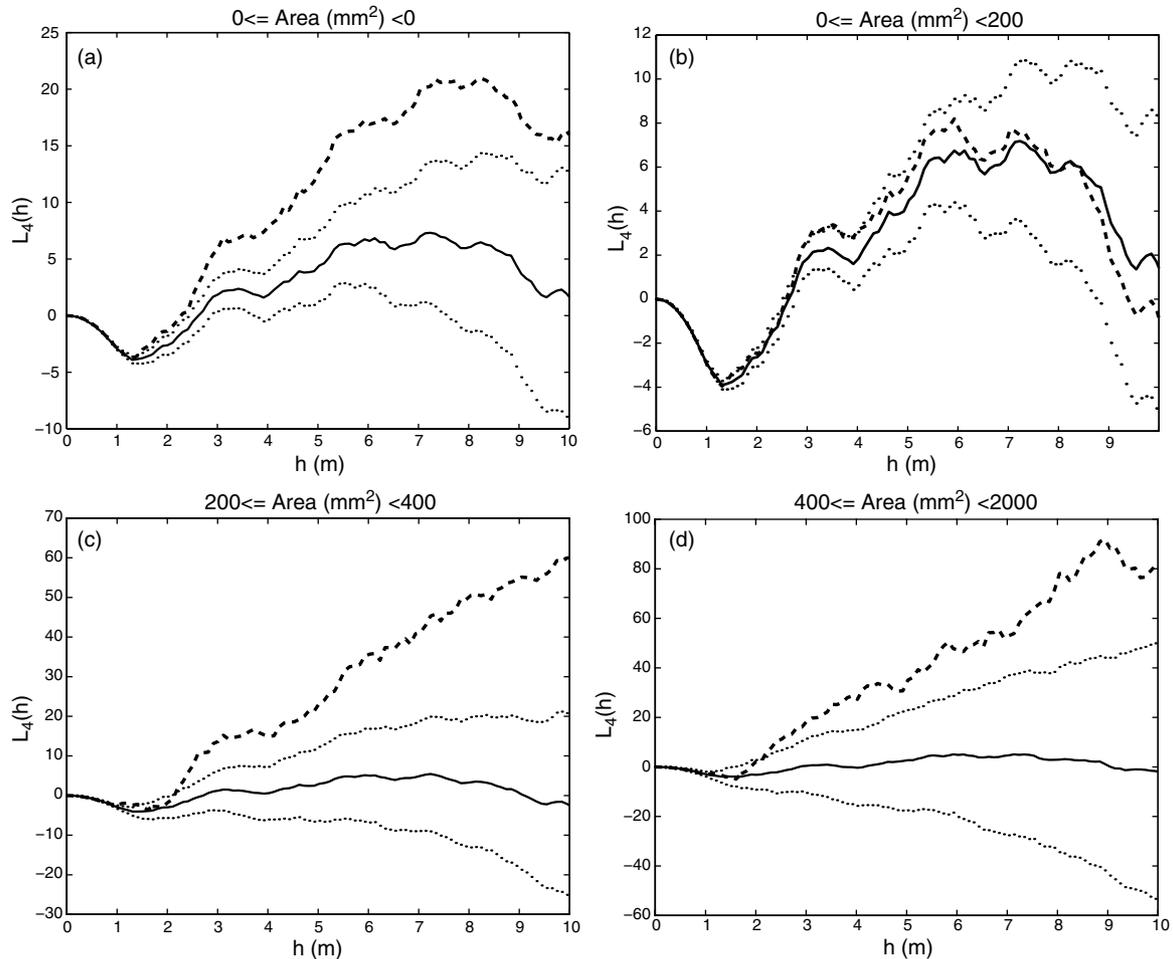
Figure 3. L_4-function for the four damage classes (bold dashed line) 95% confidence limits (dotted lines) and average function under complete spatial randomness (solid line). Note differences in scale on the ordinate. (a) Damage class 0; (b) damage class 0–200 mm^2; (c) damage class 200–400 mm^2; (d) damage class 400–2000 mm^2.

undertaken by both crawling and flying. They also found that the abundance of beetles seems to be rather independent of forest type and stand structure. In accordance with Solbreck (1980), they therefore concluded that pine weevil populations are spatially very fluid. The above conclusion was also supported by Eidmann and Lindelöw (1997), who found that the within-stand recapture rate was not correlated with dispersal distance. Similarly, Nordlander et al. (2003*b*) found no correlation between trap catches and damage to seedlings on a local scale, and concluded that weevils move around considerably. This conclusion is further documented by the results of this study, i.e. there seems to be no relationship between seedling damage and distance to potential points of attraction (food sources and breeding sites). Neither do there seem to be any correlations between the clear-cut area frequency and frequency of *H. abietis* attacks.

One possible reason for not detecting any significant correlation in this study may be that a low number of stands was harvested, and those that were

harvested were small compared with the beetles' ability to move around and locate their preferred food sources. For instance, Manlove, Styles, and Leather (1997) and Leather et al. (1999) found that the beetles have a significant preference in food, e.g. they prefer conifers, especially *Pinus sylvestris*, over other food sources, and seem able to locate these by semiochemical cues (e.g. Björklund, 2004). It may also be noted that stand sizes in Denmark are generally small compared with those in Sweden, for instance. In effect, the Danish clear-cuts do not qualify as clear-cuts in the Swedish sense and hence do not provide the same risks and conditions for attack.

A possible reason for the lack of within-stand effect may be that the beetles move around the stand seasonally, as found by Nordlander, Örlander, and Langvall (2003*a*). The overall feeding pressure is also influenced by incoming beetles migrating from other stands (Zumr et al., 1994). Furthermore, individuals from several generations may frequent the same stand. For instance, Nordenhem (1989)
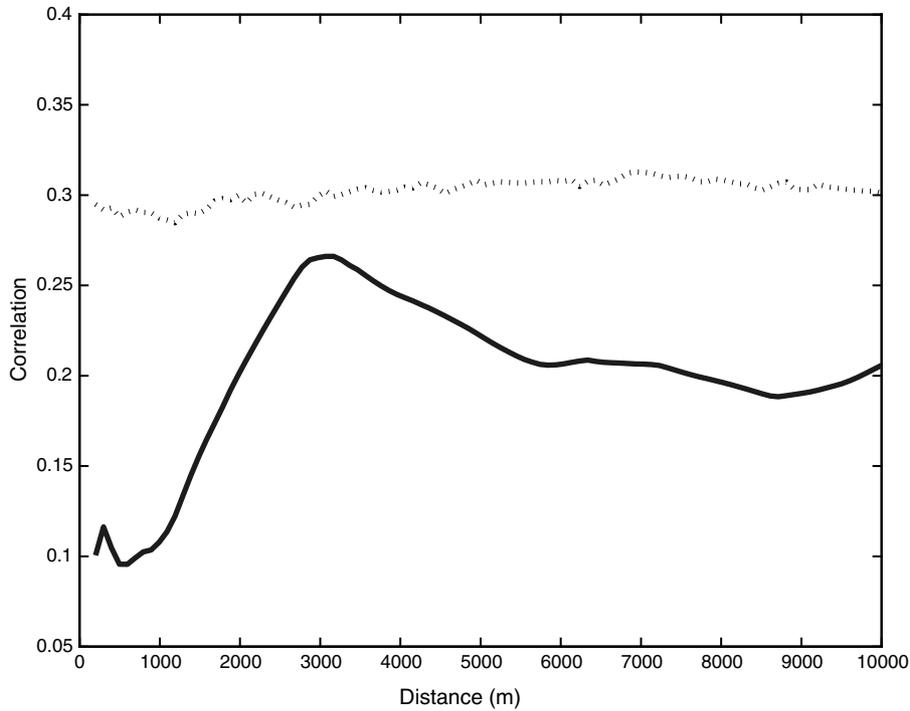
Figure 4. Correlation between *Hylobius abietis* intensity (HI_s) and clear-cut intensity (CC) as a function of c_1 (solid line), and the 95% confidence limit from Monte Carlo sampling (dotted line).

found that a large proportion of the population that arrived at the fresh clear-cut remained there throughout the following season, thus also causing damage to seedlings. Nordenhem (1989) also observed that a significant proportion of the beetles overwinter in the ground before migrating. Hence,

there is a large proportion of beetles that emerges not from the breeding material, but rather from the ground. This may, for instance, also explain the clustered tendency in the spatial distribution of within-stand feeding activity, in that some areas are more suitable for overwintering, and the beetles are
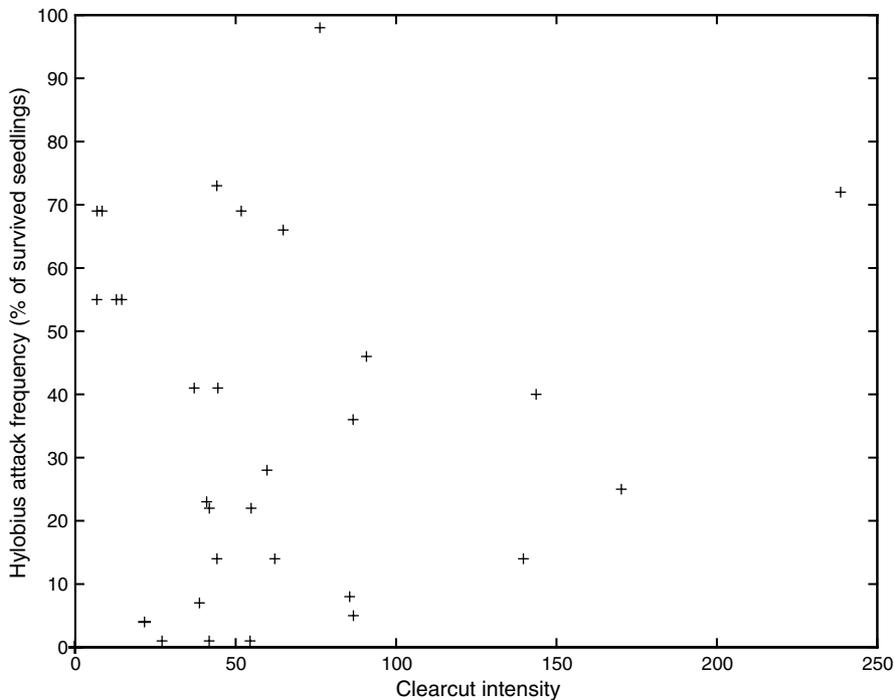

Figure 5. Pairwise observation of *Hylobius abietis* intensity (HI_s) and clear-cut intensity (CC).
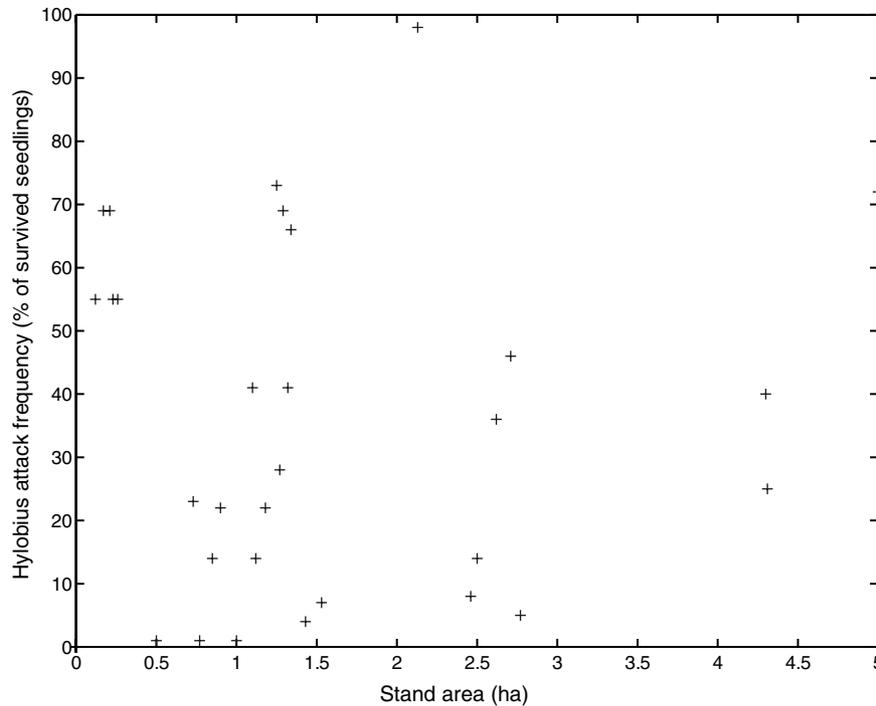
Figure 6. Pairwise observation of *Hylobius abietis* intensity (HI_s) and stand area.

thus present here in greater numbers. This tendency in within-stand distribution was also observed by Wilsson and Day (1994).

In the present study it was found that some stands were attacked much more than others, and there were no apparent physical or ecological differences between the stands (e.g. climate/location, aspect, size, species composition or species of surrounding stands). This was also observed by Örlander et al. (2000), who found that the beetles may feed on alternative sources, e.g. in the crown of nearby trees and on dwarf shrubs and herbs. Another example is that during fieldwork for another study a marked temporal variation in the spatial distribution was observed (J. Geldmann, personal observation), i.e. seedlings closer to the slash piles were visited first, but at the time of final damage assessment none of this was observable. A similar observation, but quantified, was noted by Korczyski (1988). Future studies may address this issue.

The maximum correlation in the between-stand study was achieved for distances from 2000 to 3000 m. This may be interpreted as the beetles most commonly dispersing 2–3 km. The correlation is, however, not significant and the conclusion is thus mere speculation. Logically, more and larger clear-cuts should lead to higher attack frequencies, because the more breeding sites available, the more beetles will hatch and need to feed. Combining several smaller clear-cuts does not seem to cause this effect. Apparently, the beetles disperse easily up to

3000 m, and thereby increase the risk of *H. abietis* attacks in larger areas, under Danish conditions.

In conclusion, the population of *H. abietis* seems to be spatially very fluid, and the within-stand variation in attack density could not be explained by the point-of-attraction hypothesis. However, there are indications that climatic or ecological factors cause a concentration of attacks in certain areas within stands.

Seen in a forest management context, the following conclusions may be drawn. First, avoiding areas close to stumps or slash when planting conifers has no effect and, secondly, it seems unlikely that spatial considerations, with respect to *H. abietis* in deciding which stands to clear-cut, should limit the frequency of attacks. However, clear-cuts still provide a concentration of breeding material for *H. abietis*, and should therefore be avoided if possible.

Acknowledgements

References

Bejer, B. (1982). The present level of Hylobius damage in Denmark. *Dansk Skovforenings Tidsskrift*, *3*, 249–256. (In Danish with English summary.)

Bejer-Petersen, B. (1975). Length of development and survival of *Hylobius abietis* as influenced by silvicuturual exposure to sunlight. *Den Kongelige Veterinær- og Landbohøjskolesårsskrift*, *1975*, 111–120.

Bejer-Petersen, B., Juutinen, P., Kangas, E., Bakke, A., Butovitsch, V., & Eidmann, H. H. (1962). Studies on *Hylobius abietis* L. 1. Development and life cycle in the Nordic countries. *Acta Entomologica Fenniae*, *17*, 1–106.

Bichel-udvalget (1998). Rapport fra hovedudvalget. Technical Report. *Skov og Naturstyrelsen*. (In Danish).

Björklund, N. (2004). Movement behaviour and resource tracking in the pine weevil *Hylobius abietis*. PhD Thesis. Silvestria 302. Department of Entomology, Swedish University of Agricultural Sciences, Uppsala.

Cressie, N. A. C. (1993). *Statistics for spatial data* (2nd ed.). New York: John Wiley & Sons.

Danish Forest and Nature Agency (2004). *Proteus—forest management and planning system*. Copenhagen: Danish Forest and Nature Agency.

Eidmann, H. H., & Lindelöw, Å. (1997). Estimates and measurements of pine weevil feeding on conifer seedlings: Their relationships and applications. *Canadian Journal of Forest Research*, *27*, 1068–1073.

Eidmann, H. H., Nordenhem, H., & Weslien, J. (1996). Physical protection of conifer seedlings against pine weevil feeding. *Scandinavian Journal of Forest Research*, *11*, 68–75.

Engberg, B. (1976). Snudebillen og dansk kulturteknik. *Skogen*, *63*, 54–56. (In Danish/Swedish.)

de Groot, M. H. (1986). *Probabilities and statistics*. Reading, MA: Addison-Wesley.

Hannerz, M., Thorsén, Å., Mattson, S., & Weslien, J. (2002). Pine weevil (*Hylobius abietis*) damage to cuttings and seedlings of Norway spruce. *Forest Ecology and Management*, *160*, 11–17.

Korczyski, I. (1988). Seasonal change in the spatial distribution of feeding by the pine weevil *Hylobius abietis* in Scots pine plantations. *Sylwan*, *132*, 40–53.

Korczyski, I. (1989). Effect of pine stumps on the distribution of damage by *Hylobius abietis*. *Sylwan*, *133*, 25–29. (In Polish with summary in Russian and English.)

Kudela, M. (1983). Influence of site temperature conditions on large pine weevil (*Hylobius abietis* L.) population density. *Sbornik stavu Aplikované Ekologie A Ekotechniky Vysokéskoly Zemedelské*, *1*, 129–148.

Leather, S. R., Day, K. R., & Salisbury, A. N. (1999). The biology and ecology of the large pine weevil, *Hylobius abietis* (Coleoptera: Curculionidae) a problem of dispersal? *Bulletin of Entomological Research*, *89*, 3–16.

Manlove, J. D., Styles, J., & Leather, S. R. (1997). Feeding of the adults of the large pine weevil, *Hylobius abietis* (Coleoptera: Curculionidae). *European Journal of Entomology*, *94*, 153–156.

Nordenhem, H. (1989). Age, sexual development, and seasonal occurrence of the pine weevil *Hylobius abietis* (L.). *Journal of Applied Entomology*, *108*, 260–270.

Nordlander, G., Nordenhem, H., & Bylund, H. (1997). Oviposition patterns of the pine weevil *Hylobius abietis*. *Entomologia Experimentalis et Applicata*, *85*, 1–9.

Nordlander, G., Örlander, G., & Langvall, O. (2003a). Feeding by the pine weevil *Hylobius abietis* in relation to sun exposure and distance to forest edge. *Agricultural and Forest Entomology*, *5*, 191–198.

Nordlander, G., Bylund, H., Örlander, G., & Wallertz, K. (2003b). Pine weevil population density and damage to coniferous seedlings in a regeneration area with and without shelterwood. *Scandinavian Journal of Forest Research*, *18*, 438–448.

Örlander, G., & Nilsson, U. (1999). Effect of reforestation methods on pine weevil (*Hylobius abietis*) damage and seedling survival. *Scandinavian Journal of Forest Research*, *14*, 341–354.

Örlander, G., Nordlander, G., Wallertz, K., & Nordenhem, H. (2000). Feeding in the crowns of Scots pine trees by the pine weevil *Hylobius abietis*. *Scandinavian Journal of Forest Research*, *15*, 194–201.

Örlander, G., Nordlander, G., & Wallertz, K. (2001). Extra food supply decreases damage by the pine weevil *Hylobius abietis*. *Scandinavian Journal of Forest Research*, *16*, 450–454.

Petersson, M., & Örlander, G. (2003). Effectiveness of combinations of shelterwood, scarification and feeding barriers to reduce pine weevil damage. *Canadian Journal of Forest Research*, *12*, 225–240.

Ripley, B. D. (1976). The second-order analysis of stationary point processes. *Journal of Applied Probability*, *13*, 255–266.

Salisbury, A. N. (1998). Some observations on the large pine weevil *Hylobius abietis* (L.) (Coleoptera: Curculionidae). *Entomologist's Gazette*, *49*, 195–197.

Skogstyrelsen (2003). Nytt medel mot snytbagge 10 ganger giftigare för fisk. *Skogseko*, *1*. (In Swedish.)

Solbreck, C. (1980). Dispersal distances of migrating pine weevils, *Hylobius abietis* L. (Coleoptera: Curculionidae). *Entomologia Experimentalis et Applicata*, *1980*, 123–131.

von Sydow, F. (1995). Abundance and impact of the pine weevil *Hylobius abietis* (L.) in relation to breeding substrate condition and silvicultural practice. PhD thesis. Sveriges Lantbruksuniversitet, Uppsala.

von Sydow, F. (1997). Abundance of pine weevils (*Hylobius abietis*) and damage to conifer seedlings in relation to silvicultural practice. *Scandinavian Journal of Forest Research*, *12*, 157–167.

von Sydow, F., & Birgersson, G. (1997). Conifer stump condition and pine weevil (*Hylobius abietis*) reproduction. *Canadian Journal of Forest Research*, *27*, 1254–1262.

von Sydow, F., & Örlander, G. (1994). The influence of shelterwood density on *Hylobius abietis* (L.) occurrence and feeding on planted conifers. *Scandinavian Journal of Forest Research*, *9*, 367–375.

Watson, P. G. (1999). Influence of insecticide, wax and biofungicide treatments applied to *Pinus sylvestris* and *Picea abies*, on the olfactory orientation of the large pine weevil, *Hylobius abietis* L. (Coleoptera: Curculionidae). *Agricultural and Forest Entomology*, *1*, 171–177.

Wilson, W. L., & Day, K. R. (1994). Spatial variation in damage dispersion and the relationship between damage intensity and abundance of the pine weevil. *International Journal of Pest Management*, *40*, 46–49.

Wilson, W. L., & Day, K. R. (1995). The relative effectiveness of chemical traps, and fir, spruce and larch billets, for the estimations of pine weevil (*Hylobius abietis* L.) (Col. Curculionidae) density indices. *Journal of Applied Entomology*, *119*, 157–160.

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.

Zumr, V., Stary, P., & Dostálková, I. (1994). Monitoring of *Hylobius abietis* (L.) (Col. Curculionidae). *Anzeiger für Schädlingskunde Pflanzenschutz Umweltschutz*, *67*, 90–92.