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RED OAK BORER (COLEOPTERA: CERAMBYCIDAE) FLIGHT TRAPPING IN THE OZARK NATIONAL FOREST, ARKANSAS

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ABSTRACT

High population densities of red oak borer, *Enaphalodes rufulus* (Haldeman), are believed to be a major contributor to recent widespread oak mortality in the Ozark Mountains of Arkansas. The intent of this research was to expand our knowledge on specific aspects of this insect's biology, life history, and distribution by trapping flying adults in the Ozark National Forest during emergence of 2001, 2003, and 2005 cohorts. Passive flight intercept trap catches revealed that preferred flight height and thus optimal trap placement for monitoring populations was close to the base of the dominant/co-dominant northern red oak, *Quercus rubra* L., canopy. Flight periods and peak flight were different in 2001 and 2003. Emergence occurred a week earlier in 2001 vs. 2003. Peak flight occurred over a 3-week period from mid Jun to early Jul in 2001 in contrast to 2003 peak flight, which occurred the first week of Jul. Male to female ratios were 1.9:1 and 1.4:1 for 2001 and 2003, respectively. In 2003, sex ratios varied significantly among 5 topographic positions evaluated, north, south, east, and west-facing benches and ridges. Total numbers of red oak borers caught varied both spatially and temporally from cohort to cohort in traps placed in 3 different areas on 5 topographic positions. This research should facilitate efficient future monitoring of adult red oak borer and form a basis for investigating stand and landscape-level factors affecting population densities throughout the forest.

Key Words: *Enaphalodes rufulus*, insect trapping, *Quercus*, native insect pest, oak decline

RESUMEN

Se cree que las altas densidades de la población del barrenador del roble rojo, *Enaphalodes rufulus* (Haldeman), es un contribuidor importante en la reciente mortalidad extensiva de los robles en las Montañas de Ozark en el estado de Arkansas (EEUU). El propósito de esta investigación fue para ampliar el conocimiento de aspectos específicos de la biologia, historia de vida y distribución de este insecto por medio de la captura de los adultos volantes en el Bosque Nacional de Ozark durante la emergencia de los cohortes de los años 2001, 2003 y 2005. Los individuos volantes interceptados y capturados en trampas pasivas de revelaron que la altura de vuelo preferida y la colocación óptima de las trampas para el monitoreo de la población fue cerca del base de la copa (parte superior del arbol) del árbol dominante/co-dominante roble rojo del norte, *Quercus rubra* L. Los periodos de vuelo y el pico en el número de individuos volantes fue diferente en los años 2001 y 2003. La emergencia ocurrió una semana mas temprana en 2001 versus el 2003. El pico en número de individuos volantes ocurrió en el período que va desde el medio de junio hasta la primera parte del julio en el 2001, a diferencia del el pico de individuos volantes en 2003 que ocurrió en la primera semana de julio. La proporción del numero de machos a hembras fue 1.9:1 y 1.4:1 para los años 2001 y 2003 respectivemente. En el 2003, la proporción de machos a hembras varia significativamente entre las 5 posiciones topográficas evaluadas, los bancos y los lomos dirigidos hacia el norte, sur, este y oeste. El número total de los barrenadores del roble rojo capturados varia espacialmente y temporalmente de cohorte a cohorte en trampas colocados en 3 áreas diferentes en 5 posiciones topográficas. Esta investigación facilitará la eficiencia del monitoreo de los adultos del barrenador de roble rojo en el futuro y da una base para investigar los factores a nivel de las áreas uniformes manejadas del bosque y terreno afectando la densidad de la población a travez del bosque.

An oak decline event occurring in the Ozark National Forest of northern Arkansas (Starkey et al. 2000) is unique as red oak borer, *Enaphalodes rufulus* (Haldeman) (Coleoptera: Cerambycidae), has been implicated as a major contributor to tree mortality (Stephen et al. 2001; Fierke et al. 2005a, b). Red oak borer is a native long-horned wood-boring beetle that exhibits a rare synchronous 2-year life cycle with adult emergence occurring only in odd-numbered years (Hay 1969). These beetles normally occur at low population densities reported at fewer than 1 adult emerging per tree from mature oaks in Ohio (Hay 1974). Populations associated with the current oak mortality event are many times higher, averaging 45 late-stage red oak borers per tree, range 0-130, in 24 whole trees dissected just before adult emergence in 2003 (Fierke et al. 2005a, b).

The life cycle of red oak borer has been described previously in Ohio and Kentucky oaks (Hay 1969) and is similar in Arkansas (Fierke et al. 2005a). Reports of economic losses associated with wood degrade due to red oak borer are numerous (Hay & Wootten 1955; Morris 1964; Donley et al. 1974; Feicht & Acciavatti 1985). "Black check" caused by larvae of large beetles was described in Ozark Mountain oaks as a very common defect in the early 1920s (Snyder 1927). Red oak borer attack and emergence holes also serve as entryways for decay fungi (Berry 1978) and other organisms, e.g., carpenter worms (Lepidoptera: Cossidae), and oak timber worms (Coleoptera: Brentidae), which cause additional wood degrade and further decrease timber values (Donley & Acciavatti 1980).

Research objectives were to determine adult flight height, flight period, peak flight, and ratio of adult males to females. Determination of preferred flight height as well as peak flight period should enhance trapping of adult beetles in future research as well as being valuable for monitoring population densities in high risk areas. Additional objectives were to investigate distribution and densities of flying adults on 5 topographic positions, north, south, east, and west-facing benches and ridges, in 3 areas of the Ozark National Forest that recently experienced high levels of red oak borer-induced tree mortality. Elucidation of adult red oak borer abundance and distribution should enhance efforts to understand the recent outbreak and to predict stands/areas that may be susceptible to future outbreaks.

Materials and Methods

Study Areas

Study areas were located in northern Arkansas within the Boston Mountain physiographic section of the Ozark Plateau. Boston Mountain elevations range from 370 to 700 m and the landscape is characterized by deep valleys, steep ledges, and cliffs with rock formations of limestone, sandstone, and shale (Fenneman 1938; Adamski et al. 1995). Passive flight intercept traps were located in 3 general geographic areas experiencing high levels of tree mortality (UTM Zone 15–N NAD83: Fly Gap–0431660, 3954978, White Rock–412668, 3949429 and Oark–0450792, 3952369) in the Boston Mountain, Pleasant Hill, and Buffalo Ranger Districts of the Ozark National Forest (Fig. 1). Flight was monitored for 3 red oak borer emerging adult cohorts during the summers of 2001, 2003, and 2005.

Traps

Handmade passive flight intercept traps had flat 60 × 60 cm plywood tops mounted to 56 × 3-cm slotted wood centerpieces within which four 25 × 56-cm rectangles of clear plexiglass fit. Fifty cm diameter handmade galvanized steel funnels were attached to the bottom of traps and emptied into 0.95-L glass jars. Collecting jars were filled to 1/3 of volume with a 1/3 dilution of propylene glycol/water as a preservative. These traps were used only in 2001.

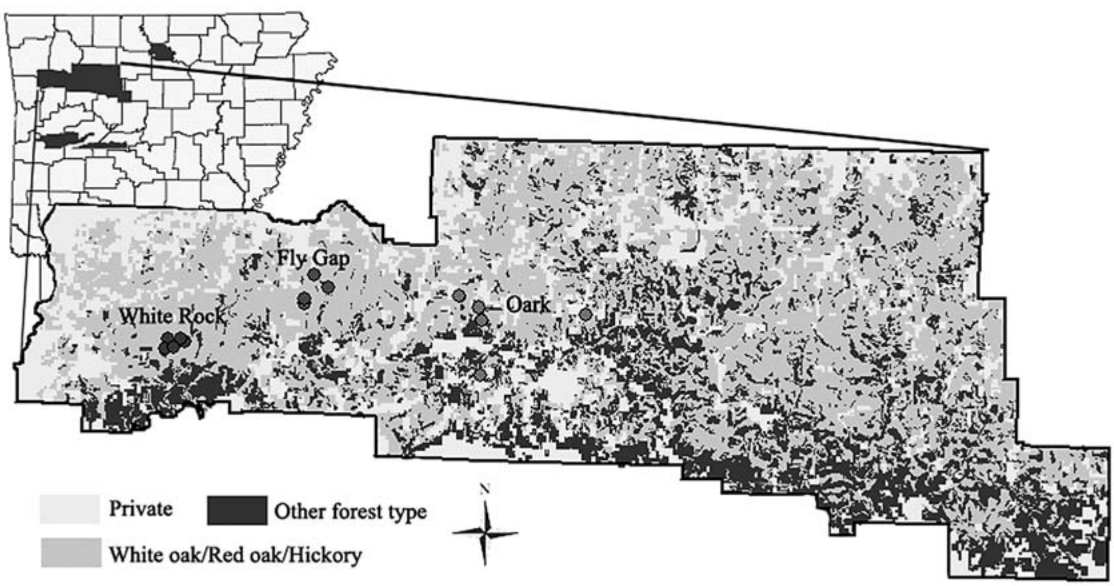

Fig. 1. Research sites were located in 3 general areas of the Ozark National Forest in Northwest Arkansas experiencing oak mortality. Circles indicate 5 stands in each area on 5 topographic positions; north, south, east, and west-facing benches, and ridges. Ridge, south, and west plots at Fly Gap appear to overlap due to their proximity and scale of map.

Commercially available black passive flight-intercept traps (IPM Technologies, Portland, OR) were made of corrugated plastic with 81 × 30.5-cm folding-interlocking vanes. Clear plastic 1-L holding cups were attached to the bottom of traps and contained ~300 mL of a 1/3 dilution of propylene glycol/water as the liquid preservative. This type of trap was used as black cross-vane traps with cylindrical silhouettes and wet cups have been shown to be more effective than other methods of trapping for large wood-boring insects (McIntosh et al. 2001; Morewood et al. 2002; de Groot & Nott 2003; Sweeney et al. 2004).

2001

Ten hand-made passive flight-intercept traps and 1 IPM trap were placed in mixed hardwood forests experiencing elevated levels of oak mortality in the Fly Gap area. Three traps were installed on 1 Jun, 4 on 12 Jun, and 4 more on 15 Jun. Adult flight was monitored weekly or more often from 8 Jun through 24 Aug to determine 2001 flight period, peak flight, and sex ratios. Ultraviolet lights were installed in two traps on 31 Jul and in a third trap on 17 Aug. Sex, based on antennal length, was noted for all beetles. Female antennae are about body length and male antennae are about twice body length (Solomon 1995). Preliminary data on this flight period were reported by Stephen et al. (2001).

2003

To determine optimal trap placement, 5 vertical trapping systems were constructed with 25 IPM traps placed just below the northern red oak canopy layer in stands located on 5 topographic positions in the Fly Gap area. This allowed evaluation of differences in trends to catch beetles relative to the base of the dominant/co-dominant northern red oak canopy on the different topographic positions. The trapping system was hung from the lowest large branches of northern red oaks that allowed access to raise and lower traps without undue interference from mid and understory trees. The base of the canopy was chosen as the point of origin as field observations indicated that these insects spend their day within the canopy with nocturnal flight being initiated from there. This made a ground-based point of origin illogical considering beetles likely never encounter the forest floor throughout their entire life cycle. Height of limbs ranged from approximately 17-20 m for the 5 stands and was assumed equivalent to the base of the dominant/co-dominant northern red oak canopy layer. Base of the canopy layer was defined as an imaginary horizontal line across tree boles to represent the average live dominant/co-dominant crown base (USDA FS 2001).

Vertical trapping systems were constructed with 5 interconnected IPM traps with 2-m spacing intervals totaling about 15 m in length. A pulley was installed at the top of the system, the system was raised to the base of the canopy, and the bottom trap was tied off to stabilize the system. Insect catch data for this experiment are reported relative to the height of the limb on which traps were hung, e.g., 1 m below the limb. Height of the trapping systems above the forest floor varied and specific heights relative to the forest floor in the different stands were not measured. Vertical trap systems were installed in ridge, south, and west plots on 22 Jun, the east plot on 24 Jun, and the north plot on 25 Jun. Data were collected weekly or more often beginning 27 Jun and ending 28 Aug.

To determine spatial distribution and abundance among 5 topographic positions, 15 IPM flight intercept traps were hung 2-4 m above the forest floor (approximately 15-18 m below tree canopy) in 15 stands on 5 topographic positions in the 3 geographic areas. Trap data were collected weekly beginning 13 May through 28 Aug. Individual traps in Fly Gap plots were incorporated into vertical trapping systems and data from the bottom trap in the vertical systems (2-4 m above the forest floor) were used in data analyses as those traps were comparable to traps hung 2-4 m above the forest floor in other areas. All trap data from 2003 were used to evaluate flight period, peak flight, and sex ratios.

2005

To compare number of adult red oak borers trapped on ridges among the 3 areas, 3 IPM flight intercept traps were hung just below the northern red oak canopy (approximately 16-19 m above the ground) in each of the 3 ridge stands. Trap data were collected beginning 5 Jul and ending 18 Aug.

Data Analysis

Data were analyzed with JMP 6.0 (SAS 2006). ANOVA, LSD Means Comparison Student's t-test, and regression analyses were used to test for significance at $\alpha = 0.05$. Distribution and abundance trapping data from 2003 were blocked by geographic area to accommodate environmental heterogeneity (Potvin 2001) so that differences in trap catches among the 15 plots on the 5 topographic positions provided a measure of topographic position effect. Data were checked for normality with the Shapiro-Wilk W test and then, if necessary, square root transformed to improve assumptions of normality (McCune and Grace 2002). Chi square analysis was used to test for differences in sex ratios among trap heights and topographic positions.

Some data were lost early in the summer of 2003 in the White Rock and Oark east plots due to damage from black bears, *Ursus americanus* Pallus, and the bottom 2 traps in the Fly Gap ridge plot were blown down once by high winds. Bear damage occurred before adult flight and traps that were blown down were after peak flight. Traps were replaced and it was unlikely that losses appreciably impacted results.

Results

Flight Period and Sex Ratios

One hundred and seventy-two adult red oak borers were caught in 11 traps in 2001. The flight period began in mid-Jun with the first beetles caught the week of 15 Jun (Fig. 2A). The last beetle caught in traps without lights was 7 Aug. Nine of the last 10 beetles trapped after 31 Jul were in traps with UV lights. Peak flight was over a 3-week period from the third week of Jun through the first week of Jul. Average male to female ratio was 1.9:1 (111 to 52) for traps without lights.

One hundred and seventy-six beetles were caught in 35 traps in 2003 with flight beginning late Jun and ending mid Aug (Fig. 2B, C). Peak flight was the first week of Jul with 68 beetles or 38% of the total catch occurring within that week. Average male to female ratio was 1.4:1 (103 to 73). Considering beetles caught in vertical systems in Fly Gap, sex ratios were significantly different from 1:1 on 2 of the 5 topographic positions (Table 1), and there were significant differences among the different topographic positions ($\chi^2 < 0.0001$). There were no differences in sex ratios among different trap heights ($\chi^2 = 0.1994$) and no interaction effect occurred between trap height and topographic position ($\chi^2 = 0.5926$).

Flight Height

One hundred forty-five red oak borers were caught in 25 vertical flight traps in 2003. Vertical trapping systems on the ridge caught 83 beetles, 26 were caught on east-facing, 22 on south-facing, 9 on west-facing, and 5 on north-facing plots. There was a significant negative linear trend in numbers of beetles caught in traps down from the base of the forest canopy for trapping systems in the ridge, north, south, and west-facing stands ($F_{1,4} > 10, P \leq 0.05$) (Fig. 3). Trap catches from the east stand did not exhibit a significant trend with linear, transformed, or second degree polynomial trendlines.

Abundance and Distribution

Thirty-two red oak borers were caught in traps placed 2-4 m off the ground in 2003. Trap catches varied among topographic positions based on analysis of transformed data ($F_{4,14} = 4.2, P = 0.04$). More beetles were caught in traps hung in south (14) and ridge (10) plots than those hung on east (1) and north-facing (1) benches. West-facing benches had intermediate beetle catches (6). The area blocking term was significant ($F_{2,14} = 13.1$, $P = 0.003$) with White Rock traps catching 22 beetles, Oark 9, and Fly Gap 1.

Twenty-seven beetles (16 males, 10 females, and 1 unknown (broken antennae)), were caught in 9 traps hung on ridge plots in the three areas in 2005. Trap catches varied among ridges in the three areas based on analysis of transformed data ($F_{2,8} = 13.4, P = 0.0061$). Traps placed in the Oark ridge plot caught 19 beetles, Fly Gap 3, and White Rock 5.

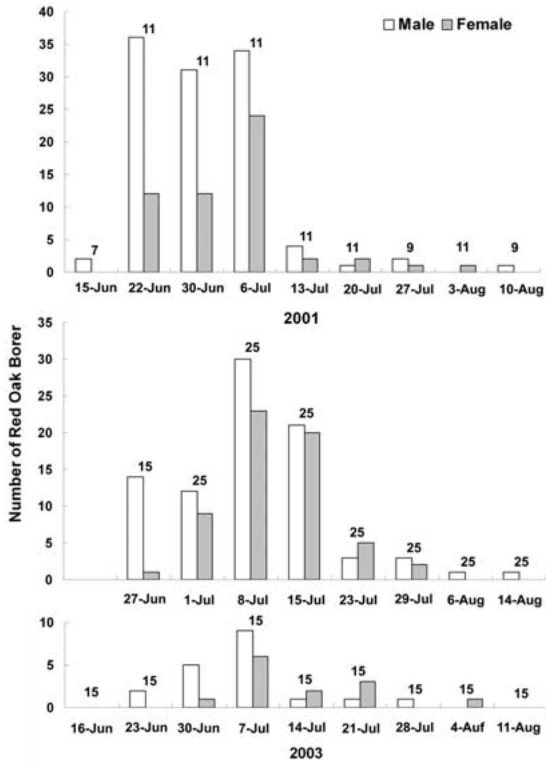

Fig. 2. Number of beetles caught by sex in (A) 2001 traps at Fly Gap, (B) 2003 vertical traps at Fly Gap, and (C) 2003 abundance and distribution traps in three areas. Number of traps given above bars. 2001 traps monitored 8 Jun to 24 Aug (data from traps with lights were not included). 2003 vertical traps monitored 25 Jun to 28 Aug and distribution traps from 13 May to 28 Aug.

Discussion

Flight periods in 2001 and 2003 were similar at 9 and 8 weeks, respectively, but the beginning of the flight period started a week later in 2003. The 2001 distribution is also different from 2003 as numbers increased sharply, remained high for 3 weeks and dropped off abruptly the second week of

TABLE 1. NUMBER OF RED OAK BORER CAUGHT BY SEX IN VERTICAL TRAPS ON 5 TOPOGRAPHIC POSITIONS IN THE FLY GAP AREA OF THE OZARK NATIONAL FOREST.

	Ridge	East	South	West	North
Male	63	11	6	4	1
Female	20	15	16	5	4
Sex ratio	3.2:1	0.7:1	0.4:1	0.8:1	0.3:1
χ^2	<0.0001	0.4319	0.0299	0.7389	0.1650

χ^2 < 0.05 indicates sex ratios significantly different from 1:1.

Jul. In 2003 the first males were caught the third week of Jun, numbers peaked the first week of Jul and decreased steadily to the second week of Aug.

Temperature controls developmental rates of many organisms, including insects, many of which require a certain amount of heat to develop from one point in their life cycle to another (Shelford 1927; Howe 1967; Galford 1974; Wagner et al. 1987). Red oak borer late-stage larvae pupate in late May to early Jun with adult eclosion in mid-Jun to early Jul in Arkansas oaks (Fierke et al. 2005a). An investigation of accumulation of degree-days with a base temperature of 65° from 2 nearby weather stations, Hunstville and Deer, AR, revealed that >30% more degree days accumulated by end of May 2001 than by the same time in 2003. The developmental threshold is unknown for red oak borer; however these calculated differences in degree-day accumulation may be an explanation for earlier flight in 2001.

Adult emergence of 3 red oak borer cohorts from Ohio oaks occurred over 5-6 weeks starting the 3rd or 4th week of Jun and lasting through the 3rd or 4th week of Jul (Hay 1972). This emergence period corresponds nicely to our flight period as beetles normally live 2 to 3 weeks (Donley 1978). A 1:1 sex ratio was observed in Ohio beetles with males outnumbering females in the first 2 weeks and females outnumbering males in the last 2 weeks of the emergence period (Hay 1972). This is lower than the 1.4:1 ratios seen in Arkansas beetles in 2003, and much lower than the 1.9:1 ratio in 2001. This indicates that there may be other unexplained factors involved in the skewed sex ratios documented in Arkansas forests.

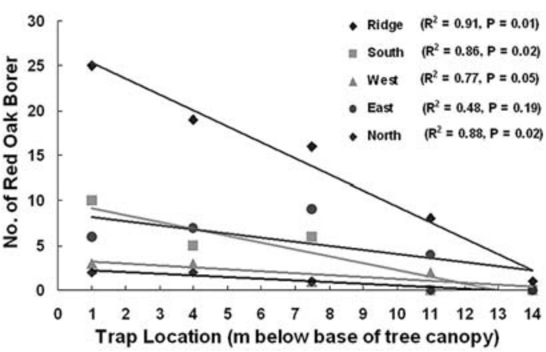

Fig. 3. Trap data from passive flight intercept traps located vertically down from the base of the tree canopy in the Fly Gap area of the Ozark National Forest, Arkansas. Data collected from 25 Jun to 28 Aug 2003.

One possible explanation may be that males fly more than females in search of mates. Hay (1972) installed cages on active attack sites and so ratios were for emerging rather than flying adults. Another explanation may be increased male flight associated with higher red oak borer population densities. Numbers of red oak borer caught in the Fly Gap area in 2001 (174) were high compared with 2003 catches in the same area (145). There were fewer traps in 2001 vs. 2003 (11 vs. 25, respectively) and although handmade traps had a little more functional surface area (2,800 vs. 2,470 cm^2), all 2001 traps were hung about 2 m from the ground while some of the 2003 traps were hung at more "optimal" heights relative to the dominant/co-dominant oak canopy. Field personnel also noted abundant red oak borer adults on understory vegetation in 2001, an observation not made during 2003. Ridge plots have higher within-tree beetle densities (Fierke et al. 2007) and sex ratios based on trap data on the different topographic positions appeared to be very different with much higher male to female sex ratios in ridge traps (3.2:1) compared with traps on other topographic positions (0.3-0.8:1). Flight period and sex ratios were not specifically reported for 2005 as some traps were not in place until the end of Jun, however, considering the data gathered, a 1.6:1 male to female ratio was found on ridge plots.

Installation of black lights in traps late in the field season in 2001 indicated that doing so likely increased number of beetles caught. This suggested that flying adults are attracted to light and was corroborated by lab personnel, who used black lights and white sheets to capture large numbers of adults for genetic analyses and lab-rearing of eggs and neonates. This knowledge should prove useful trapping adults in low density areas to ascertain presence/absence.

Previous research has shown that changing trap height in both agricultural and forested systems results in varying catches of different organisms (Moeed & Meads 1984; Schulze et al. 2001; Su & Woods 2001; Botero-Garces & Isaacs 2003). There were significant linear trends in number of red oak borers caught relative to vertical trap location below the dominant/co-dominant tree canopy with 4 out of 5 trapping systems having increased catches closer to the canopy base. This suggests that optimal trap placement for monitoring adult red oak borer populations should be close to the base of the tree canopy. This supports field observations that beetles likely spend their days in or near the canopy with nocturnal beetle flight initiating from there and remaining just below the canopy until beetles land on other trees. Nocturnal field observations revealed beetles frequently walked down and up tree boles with females spending a great deal of time probing bark crevices with their ovipositors and males moving relatively rapidly along tree boles with antennae held out in front of their bodies.

Adult red oak borer population densities varied both spatially and temporally in study stands. In 2003, more adult beetles were captured in traps located on ridges and south-facing benches compared with traps on east and north-facing benches. These data were corroborated by vertical flight trapping data as there were obvious differences in y-intercepts of linear trendlines for height models on different topographic positions (Fig. 3). Adult flight data presented here on differences in topographic population densities also are supported by other lab research showing higher red oak borer population densities on ridge topographic positions (Fierke et al. 2007).

Flight catches in 2005 were much lower than expected. This was likely due to a precipitous decrease in population densities. This decrease was documented through intensive sampling of whole trees conducted within the same plots (unpublished data) but may also be inferred from trapping data presented here as there was a large decrease in the number of borers caught in the Fly Gap ridge plot between 2003 and 2005. In 2003, one trap just below the canopy in the vertical trapping system caught 25 beetles whereas only 2 borers were caught in 3 traps similarly hung in the same plot in 2005.

This research should enable efficient trap placement and timing of trapping efforts for future monitoring efforts. More information is needed to understand influences of population densities on variation in male to female flight ratios. Increased knowledge of relative distribution and population densities in different areas and in different forest stands should provide insight regarding important factors influencing population densities and may prove helpful in predicting future outbreaks.

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