Movement of adult pecan weevils *Curculio caryae* within pecan orchards

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**Abstract**  
1. The pecan weevil *Curculio caryae* (Horn) (Coleoptera: Curculionidae) is an indigenous pest of pecan *Carya illinoinensis* (Wangenh.) K. Koch, in North America. Understanding the movement of this pest from the orchard floor to host trees could lead to pest management practices that exploit weevil behaviour and thus reduce insecticide application to the entire orchard canopy. Furthermore, no information exists on diel periodicity of pecan weevil movement.  
2. Movement of adult pecan weevils crawling and flying to the host trunk, flying to the host canopy, crawling within the host canopy and flying between host trees was studied using four types of passive traps over four seasons. Each type of trap was used to capture weevils at different locations on or near the tree and to discriminate flying versus crawling behaviour.  
3. More pecan weevils crawl to the trunk than fly and a proportion of the population flies directly from the orchard floor into the pecan canopy. The majority of this movement occurs at dusk.  
4. The vertical distribution of weevils was generally uniform throughout the canopy but more weevils were captured in suspended traps nearest tree tops, rather than traps near the ground, when flying between trees and this was significantly so for two of 4 years.  
5. The results of the present study are contrary to previous reports suggesting that most adult pecan weevils fly to the pecan trunk after emergence from the soil; however, our results did indicate that a proportion of the population flies directly from the orchard floor into the pecan canopy and thus would circumvent strategies that attempt to control weevils moving up the trunk.  

**Keywords** Behaviour, Coleoptera, *Curculio caryae*, Curculionidae, diel periodicity, movement, orchard, pecan, trap.

Pecan *Carya illinoinensis* (Wangenh.) K. Koch is economically the most-important native nut crop produced in North America. Average annual production (1999–2002) in the U.S.A. is valued at $233.8 million (USDA-NASS, 2006). The pecan weevil *Curculio caryae* (Horn) (Coleoptera: Curculionidae) can be a serious direct pest of pecan nuts across much of the southern U.S.A. All North American *Carya* spp. are susceptible to this indigenous pest (Ring et al., 1991).

The pecan weevil has a predominantly 2-year life cycle coinciding with masting by its *Carya* host. Adults emerge from the soil zone beneath the tree canopy from mid-summer to early autumn. They feed on and lay eggs in the developing nut of the fruit (Harris, 1985). Larvae develop from egg to late fourth-instar over an approximately 1-month period within the nut. They then chew through the involucre, or shell, drop to the soil and burrow to a depth of 8–25 cm, where they form a pupation cell and overwinter. Approximately 90% of larvae pulate the next autumn and spend the next 9 months in their soil cell as an adult (Harris, 1985). The remaining 10% of the larval population spend an additional 1 year in the soil as larvae and emerge as adults after almost 3 years (Harris, 1985). The majority of *C. caryae* adults emerge from soil over a 4–6-week period usually beginning in mid-August when fruit development nears the stage of rapid cotyledon growth (Harris, 1976). Larvae emerge from ripe, or near ripe, nuts over several months in the autumn and early winter (Boethel & Eikenbary, 1979; Harris & Ring, 1979).
Adult pecan weevils move to the canopy of the host tree, after their emergence from the soil, by flying or crawling. Weevils flying to the tree either fly directly into the canopy from the orchard floor or fly to the trunk and then crawl into the canopy. Crawling weevils enter the canopy by moving across the orchard floor to the tree trunk. Movement of weevils to the trunk may allow for implementing a strategy of controlling weevils on the pecan trunk rather than relying on airblast applications of insecticides (i.e. carbaryl) to the orchard canopy. Applications of carbaryl to the orchard canopy are highly efficacious against the pecan weevil but also lead to resurgent populations of aphids and mites (Dutcher, 1983; Dutcher & Payne, 1983). Exploration of an alternative pecan weevil management strategy that targets the pecan trunk or the orchard floor has been suggested by McVay (1999). A strategy to manage pecan weevils on the trunk is supported by Raney and Eikenbary (1968) who observed that release of field-collected weevils onto the orchard floor resulted in approximately 85% moving to the trunk of the pecan tree host, of which approximately 90% flew and 10% crawled. It is, however, unknown whether the movement of these previously-handled pecan weevils is representative of undisturbed pecan weevils. Information on natural movement of the adult pecan weevil to the host pecan tree and their movement within and between trees is needed to develop alternative pecan weevil management strategies not solely reliant upon application of insecticides to the pecan canopy.

The present study examined the natural movement of male and female pecan weevils to the host pecan tree, within the

![Figure 1](image-url)
Movement of adult pecan weevils within orchards

host tree canopy, and between host pecan trees. Passive interception traps were placed on pecan trunks, suspended from tree canopies, attached to limbs, and suspended between pecan trees. Weevils were captured in traps when crawling or flying to trunks, flying directly to the canopy from the orchard floor, crawling within the canopy, and flying between trees. We also determined diel periodicity of adult pecan weevils moving to the trunk.

Materials and methods

Trap designs

Pecan weevil movement was studied over four seasons, 1999–2002, in an approximately 100-year-old pecan orchard, cv. Schley, in Byron, Georgia (32°39′40.60″N, 83°44′04.90″W). Adult pecan weevils were captured using four different passive trap types, each employed to capture weevils at different locations on or near the tree. Although the base of each type of trap was designed differently, all traps ultimately channeled weevils into a collection device as used to collect the boll weevil *Anthonomus grandis grandis* (Coleoptera: Curculionidae) (Hardee et al., 1996) (Fig. 1C). The pecan weevils were retained in this part of each trap until collected. Pecan weevil movement was studied by collecting weevils: (i) crawling and flying from the orchard floor to the trunk; (ii) flying directly from the orchard floor to the canopy; (iii) crawling within the canopy; and (iv) flying between trees.

‘Trunk traps’ were used to study movement behaviour of weevils (i.e. crawling or flying, from the orchard floor to the pecan trunk). Weevils captured in traps placed low on the trunk were indicative of crawling behaviour whereas those weevils captured in traps placed high on the trunk indicated flying behaviour. These trunk traps were constructed similarly as outlined by Mulder et al. (1997) (Figs 1A, 2A, 3A).

‘Cone traps’ suspended from the canopy captured weevils flying directly from the orchard floor into the canopy. Construction of these cone traps was similar to that described by both Raney and Eikenbary (1969) and Polles and Payne (1972). Modifications were made to suspend cone traps from the canopy, and one of the two attached boll weevil traps

![Figure 2 Trap diagrams: (A) trunk trap, (B) suspended pyramid trap and (C) suspended cone trap. Although the base of each type of trap was designed differently, all traps ultimately channeled weevils into a collection device originally designed to collect the boll weevil *Anthonomus grandis grandis* (Coleoptera: Curculionidae). Traps are not drawn to scale.](image-url)
captured weevils flying into the suspended cone whereas the other captured those alighting on the outside and crawling upward (Figs 1B, 2C, 3B).

‘Limb traps’ captured weevils crawling along limbs within the canopy. They were used to study vertical dispersal of pecan weevils in trees and were made from boll weevil traps modified to fit onto limbs (Fig. 1C). This modification consisted of using a wooden block (6.0 × 1.0 cm) attached to the inside cone of the boll weevil trap. The distal end of the block was V-notched to allow firm seating of the block onto a limb. Traps were secured to limbs using tie straps around the limb and through a hole drilled in the block. A rectangular piece of hardware cloth was attached to the block and extended down to the limb whereas a lower, matching piece of hardware cloth (notched to allow for the limb), was attached with staples to the upper piece of hardware cloth. These joined pieces prevented weevils from passing the trap and directed their movement up into the trap (Fig. 1C).

‘Suspended pyramid traps’ captured weevils flying between trees. They were constructed from lightweight corrugated plastic, similarly as described by Tedders and Wood (1994) and were used to determine prevalence of flight by males and females and the height at which weevils flew between trees (Figs 1D, 2B, 3D). Although the smooth, corrugated plastic was scored to facilitate weevils alighting and maintaining a foothold, a square piece of hardware cloth, attached to the bottom of the pyramid trap, ensured that if any weevils fell, they had a means of recovery and another chance to enter the trap.

Pecan weevils flying and crawling to the pecan trunk
Trunk traps were attached with a screw through the spine of the trap to 14 pecan trees. The lower edge of this mostly wire-screen trap was stapled to the trunk to prevent weevils circumventing capture. Traps were placed at both a low and a high position on each trunk (Figs 1A, 3A) and used to monitor...
weevil movement by crawling (low traps) or flying (high traps) to the trunk. Trap height was measured as the distance from the soil to the distal edge of the trap’s semi-cone located away from the trunk (Figs 1A, 2A). Five to six trunk traps were placed 67 ± 3 cm above soil level (low traps) and completely encircled the trunk to intercept weevils arriving low on the trunk. Five to seven traps were placed 193 ± 5 cm above soil level and also completely encircled the trunk to intercept those weevils flying to the trunk, 67–193 cm above the ground (Figs 1A, 2A). These traps were sampled three times per week each year (1999–2002): 19 July to 5 November, 12 July to 10 November, 13 July to 26 October, and 15 July to 11 October, respectively. The numbers of male and female weevils captured in low and high traps were recorded on each date. Observations of weevils entering these traps indicated that weevils did not stop upward movement, which could have retarded collection or facilitated trap circumvention.

Detection of weevils flying from the orchard floor to the pecan canopy

Six cone traps (mouth diameter 1.22 m) were suspended from limbs around four trees (Figs 1B, 2C, 3B). Traps were approximately 5 m distal to the trunks of these large trees. The bottom of each trap was approximately even with the lowest level of each tree’s canopy. This canopy level was maintained by pruning limbs and foliage to approximately 2.5 m above soil level. No limbs or foliage were allowed to contact the traps such that weevil capture probably would have been through flight activity to the outside or the inside of the cone traps. A double collection device on the trap (Figs IB, 2C) allowed separate collection of those weevils from the cone exterior and the cone interior. These traps were affixed in position using a rope and pulley that also allowed traps to be easily lowered for sampling and then raised. Sampling was performed weekly (1999–2002): 23 July to 29 October, 17 July to 3 November, 27 July to 25 October, 18 July to 10 October, respectively. Nonflight-related captures could have occurred in these cone traps if adult weevils crawled down the suspending rope or, when feigning death, dropped from the canopy and recovered on the cone exterior. These possibilities were remote and unlikely to result in appreciable numbers of captured weevils.

Vertical movement by weevils within the canopy of pecan trees

Limb traps were used to capture and assess vertical activity of pecan weevils within the tree canopy (Figs 1C, 3C). Limb traps were placed in the canopy of 20 pecan trees during 1999: ten were trees that had trunk traps attached (not including the four trees shown in Fig. 4) and ten trees did not have trunk traps attached. Placement of limb traps on trees with and without trunk traps allowed a comparison of the vertical distribution of weevils as affected by trunk traps. In addition, from 1999–2002, limb traps were placed in the four trees shown in Fig. 4 to monitor vertical distribution of
weevils. These four trees always had trunk traps attached. Each year, for trees receiving limb traps, 12 limb traps were used per tree with four traps placed at three different heights in the canopy (bottom third, middle third and top third). The four traps at each height were spaced equidistant around the periphery of the canopy with one at each cardinal direction. Trap height was estimated in these approximately 25-m tall trees. An articulating boom lift (JLG Industries, Inc., McConnellsburg, Pennsylvania) provided access to sample traps. Trap sampling was performed weekly (1999–2002): 22 July to 7 October, 19 July to 1 November, 1 August to 25 October, 18 July to 10 October, respectively. Limb traps were sampled near the beginning of weevil emergence until 3 weeks had elapsed with no weevils captured in limb traps.

Movement by weevils between pecan trees

Twelve sets of three pyramid traps were suspended vertically between trees (Figs 1D, 2B, 3D) to assess intertree flight activity (Fig. 4). Galvanized wire cables were stretched taut between tree tops and enabled suspension of a support rope tethered to each set of three traps. The bottom of the lowest trap in the three-trap set was 4.6 m above the ground and there were 3 m separating the tops and bottoms of all traps in each set. A pulley system enabled raising and lowering traps for sampling. Sampling was performed weekly (1999–2002): 23 July to 29 October, 17 July to 3 November, 27 July to 25 October, 18 July to 10 October, respectively.

Diel movement of weevils from the orchard floor to the pecan trunk

Trunk traps were attached, at low and high positions, to the trunks of four pecan trees and to the trunks of eight pecan trees, as previously described, during 1999 and 2000, respectively. During 1999, diel movement was monitored for 29 consecutive days (31 August to 28 September) using three collection intervals: day [07.00 h to 17.00 h Eastern Daylight Time (EDT)], evening (17.00 h to 21.00 h EDT) and night (21.00 h to 07.00 h EDT). These data were collected and recorded as the number of weevils per collection interval and as the number of weevils per hour. In 2000, diel movement was monitored every 3 h (03.00 h, 06.00 h, 09.00 h, 12.00 h, 15.00 h, 18.00 h, 21.00 h and 00.00 h EDT) for 24 h starting on four separate dates: 5, 7, 10 and 14 September. The number of weevils per collection interval was recorded. Across both years, daylight (i.e. sunrise to sunset) ranged from 07.11–20.05 h EDT for the earliest collection date and from 07.30–19.26 h EDT for the latest date.

Figure 6 Pecan weevil capture in suspended cone traps: (A) by weevils collected from inside or outside of the trap and (B) by captures of male versus female weevils. Pooled data from all years are shown as the percentage of weevils captured: (A) inside or outside of the cone trap and (B) gender. *Significant difference ($P < 0.05$) between paired columns.
Statistical analysis

Cumulative data on the mean number of weevils captured was examined for each year, separately, using a factorial analysis of variance (ANOVA) (JMP, 2002). This was performed for each trapping method using trap position (or capture location for suspended cone traps) and gender as main effects. If the interaction of the main effects (i.e. trap position × gender) was not significant (i.e. P > 0.05), main effects were individually examined. Mean separation was accomplished using Tukey’s HSD when P < 0.05. Data for diel movement of pecan weevils to trunks was pooled separately by year, 1999 and 2000, due to unlike sampling methods for each year. Diel movement data was analysed by the number of weevils collected per sampling interval using repeated measures ANOVA (JMP, 2002). Due to differences in duration of the three collection periods during 1999 (i.e. day = 10 h; evening = 4 h; night = 10 h), repeated measures ANOVA (JMP, 2002) was used to analyse that data as the number of weevils captured per hour.

Results

Pecan weevils flying and crawling to the pecan trunk

Numbers of weevils captured relative to trunk trap position (i.e. low or high) differed during 1999, 2000, 2001 and 2002 (F_{1,52} = 5.27, P = 0.0258; F_{1,52} = 10.09, P = 0.0025; F_{1,52} = 6.09, P = 0.0170; and F_{1,52} = 0.0045, P = 0.9944, respectively), with more weevils captured in low traps (Fig. 5A). The only time the number of captured weevils differed by gender was 2001 (F_{1,52} = 7.39, P = 0.0089) when more males were trapped (Fig. 5B). The interaction of trap position × gender was not significant for pecan weevils captured in low or high trunk traps during 1999, 2000, 2001 or 2002 (F_{1,52} = 0.30, P = 0.59; F_{1,52} = 0.36, P = 0.55; F_{1,52} = 1.78, P = 0.19; and F_{1,52} = 0.01, P = 0.95, respectively).

Detection of weevils flying from the orchard floor to the pecan canopy

Examination of the main effect capture location did not reveal any differences for weevils captured inside or outside the suspended cone trap (F_{1,9} = 2.51, P = 0.15; F_{1,9} = 0.00, P = 1.00; F_{1,9} = 0.03, P = 0.87; and F_{1,9} = 0.20, P = 0.66, respectively) (Fig. 6A). The only difference detected when using suspended cone traps was the higher capture of males (118.4 ± 24.3 per trap) than females (43.9 ± 7.8 per trap) during 2001 (F_{1,9} = 18.69, P = 0.0019) (Fig. 6B). There was no interaction of capture location × gender for weevils captured in suspended cone traps during any of the 4 years (F_{1,9} = 0.00, P = 1.00; F_{1,9} = 1.62, P = 0.24; F_{1,9} = 0.39, P = 0.55; and F_{1,9} = 1.10, P = 0.32, respectively).

Figure 7 The presence/absence of trunk traps on pecan trees had no significant (P > 0.05) impact on (A) the vertical distribution of pecan weevils as indicated by capture in limb traps but did have a significant impact on (B) the occurrence of males and females in traps. Within grouped columns, different letters above columns indicate a significant difference (Tukey’s HSD, P < 0.05) between columns. *Significant difference (P < 0.05) between paired columns.
Vertical movement by weevils within the canopy of pecan trees

Limb trap capture of weevils by trap position (lower third, middle third and upper third) was not affected by presence or absence of trunk traps (\( F_{2,54} = 0.87, P = 0.43 \) and \( F_{2,54} = 2.97, P = 0.06 \), respectively) during 1999 (Fig. 7A). In both instances (i.e. with or without trunk traps), more males than females were captured during 1999 (\( F_{1,54} = 16.03, P = 0.0002 \) and \( F_{1,54} = 21.61, P < 0.0001 \), respectively) (Fig. 7B). Nor was there an interaction of trap position × gender during 1999 for trees with or without trunk traps (\( F_{2,54} = 0.59, P = 0.56 \) and \( F_{2,54} = 1.40, P = 0.26 \), respectively). In the four trees used from 1999 – 2001, only during 2001 were more weevils captured in middle limb traps than bottom limb traps within the canopy (\( F_{2,15} = 4.27, P = 0.0340 \)) (Fig. 8A).

More male pecan weevils than females were captured in limb traps during 1999 (\( F_{1,15} = 11.82, P = 0.0037 \)) and 2001 (\( F_{1,15} = 33.46, P < 0.0001 \)) (Fig. 8B). Movement by weevils within the canopy of the four trees (i.e. weevil capture in limb traps) revealed no interaction of trap position × gender during any of the four years (\( F_{2,15} = 0.69, P = 0.52; F_{2,15} = 0.76, P = 0.48; F_{2,15} = 2.32, P = 0.13; \) and \( F_{2,15} = 1.26, P = 0.31 \), respectively).

Movement by weevils between pecan trees

Pecan weevil flight between trees was detected using suspended pyramid traps. Weevil capture by trap position (i.e. top, middle or bottom) differed during 1999 (\( F_{2,55} = 4.75, P = 0.013 \)) and 2002 (\( F_{2,55} = 8.38, P = 0.0007 \)) (Fig. 9A) when more weevils were intercepted in top traps than bottom traps. No gender difference in weevil capture was detected in any year (Fig. 9B), nor was there an interaction of trap position × gender from 1999–2002 (\( F_{2,55} = 0.15, P = 0.86; F_{2,55} = 0.27, P = 0.76; F_{2,55} = 0.37, P = 0.70; \) and \( F_{2,55} = 1.87, P = 0.16 \), respectively).

Diel movement of weevils from the orchard floor to the pecan trunk

Diel movement of weevils did not differ for any of the three collection intervals (i.e. day, evening or night) during 1999 (\( F_{2,230} = 0.35, P = 0.7046 \)) (Fig. 10A). However, when diel movement was examined upon the basis of weevils captured per hour during 1999 (i.e. because two of the collection intervals were 2.5-fold longer than the other), more weevils were captured during the evening than during the day or night (\( F_{2,230} = 79.77, P < 0.0001 \)) (Fig. 10A). During 2000, when
eight 3-h sampling intervals were used to examine diel movement, more weevils were captured from 18.00–21.00 h than any other interval ($F_{2,217} = 18.51$, $P < 0.0001$) (Fig. 10B).

**Discussion**

The cyclical-like pattern of adult weevils captured in host trees, alternating from high to low to high to low, over the 4 years of study is reflective of the fact that pecan weevil populations are largely synchronized with crop load by host trees. This emergence pattern is typical in commercial pecan orchards, as alternate bearing ensures biennial cycling of the nut crop.

The movement of adult pecan weevils from the orchard floor to the host pecan tree and between host trees is now better understood. Prior research on pecan weevil movement by Raney and Eikenbary (1968) used previously-handled weevils and subsequent weevil behaviour was likely affected when released for study. The present study ascertained natural movement of adult pecan weevils using passive interception traps. These data are not affected by artefacts of handling and should be indicative of normal weevil movement patterns that may be useful for implementation of pecan weevil management tactics seeking to exploit weevil behaviour (Cottrell & Wood, 2003).

More adult weevils were captured in trunk traps placed near the ground than in traps higher on the trunk, indicating that most weevils crawl to the trunk of the host tree rather than fly. This finding contradicts the conclusion made by Raney and Eikenbary (1968) suggesting that most adult weevils fly to the trunk. In the present study, the percentages of male and female weevils that are crawling versus flying to the trunk are similar. Even when more males than females were caught in trunk traps during 2001, there still was no interaction of trap position × gender. Raney and Eikenbary (1968) suggested that male pecan weevils are weaker fliers than females because previously-handled males tended to fly to lower parts of the tree whereas females flew higher. Our data do not support this conclusion, indicating that handling effect can seriously impact the behaviour of the adult pecan weevil.

Sex ratios of the pecan weevil are typically 1 : 1 (Harp & Van Cleave, 1976). Given the passive nature of sampling with trunk traps and the detected difference in males and females during 2001, it is tempting to dismiss this difference in sex ratio and hypothesize that more male weevils were the consequence of males moving in from other trees and being captured in trunk traps. However, Dutcher et al. (1986) also found a difference in the sex ratio of pecan weevils when using both closed cone emergence traps (i.e. weevils collected emerging from the soil directly underneath the trap) positioned on the...
orchard floor as well as open malaise traps, used similarly as trunk traps, situated in the main-fork of host trees.

Even though high numbers of weevils were captured on the pecan trunk, these data cannot be used to estimate the proportion of emerging adults entering the pecan canopy via the trunk. Likewise, our data did not quantify the proportion of weevils flying directly into the canopy but indicated weevil flight activity. Capture of weevils in the interior of suspended cone traps, as opposed to the exterior, strongly suggests that at least a portion of the population flies directly from the ground to the canopy, altogether bypassing the trunk. Unlike weevil capture in trunk traps, where the entire trunk was sampled, combined suspended cone traps on each tree sampled approximately 10% of the area within the drip line of the canopy. If the suspended cone traps are not unduly attractive to pecan weevils, and it is likely they are not, then we may hypothesize that the percentage of the total weevil population flying directly from the orchard floor to the canopy is nearly ten-fold greater than the sum of weevils captured within suspended cone traps.

Because trunk traps had no impact on the vertical distribution of adult weevils in the pecan canopy during 1999, vertical distribution of weevils was examined in four trees with trunk traps from 1999–2002. In these four trees, capture of pecan weevils at different heights throughout the canopy was similar except during 2001 when fewer weevils were captured at the canopy bottom than middle. Differences in sex ratios, as indicated by limb trap capture during 1999 when no difference in sex ratio was detected by trunk trap captures, may indicate that males were more actively searching for females in the canopy and thus being trapped more frequently. Higher capture of males than females in limb traps during 2001 could be expected because this difference also was present for trunk trap captures.

Weevil capture in suspended pyramid traps showed a trend of more weevils in the most-elevated traps, with significant differences during two of the 4 years. This could be because weevils take flight and fly upward, or because more weevils take flight from higher positions in the tree. It is unlikely that flying adult weevils were attracted to suspended pyramid traps (because of the low numbers captured) but more plausible that the traps intercepted some flying weevils. Nonetheless, it is clear that weevil flight must be considered when developing control strategies that incorporate weevil movement behaviour.

The pecan weevil is crepuscular, seeking to move to the host pecan tree at dusk. This behaviour, which has the advantage of decreasing bird predation, did not continue at the same rate throughout the night. Nor was increased activity evident at dawn. However, adult weevils are active within the canopy during the night (T. E. Cottrell, personal observation) and are readily detectable using a light source. Similarly, the plum curculio Conotrachelus nenuphar (Coleoptera: Curculionidae) and banana weevil Cosmopolites sordidus (Coleoptera: Curculionidae) exhibit diel periodicity, being primarily nocturnal (Chouinard et al., 1992; Chouinard et al., 1994; Gold et al., 2001).

In conclusion, pecan weevil management strategies need to take flight activity into consideration and studies of behaviour need to consider the effect of handling. Cottrell and Wood (2003) demonstrated that brief exposure of adult pecan weevils to trunks treated with a high rate of carbaryl results in high weevil mortality for up to 13 days after insecticide application. In light of the present study, even if most of the emerging pecan weevil population were controlled via trunk-applied insecticides, those weevils flying directly into the host canopy from either the orchard floor or other trees would substantially damage the pecan crop if the canopy were not treated with insecticide.

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