Pine Weevil (Coleoptera: Curculionidae) Population Monitoring in Christmas Trees Using Volatile Host Compounds[1]

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Abstract The eastern pine weevil, *Pissodes nemorensis* Germar, and the pales weevil, *Hylobius pales* (Herbst), are major pests of pine production in eastern North America. Ethanol- and turpentine-baited pitfall traps and flight traps, and pit traps baited with fresh pine billets, were used to characterize weevil species composition in north-central Kentucky (USA) and assess seasonal activity by exploiting the weevils' attraction to host plant volatiles. During the 1998 growing season, *P. nemorensis* was the predominant species, comprising over 95% of the total trap catch for the season. Weevils were most responsive to fresh pine billets in pit traps, followed by ethanol- and turpentine-baited flight traps, and ethanol- and turpentine-baited pitfall traps. The sex ratio of *P. nemorensis* captured in pit traps was male biased, and in pitfall traps it was weakly female biased. Flight trap catch in traps placed 0.8 m above ground level was female biased. More weevils were captured in flight traps at 0.8 m than in flight traps at 1.6 m. Catches were greatest in traps placed perpendicular to the slope. Although *H. pales* was present at the site, numbers captured were too low to statistically assess trap efficacy.

Key Words Pine weevils, *Pissodes, Hylobius,* host volatiles, Christmas tree pests, distribution patterns

Plantation pine production in eastern North America is frequently threatened by several weevil species (Coleoptera: Curculionidae) which can cause extensive tree disfigurement and/or seedling mortality. The eastern pine weevil, *Pissodes nemorensis* Germar, and the pales weevil, *Hylobius pales* (Herbst), are significant pests of conifer reproduction (Drooz 1985).

Pissodes nemorensis occurs throughout eastern North America and attacks most conifer species, including many pines. Favored hosts include loblolly, *Pinus taeda* L., longleaf, *P. australis* Michx., red, *P. resinosa* Ait., Scotch, *P. sylvestris* L., and shortleaf pines, *P. echinata* Mill. (Finnegan 1958, Bliss and Kearby 1969, Drooz 1985). *Pissodes nemorensis* preferentially oviposits in the basal stem region and lower lateral branches of stressed trees, and frequently breeds in stumps and logs (Drooz 1985). Seedlings are particularly susceptible to adult feeding damage.

The pales weevil also occurs throughout eastern North America, attacking stressed trees and breeding in slash and stumps. Its host range includes most pines, spruce, *Picea* spp., fir, *Abies* spp., juniper, *Juniperus* spp., larch, *Larix* spp., hemlock, *Tsuga* spp., northern white cedar, *Thuja occidentalis* (L.), and Douglas fir, *Pseudo-*

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tsuga menziesii (Mirb.) Franco. Larval tunneling and adult feeding can damage harvestable pines; adult feeding alone can cause seedling mortality (Drooz 1985).

Plantation conifers in eastern North America are also susceptible to attack by other *Pissodes* and *Hylobius* species, most notably the white pine weevil, *P. strobi* (Peck), and the pine root collar weevil, *H. radicis* Buchanan. Both species attack and breed in healthy conifers and are frequently cited as limiting factors in the production of plantation pines in eastern North America (Drooz 1985).

Larval damage from one of the more aggressive weevil species can increase the susceptibility of host trees to attack by *P. nemorensis* or *H. pales.* Because both species breed in stressed or dying tissue, thinning and harvesting practices supply ideal habitat for brood development. Fresh stumps and unsalable trees commonly associated with Christmas tree production, as well as stressed and weakened trees, further contribute to an increase in larval habitat. In addition, seedlings in intensively managed plantations, including Christmas trees, are especially susceptible to adult feeding damage (Drooz 1985, McCullough et al. 1998).

The progression of foliar symptoms resulting from weevil attack tends to be slow, and damage due to larval tunneling or adult feeding may not become evident until host mortality has occurred. Thus, management strategies for conifer weevils must be preventive because infestations generally are detected only after irreversible damage has occurred (McCullough et al. 1998). Calendar applications, pre-plant dipping, and stump applications of restricted-use pesticides such as lindane or permethrin are the most commonly employed control methods (Shetlar and Herms 1997, McCullough et al. 1998). Such chemicals are highly toxic, persistent, and potentially carcinogenic (Reuben 1979). Minimizing the use and potential applicator exposure to such chemicals in the production of expendable commodities such as Christmas trees is advisable.

Detection of potentially damaging weevil populations is possible through exploitation of the insects' attraction to host volatiles. Ethanol and monoterpenes are volatile compounds emanating from pine tissue which have been shown to attract many pine-infesting insects (Moeck 1970, Fatzinger 1985, Tilles et al. 1986, Phillips et al. 1988, Chenier and Philogene 1989), including *Pissodes* spp. and *Hylobius* spp. Several weevil trapping methodologies have been developed which exploit this semiochemical-based attraction. However, they vary in efficacy depending on geographic region, weevil species composition, and host plant age and structure (Phillips et al. 1988, Rieske and Raffa 1990, 1993a, b, 1999, Fettig and Salom 1998).

The first objective of this study was to identify species of pine-infesting weevils impacting plantation pine production in Kentucky. The second objective was to characterize seasonal activity of these weevils by exploiting their attraction to host plant volatiles. Knowledge of the composition of the weevil complex, as well as its seasonal activity, will help to develop predictive capabilities that could reduce the number of preventative applications or provide better timing of insecticide treatments.

Materials and Methods

This study was conducted in north central Kentucky (Campbell Co.) during the 1998 growing season on a ridge top site having silty clay-loam soils from the Eden and Faywood series. Christmas trees at this site were 5 to 10 yrs old with a 1.7-m tree spacing. Scotch pine was the predominant species, but Austrian pine, *P. nigra* Turra, white pine, *P. strobus* (L.), Virginia pine, *P. virginiana* Mill, Fraser fir, *Abies fraseri*

(Pursh) Poir., Douglas fir, Norway spruce, *Picea abies* (L.) Karst, and Colorado blue spruce, *Picea pungens* (Engelm.), were also present.

Three trap types, each of which have been used successfully to monitor activity of various weevil species, were employed to characterize weevil populations and monitor their activity. Two trap types were designed to assess activity of walking/crawling insects. The first was modification of a PVC pitfall trap developed by Tilles et al. (1986) for *Hylobius* spp. The pitfall traps consisted of white plastic PVC drainpipe (10 × 18 cm) with a series of eight 7-mm diam holes drilled around the perimeter, 7 cm from one end. The trap interior was lined with liquid teflon (Northern Products Inc., Woonsocket, RI, USA) to prevent weevil escape. Baits consisted of a 1:1 volumetric ratio of 95% ethanol and turpentine (Sunnyside Corp., Wheeling, IL) which were dispensed separately from 8-ml glass vials (17 × 60 mm) suspended by a thin wire from the top of the trap. The turpentine consisted of 80% α-pinene, 7.3% β-pinene, 2% limonene and 0.9% myrcene (Raffa and Steffeck 1989). Traps were capped at each end and inserted into the ground so that the holes were flush with ground level.

The second trap type used to assess weevil walking/crawling activity was a modification of the pit trap design of Fettig and Salom (1998). Pit traps consisted of excavated soil depressions approximately 30 × 30 × 8 cm, containing a 10 × 30 cm section of Virginia pine log cut longitudinally, with the cut surface placed face down. The volatile plume emanating from each individual pine billet served as the sole bait. Billets in pit traps were covered with fresh foliage and changed at approximately 21 to 28-d intervals.

The third trap type was designed to assess activity of flying weevils and was patterned after those developed for *Hylobius* spp. (Rieske and Raffa 1990). Each baited flight trap consisted of an inverted 4-L plastic drink container with three sides cut away. The fourth side served as a mounting and strike surface for in-flying insects. A 200-ml polyethylene jar was attached at the bottom of each trap to collect captured insects. Two drainage holes (2 mm) were drilled in the bottom of the holding jar, and the interior of each was coated with liquid teflon to prevent weevil escape. Vials containing the 95% ethanol and turpentine baits as described above were suspended by a thin wire attached to the strike surface of each trap. Traps were attached to wooden stakes (5 × 5 × 180 cm) at 0.8 and 1.6 m above the surface. Those heights were chosen because they proved effective for trapping pine-infesting insects in similar studies (Rieske and Raffa 1993a, b). The direction of the upper and lower traps was randomly assigned to one of the four cardinal directions, and the relative orientation (i.e., upslope, downslope, perpendicular) of each flight trap was noted.

Each plot consisted of one of each of the three trap types arranged in a 1.0 × 1.0 × 1.0 m triangular pattern. All traps were placed within 0.5 m of the base of a tree. Plots were blocked by location and host species. Block 1 (0.44 ha) consisted of 4 plots (12 traps) and was located in a second rotation, 8 to 9-yr-old Scotch pine stand showing moderate to severe decline due to weevil activity. Interspersed among the pine were Fraser fir, Colorado blue spruce, and Norway spruce. Block 2 (0.57 ha) was located in a 5-yr-old Scotch pine stand with no signs of decline and consisted of 6 plots (18 traps). Block 3 (0.49 ha) consisted of 5 plots (15 traps) and was located in 9-yr-old Virginia pine showing light to moderate signs of weevil activity. Block 4 (0.89 ha) consisted of 9 plots (27 traps) in an 8-yr-old Scotch pine stand with scattered signs of weevil activity. Blocks 2 through 4 were first rotation stands. Each block was separated by a buffer of at least 30 m.

Weevils were removed, and the baits replenished at approximately 7-d intervals from 20 March through 1 August. Thereafter, only traps in the heavily-damaged block (block 1) were monitored until 7 September. *Pissodes* weevils were identified using the discriminant analysis technique developed by Godwin et al. (1982) and sexed according to the technique of Harman and Kulman (1966). *Hylobius* weevils were identified to species and sex using available keys (Warner 1966, Wilson et al. 1966).

Weevil response to trap type, expressed as seasonal means by species and sex, was assessed using analysis of variance. A transformation of square root (x + 0.5) was used because data generated from trap catches frequently contain a large number of zeroes and are not normally distributed. To assess weevil distribution patterns based on blocking, means for trap type across all plots within a block were compared for each time interval, using one-way analysis of variance replicated over time. Fisher's Protected LSD (Abacus Concepts 1996) was used to separate means where appropriate. A Chi-square contingency table was used to determine if weevil flight trap catch differed between heights and between weevil sex. Trap catch based on trap height was compared with Student's *t*-test. Analysis of variance was used to analyze trap catch based on trap orientation.

Results and Discussion

Over the course of the monitoring season, 556 weevils were captured across all trap types. Of these, 95% (527) were *P. nemorensis,* and 5% (29) were *H. pales.* Peak activity of *P. nemorensis* occurred during the 1 April monitoring interval (Fig. 1), when 28% of the season total was captured. There were two smaller peaks of weevil activity during weeks 6 to 8 (1 to 15 May) and week 12 (12 June). Response by *P. nemorensis* dropped to nearly zero by mid-July. Although numbers were extremely low, *H. pales* were active from 1 April to 21 June, with peak trap catch occuring during the 1 April (21%) and 1 May (21%) sampling intervals.

Trap type significantly affected capture of both *P. nemorensis* and *H. pales.* Pitfall traps performed poorly for both species, capturing only 6% of the *P. nemorensis* and 17% of the *H. pales.* In contrast, weevils were most responsive to the pine billet-baited pit traps which captured 53% of the *P. nemorensis* and 79% of the *H. pales.* Flight traps captured 41% of the *P. nemorensis* and 3% of the *H. pales.*

Table 1 lists the activity of each trap type for each weevil group. Most male *P. nemorensis* were captured in pit traps, followed by flight traps and then pitfall traps. Female *P. nemorensis* and total *P. nemorensis* responded equally to pit traps and flight traps and in greater numbers than to pitfall traps.

Significantly more male than female *P. nemorensis* were captured with pine billet-baited pit traps (164 male; 112 female; $\chi^2 = 9.791$; df = 1; $P < 0.005$). The ethanol- and turpentine-baited pitfall traps captured greater numbers of female *P. nemorensis* than male, though total numbers were low and this response was only weakly significant (11 male; 21 female; $\chi^2 = 3.125$; df = 1; $0.05 < P < 0.10$). Response of *P. nemorensis* to flight traps was not affected by weevil sex; the number of males (98) and females (119) captured in flight traps was statistically equivalent.

Hylobius pales males and total *H. pales* also were more responsive to pit traps baited with pine billets than to the other two trap types, although total trap catch was extremely low. Response by female *H. pales* was equivalent for all three trap types. The low number of *H. pales* captured did not allow statistical analysis for gender differences. However, male and female response to pine billets in pit traps was equal

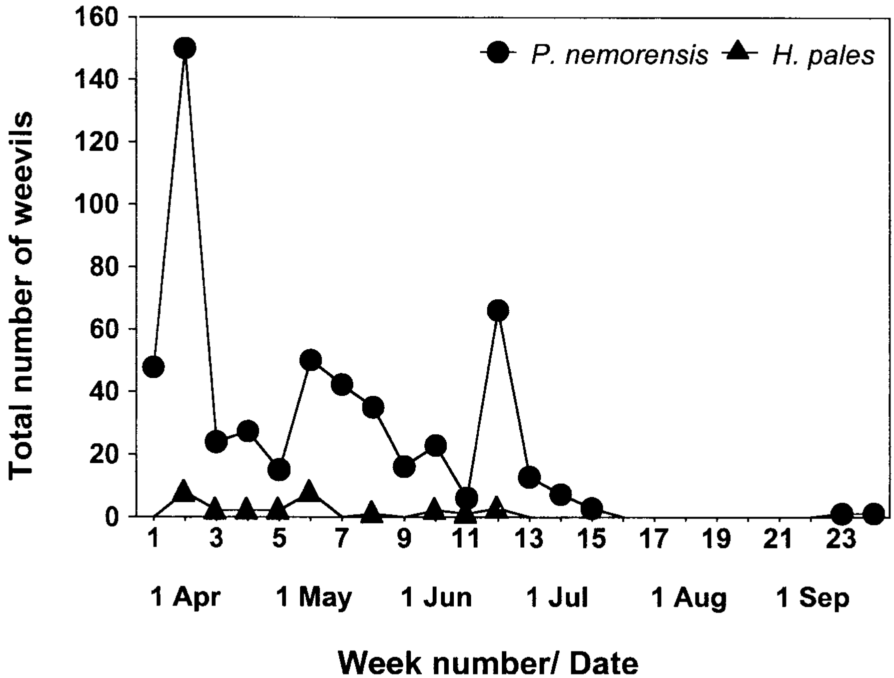

Fig. 1. Seasonal pattern of *P. nemorensis* and *H. pales* captured with three trapping methods in a Kentucky Christmas tree plantation, 26 March through 7 September 1998.

(12 males; 11 females), and only female *H. pales* were captured in ethanol- and turpentine-baited pitfall traps and flight traps (5 and 1, respectively).

Blocking was not a significant factor affecting trap catch of *P. nemorensis* or *H. pales.* However, traps in block 4 had the lowest numbers of both species, while those in block 2 had the highest.

Flight traps at the 0.8 m height captured significantly more *P. nemorensis* (82%) than did the traps at the 1.6 m height (t = 5.429, P < 0.001). Trap height was significant for both male and female *P. nemorensis,* as well as total weevils (Table 2). Weevils responded equally to traps facing each of the four compass directions. However, the relative direction of trap placement (i.e., upslope, downslope, perpendicular) did affect weevil capture rates. Traps which were placed perpendicular to the slope captured significantly more male (F = 14.25; df = 2,6; P < 0.01), female (F = 17.14; df = 2,6; P < 0.01), and total *P. nemorensis* (F = 4.69; df = 2,6; P < 0.05) than did traps facing either upslope or downslope. A single female *H. pales* was captured in the flight traps at the 1.6 m height; none were captured at the lower height.

Pine billet-baited pit traps, and flight traps baited with ethanol and turpentine, effectively monitored activity levels of *P. nemorensis* in a Kentucky Christmas tree plantation. The seasonal pattern of trap catch was consistent with results from other regions. In similar studies in more northerly regions (Bliss and Kearby 1969, Rieske

Table 1. Mean (±SE) number per week of *P. nemorensis* and *H. pales* captured in various trap types in a Kentucky Christmas tree plantation (Campbell Co., 1998).

Insects		Trap type/bait			
		Flight/ethanol and turpentine	Pit/pine billet	Pitfall/ethanol and turpentine	$F_{2,6}$ *P*-value
P. nemorensis	male	0.225 (0.033)b	0.373 (0.052)a	0.025 (0.010)c	8.65 $P < 0.05$
	female	0.273 (0.044)a	0.255 (0.036)a	0.048 (0.017)b	16.8 $P < 0.01$
	total	0.485 (0.063)a	0.611 (0.080)a	0.071 (0.022)b	11.46 $P < 0.01$
H. pales	male	0 (0)b	0.027 (0.008)a	0 (0)b	8.00 $P < 0.01$
	female	0.002 (0.002)a	0.025 (0.007)a	0.011 (0.005)a	2.22 ns
	total	0.002 (0.002)b	0.051 (0.012)a	0.011 (0.005)b	6.2 $P < 0.05$

Means within rows followed by the same letter are not significantly different (Fisher's Protected LSD, $P < 0.05$).

Table 2. Total number of *P. nemorensis* captured in ethanol and turpentine baited flight traps at 0.8 and 1.6 m above ground level in a Kentucky Christmas tree plantation, 26 March through 7 September 1998.

Insects		Trap height (m)		
		0.8	1.6	*t* (*P*-value)
P. nemorensis	male	78	21	4.219 (<0.001)
	female	102	19	4.906 (<0.001)
	total	180	40	5.429 (<0.001)

t-test (*t*) and probability (*P*-value) for differences between trap height.

and Raffa 1993a, b), both *P. nemorensis* and *H. pales* showed early season peaks in activity, followed by one or two secondary peaks. Weevil response to host plant volatiles declined as the season progressed, consistent with the findings here.

Because *P. nemorensis* was the predominant species, it is not surprising that the ethanol- and turpentine-baited pitfall traps were relatively ineffective at detecting weevil activity. Pitfall traps have proven ineffective for monitoring *Pissodes* spp. in other studies (Rieske and Raffa 1993a).

Flight traps baited with ethanol and turpentine were effective for detecting *P. nemorensis* activity. Flight activity was greatest at the lower height, consistent with previous findings (Rieske and Raffa 1993a) and suggests that these weevils orient to understory vegetation during flight. The significantly greater catch of traps oriented perpendicular to the slope may be an artifact of trap design because perpendicularly facing traps are more accessible to weevils flying with the slope of the site.

The sex ratio of trapped weevils in this study was somewhat surprising. Previous studies on *Pissodes* spp. have reported female-biased trap catches (Godwin and

Odell 1967, Phillips et al. 1984, Rieske and Raffa 1993a). However, I found the sex ratio of trapped weevils to be male-biased (pit traps), only weakly female biased (pitfall traps), or unbiased (flight traps). Although brood sex ratios are reportedly 1:1 (Phillips et al. 1988), the sex ratio of trapped weevils is thought to be influenced by female reproductive state and the emission of a male produced aggregation pheromone (Booth et al. 1983, Phillips et al. 1984, Phillips et al. 1987). Either factor could bias the sex ratio of captured weevils.

Trap catch of *H. pales* was too low in this study to accurately characterize population trends. This may be because endemic levels at this site were extremely low, and trap catch is accurately reflecting actual population levels. Alternatively, *H. pales* populations may actually be quite high, but the weevils themselves are responding poorly to the baits used. The response of *H. pales* to pitfall traps varies geographically (Phillips et al. 1988, Rieske and Raffa 1990, Fettig and Salom 1998) and has not been assessed in this region. Populations of *H. pales* in Kentucky may behave similarly to those in Virginia, which are not responsive to ethanol and turpentine baited pitfall traps (Fettig and Salom 1998). In addition to potential geographic variability in weevil population response, an abundance of rainfall and a high water table associated with the clay-loam soils at this site caused repeated flooding of pitfall traps which may have reduced early-season trap catch. The variability in the turpentine employed between studies may also be influencing weevil response. Lastly, it should be noted that the effective trapping area of pitfall traps may be much less than either pit traps or flight traps due to the smaller air volume from which these traps sample, thereby explaining the lack of response of either species in this study.

Because previous studies have demonstrated the strongly clustered nature of weevil distribution patterns, the lack of a block effect for each species was somewhat unexpected. It is interesting to note, however, that the heavily-infested block 1 did not catch the greatest number of either species, lending support to the hypothesis that weevils migrate out of an area when suitable breeding substrate has been exhausted (Rieske and Raffa 1990, 1993a, 1999). Block 1 was the only second rotation stand in my study, and harbored numerous stumps associated with harvest of the first rotation. It is reasonable to conclude that the initial build up of the weevil infestation at this site originated within these stumps in block 1, and that this substrate had since been depleted by weevil breeding activity.

Current recommendations for monitoring pine weevil activity involve visual inspection for larval tunneling and for the flagged tips resulting from adult feeding activity. These methods are reactive in that they detect weevil activity only after damage has occurred. The trapping methods investigated here are proactive and may give Christmas tree growers the tools necessary to detect weevil populations before tree disfigurement or mortality occurs, thereby allowing alternatives to calendar applications of toxic insecticides.

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