Effect of Trap Size, Trap Height and Age of Lure on Sampling Xyleborus glabratus (Coleoptera: Curculionidae: Scolytinae), and its Flight Periodicity and Seasonality

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EFFECT OF TRAP SIZE, TRAP HEIGHT AND AGE OF LURE ON SAMPLING *XYLEBORUS GLABRATUS* (COLEOPTERA: CURCULIONIDAE: SCOLYTINAE), AND ITS FLIGHT PERIODICITY AND SEASONALITY

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Abstract

Xyleborus glabratus (Coleoptera: Curculionidae: Scolytinae) is a non-native pest that transmits the causal pathogen of laurel wilt disease to plants belonging to the Lauraceae. To improve the current monitoring and survey techniques of *X. glabratus,* various trapping and flight behavior studies were conducted in natural areas with host species in Alachua County, Florida. Daylight flight rhythm studied at Austin Cary Memorial Forest twice in Sep 2010 using sticky traps baited with manuka lures showed that *X. glabratus* flies mostly between 1600 and 1800 h daylight saving time. Flight height of the beetle was determined in a trapping study using ladder-like traps. The largest number of beetles was trapped at heights of 35-100 cm above the ground. Seasonality of *X. glabratus* was studied in Florida from Mar 2010-Dec 2011. Three peaks of trap catches occurred during Apr 2010, Oct 2010 and Mar 2011. To find the optimal Lindgren funnel trap design for *X. glabratus*, a study was conducted using 4, 8, 12 and 16 funnels per trap. Funnel traps with 8, 12, 16 funnels per trap captured similar numbers of *X. glabratus,* but significantly more than with 4 funnels per trap. The effect of aging of manuka lures was studied at 2 different sites in Alachua County, Florida. New manuka lures trapped significantly more *X. glabratus* than lures aged 2, 4 and 6 wk. Trap color, whether black, white, blue, yellow, red or transparent, had no significant influence on the number of *X. glabratus* trapped.

Key Words: Redbay ambrosia beetle, flight, funnel trap, seasonality, *Xyleborus*

Resumen

Xyleborus glabratus (Coleoptera: Curculionidae: Scolytinae) es una plaga no nativa que transmite el patógeno que causa la enfermedad de la marchitez del laurel a las plantas que pertenecen a la familia Lauraceae. Para mejorar las técnicas actuales de monitoreo y llevar a cabo un sondeo de *X. glabratus*, se realizaron various estudios de captura y de comportamiento de vuelo en las áreas naturales donde habian especies de plantas hospederas en el condado Alachua, Florida. Se estudió el ritmo de vuelo diurno en el Bosque Memorial de Austin Cary dos veces en septiembre del 2010 usando trampas pegajosas con un señuelo de manuka que mostraron que *X. glabratus* vuela principalmente entre 1600 y 1800 h. Se determinó la altura de vuelo del escarabajo en un estudio de captura con trampas, en forma de una scalera. El mayor número de escarabajos fue atrapado a una altura de 35-100 cm arriba del suelo. Se estudió la estacionalidad de *X. glabratus* en la Florida desde marzo del 2010 hasta diciembre del 2011. Los tres picos en el numero de *X. glabratus* capturado sucedieron en abril 2010, octubre 2010 y marzo del 2011. Para encontrar el diseño de la trampa de embudo Lindgren óptimo para *X. glabratus*, se realizó un estudio con 4, 8, 12 y 16 embudos por trampa. Las trampas de embudo con 8, 12, 16 embudos por trampa capturaron un número similar de *X. glabratus*, pero un número significativamente mayor que las trampas con 4 embudos por trampa. Se estudió el efecto del envejecimiento de señuelos de manuka en 2 sitios diferentes en el condado de Alachua, Florida. Los nuevos señuelos de manuka capturaron significativamente más *X. glabratus* que los señuelos que tenian 2, 4 y 6 semanas. El color de la trampa, ya sea negro, blanco, azul, amarillo, rojo o transparente, no tuvo influencia significativa en el número de *X. glabratus* capturados.

Palabras Clave: escarabajo ambrosia del laurel rojo, vuelo, trampa, trampa de embudo, la estacionalidad, *Xyleborus*

The redbay ambrosia beetle (*Xyleborus glabratus* Eichhoff) (Coleoptera: Curculionidae: Scolytinae) is a non-native ambrosia beetle that acts as a vector of the pathogenic fungus, *Raffaelea lauricola* (Fraedrich et al. 2008; Hanula et al. 2008). It causes laurel wilt in species of the family Lauraceae, including avocado (*Persea americana* Mill), redbay (*Persea barbonia* (L.) Spreng.), swampbay (*Persea palustris* (Raf.) Sarg.), sassafras (*Sassafras albidum* (Nutt.) Nees), pondspice (*Litsea aestivalis* (L.) Fernald), pondberry (*Lindera melissifolia* (Walter) Blume,), and camphor (*Cinnamomum camphora* (L.) Sieb). *Xyleborus glabratus* was first discovered at Port Wentworth near Savannah, Georgia in 2002 (Rabaglia et al. 2006) and has since established in South Carolina, Georgia, Florida, Alabama and Mississippi. *Xyleborus glabratus* is a small cylindrical beetle about 2 mm in size. Males are flightless and smaller than females. The beetle actively carries the fungus *Raffaelea lauricola* in its mycangia along with *R. arxii*, *R. subalba*, *R. ellipticospora*, *R. fusca* and *R. subfusca* (Harrington et al. 2008; Harrington et al. 2010). Both the larvae and adults of the beetle are thought to feed on the fungal complex that grows inside the galleries formed by the adult females. The beetle inoculates the tree with *R. lauricola* while excavating the galleries and, subsequently, infects the host systemically, causing a vascular wilt and tree death within a few weeks to months of infection. Laurel wilt has caused mortality of yard and experimental avocado trees (Mayfield et al. 2008) and now threatens the commercial avocado production in Florida (Ploetz & Peña 2007; Crane et al. 2008; Ploetz et al. 2012).

In order to develop efficient management and monitoring strategies, a greater understanding of the life history and flight dynamics of the beetle is required. Preliminary studies have shown that adult beetles were active throughout the yr with high activity in Sep in South Carolina and Georgia (Hanula et al. 2008; Hanula et al. 2011). Manuka oil and phoebe oil can be used as attractive baits for trapping *X. glabratus* (Hanula & Sullivan 2008). However, Kendra et al. (2011) demonstrated that phoebe lure attracted more *X. glabratus* than manuka lure.

Monitoring and survey of invasive bark beetles and ambrosia beetles are generally conducted using Lindgren multifunnel traps (Lindgren 1983; Miller & Duerr 2008; Kendra et al. 2011). Hanula et al. (2011) recommended using funnel traps baited with a single manuka lure for trapping *X. glabratus*. We therefore designed tests to compare the 4-, 8-, 12-, 16-funnel Lindgren traps to find the optimal length of funnel trap for trapping *X. glabratus*. We investigated the effectiveness of the manuka bait as it ages in the hot and humid climate of Florida during field tests. In the previous studies, it was reported that 85% of *X. glabratus* were trapped at 1.5 m above the ground when flight height was investigated between 1-15 m above the ground (Hanula et al. 2011). We further investigated the flight height of the *X. glabratus* in the 0-3.45 m zone above the ground, to determine the height of the trap having the highest probability of trapping the beetle. We also investigated the flight periodicity of *X. glabratus* and the seasonality of beetle. This research also included evaluation of trap color.

Materials and Methods

Daylight Flight Periodicity

To study the daylight flight periodicity of *X. glabratus* flight activity, 2 independent studies were conducted from 17-21 Sep and 23-30 Sep 2010 at the Austin Cary Memorial Forest (ACMF), Alachua County, Florida (N 29° 45.084' W 082°12.875'). ACMF has approximately 800 ac of planted pine, primarily slash pine, 900 ac of 60-80 yr old naturally regenerated pine (predominately longleaf pine), 35 ac of bottomland hardwood, including native Lauraceae, (i.e., *Persea borbonia*), 265 ac of cypress ponds and cypress or hardwood drains, and 40 ac of non-timbered land. Transparent plexiglass panels 20 cm wide and 41 cm high were used as traps. Transparent films (3M™ Write On Transparency Film, AF4300) smeared with Tree-Tanglefoot® (Tree Tanglefoot Company, Grand Rapids, Michigan) were clipped on both sides of the plexiglass with the help of small binder clips (1.9 cm, Office Depot). A manuka lure (Synergy Semiochemicals Corp., British Columbia, Canada) was used as an attractant, and the lure was tied to the top of the plexiglass panel. Hourly environmental data for Alachua County, Florida (fawn.ifas.ufl.edu) were used to assess the correlation of hourly trapping of *X. glabratus* with solar radiation. Solar radiation was recorded at the Florida Automated Weather Network site at Department of Agronomy Forage Reseach Unit, Alachua County (N 29° 48.160' W 082° 24.649'). The distance between the two sites is about 20 km.

The traps were hung between 2 non-host (*Pinus* spp.) trees at an average height of 0.5 m above the ground. Each trap was ca. 5 m away from a host tree, i.e., *P. borbonia*. Eight traps were used with 10 m between adjacent traps. The numbers of *X. glabratus* trapped each h were counted using a 10X hand lens and the beetles were removed after each observation. During the first study, daylight observations were recorded from 700-1900 h each d while during the second study daylight observations were recorded from 1200-2000 h. Observations were expressed in daylight saving time (DST).

Trap Height

The effect of trap height on catch of *X. glabratus* was studied at ACMF from 5-13 Oct 2010. Ten transparent plexiglass panels panel (20 × 30 cm) were joined lengthwise with 5 cm distance between adjacent plexiglass panels (ladder-like trap). Each panel was numbered, with the top panel numbered trap 10 and lowest panel (touching the ground) numbered trap 1. A manuka lure was tied between all adjacent plexiglass panels. A transparent film was clipped on both the sides of plexiglass panel as described above and Tree-Tanglefoot was smeared on the transparent film. The total trap height extended to 3.45 m above the ground. Traps were hung at 5 different locations within the forest. Traps were set 10 m between adjacent traps and at a distance ca. 5 m away from the host trees. Each trap was hung between 2 non-host trees (*Pinus* spp.). Transparent films were removed each d and transferred to the laboratory where *X. glabratus* beetles were counted using a 10X hand lens.

Trap Design

The optimal trap design for trapping *X. glabratus* was studied using 4- , 8- , 12- and 16-funnel Lindgren multifunnel traps. Traps were hung in 5 blocks (locations). Each block was supplied with 1 funnel trap of each design. The various traps were hung 50 m apart from each other in the 3 blocks at Austin Cary Memorial Forest (ACMF), in 1 block at Ordway Swisher Biological Station (OSBS), Alachua County, Florida (N 29°41.040' W 082°22.109') and in 1 block at Hatchet Creek Wildlife Management Area (HCWMA), Alachua County, Florida (N 29°42.509' W082°12.502'). OSBS is characterized by a mosaic of wetlands and uplands that include sandhills, xeric hammocks, and upland mixed forest that includes *P. borbonia*, swamps, marshes, clastic upland lakes, sandhill upland lakes and marsh lakes. HCWMA comprises 1,932 ha of mixed canopy of hardwoods that include *Persea pallustris,* and *P. borbonia* with cypress as well as stands of slash and loblolly pine, *Pinus taeda* L.; Pinales: Pinaceae. In each of the above mentioned 5 blocks, the traps were spaced at least 10 m apart. Each trap was suspended at 0.5 m above the ground from a rope tied between 2 non-host trees. Each trap was ca. 5 m away from each of these trees. Manuka lure was used as an attractant. The manuka bait was tied half way between the lower and the top funnel. Manuka lures were replaced monthly from Mar-Oct 2010 and biweekly from Oct 2010-Dec 2011. A wet collecting cup (Synergy Semiochemicals Corp., British Columbia, Canada) was placed in the lower funnel and filled with antifreeze (Prestone prediluted antifreeze, Prestone Corp. Danbury, Connecticut). The contents of the cup were collected every 14 d and brought to laboratory where *X. glabratus* specimens were recorded using a microscope. This study was conducted from Mar 2010-Dec 2011.

Seasonality

The abundances of *X. glabratus* in 3 different areas in Alachua County, Florida were determined based on the mean number of *X. glabratus* trapped every 2 wk for each kind of

TABLE 1. RED, GREEN, BLUE VALUES (MEAN ± SE) AND TRICHROMATIC PERCENTAGES FROM AREAS OF DIGITAL PHOTOS OF COLORED TRAPS ANALYZED BY THE JAVA SOFTWARE FROM BYERS (2006).

		Red		Green		Blue		HSL		
Trap color	Pixels[a]	Mean ± SE	%	Mean ± SE	%	Mean ± SE	%	Hue	Saturation	Luminosity
Black	1223694	50 ± 22	44	47 ± 19	41	45 ± 18	41	0.06	0.05	0.18
Blue	1194164	30 ± 5	16	125 ± 6	5	226 ± 3	1	0.91	0.62	0.50
Yellow	1022250	175 ± 11	6	132 ± 8	6	1 ± 3	183	0.12	0.98	0.34
Red	1228437	231 ± 3	1	30 ± 5	17	34 ± 5	15	0.99	0.65	0.51
White	872410	142 ± 11	8	143 ± 10	7	143 ± 10	7	0.94	0.01	0.56

[a]Areas analyzed in pixels

trap design. These bimonthly trap catches were plotted and their trends compared from Mar 2010-Dec 2011.

Trap Color

Black, red, yellow, blue, white and transparent colors were tested for influence on *X. glabratus* trap catch. Plywood panels were cut to 20 × 41 cm and painted with 5 colors, i.e., black, red, yellow, blue, and white (Rust - Oleum® Gloss protective enamel spray paint). The colors of the traps were described by analyzing JPEG images of different colored traps using Java software described by Byers 2006 (Byers 2006). The color attributes measured were RGB (red, green, blue) values, trichometric percentages, and HSL (hue, saturation, luminosity) values (Table 1). The different colored traps were photographed 1600 h DST in the sunlight on 3 Jan 2012 using a Canon Power Shot SD 880 IS digital camera at 2048 × 3648 pixel resolution. Transparent plexiglass panels were each also cut at the same length as each plywood panel (20 × 41 cm). Transparent film was attached to each trap with Tree-Tanglefoot smeared on it as described in the flight periodicity procedure. Five blocks were set up at 5 different locations. One block was at OSBS and another at HCWMA plus 3 blocks at ACMF (blocks separated by at least 50 m). Each of these 5 blocks had a different color trap and a transparent plexiglass trap. Within each block, traps were at least 10 m apart. The traps were hung between 2 non-host trees about 0.5 m above the ground. The study was conducted from 16 Aug 2010-8 Oct 2010. The transparent films were brought to the laboratory every other wk and *X. glabratus* were counted using a 10X hand lens.

Manuka Lure Aging and Effectiveness of Aged Lures

Manuka lures (P385-Lure M, Synergy Semiochemicals Corp., British Columbia, Canada) were aged 2, 4 and 6 wk by hanging them on non-host trees in the field (ACMF). After aging, manuka lures were placed halfway between the top and lower funnel of each 4-funnel Lindgren multi-funnel trap. A wet collecting cup was fixed below the bottom funnel and filled with antifreeze. The contents of each collecting cup were removed every 14 d and bought to the laboratory where *X. glabratus* specimens were recorded using a microscope. Four blocks of traps were placed in the field (3 at ACMF and one at the OSBS). Each block had a set of traps each with a differently aged manuka lure. Adjacent traps were spaced apart approximately 10 m. The control treatment was a new manuka lure (not aged). This study was conducted from 16 Aug 2010-8 Oct 2010.

Statistical Analysis

Data were analyzed using SAS (SAS Institute 2004). The data from the diurnal flight periodicity studies were analyzed by repeated measure analysis using Proc GLIMMAX with an individual trap as the replicate. Flight periodicity data for both the studies between 1200h-1900h was combined and correlated with the solar radiation for same times using PROC CORR (Pearson correlation coefficient) in SAS. Trap height data were analyzed after log-transformation using the repeated measure of analysis facility of Proc GLIMMAX with an individual trap as the replicate. Proc GLIMMAX was used for repeated measure analysis of trap design, trap color and manuka lures studies with individual blocks as a replicate. Means were separated using the Tukey-Kramer multiple comparisons test.

Results

Daylight Flight Periodicity

There was a significant effect of the time (h) of day DST on the mean number of *X. glabratus* captured per trap per h in the first study (F = 7.47; df = 11, 464; $P < 0.0001$). During daylight hours, there was only one peak flight of the beetle, which occurred between 1700–1900 h DST (Fig. 1). A similar flight trend was observed during the second study. There was a significant effect of time of d (h) on the mean X. *glabratus* numbers/trap/h during the study (F = 11.72; df = 7, 49; $P <$ 0.0001) with one flight peak between 1600-1800 h DST. The least number of beetles were trapped between 1900-2000 h DST (Fig. 2). For both studies mean *X. glabratus* numbers/trap/h between 1200h-1900h DST were significantly negatively correlated with solar radiation (r = -0.36, $P <$ 0.0001, N = 616). The sunset time averaged 19.30 h for first study and 19.14 h for second study (Edwards 2012)

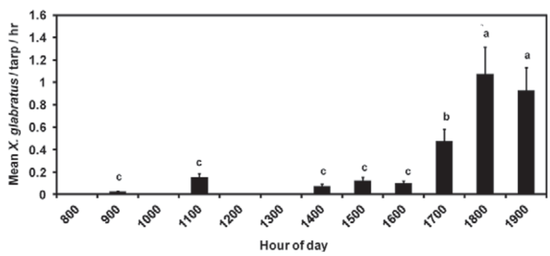

Fig. 1. Numbers of *Xyleborus glabratus* (mean ± SE) trapped per trap per hour over five days at Austin Cary memorial forest, Alachua County, Florida (17-21 Sep 2010) (N = 8). Bars with same letter are not significantly different according to the Tukey- Kramer test for difference of means ($P < 0.05$). The sunset time averaged 19.30 h DST.

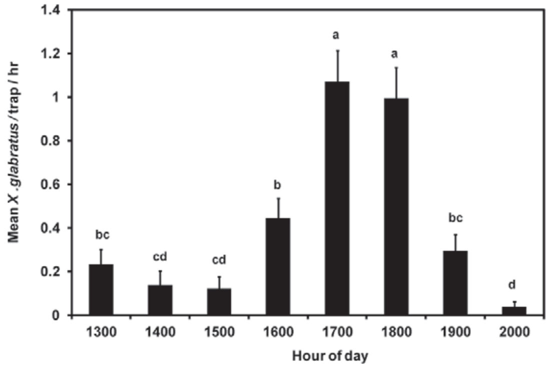

Fig. 2. Numbers of *Xyleborus glabratus* (mean ± SE) trapped per trap per hour over eight days (23-30 Sep 2010) conducted at Austin Cary Memorial Forest, Alachua County, Florida (N = 8). Bars with same letter are not significantly different according to the Tukey-Kramer test for separating means (P < 0.05). The sunset time averaged 19.14 h DST.

Trap Height

Height of the trap above the ground had significant effects on the number of *X. glabratus* trapped (F = 36.30; df = 9, 36; P < 0.0001). The highest numbers of *X. glabratus* were trapped on panels 35-100 cm above the ground. The fewest *X. glabratus* were trapped on the panels 315-345 cm above the ground. Therefore, the number of beetles trapped decreased with increasing height (Fig. 3).

Trap Design

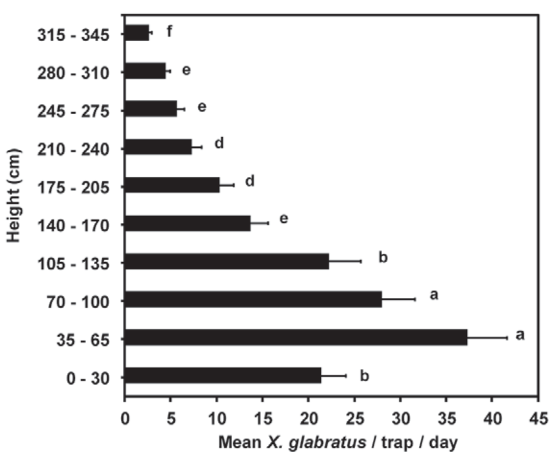

Fig. 3. Effect of height of the trap on numbers of *Xyleborus glabratus* trapped. Bars are numbers (mean ± SE) of *X. glabratus*/trap/day in a study at Austin Cary Memorial Forest, Alachua County, Florida during (5-13 Oct 2010). Analysis was conducted on log-transformed data. Bars with same letter are not significantly different according to the Tukey-Kramer test for separating means (P < 0.05).

There was a significant effect of trap design on the trap catch of *X. glabratus* (F = 5.24; df = 3, 426; P = 0.0015). Four-funnel traps captured the least number of beetles. There was no significant difference between captures of beetles in 8- , 12- and 16- funnel traps (Table 2). There was a significant difference in capture per funnel for each trap design (F = 11.52; df = 3, 83; P < 0.0001). Most beetles per funnel were trapped in the 4-funnel (mean = 1.1 per funnel per 2 wk, SE = 0.18) and 8-funnel trap (mean = 1.0 per funnel per 2 wk, SE ± 0.18) and the fewest were captured in the 12-funnel trap (mean = 0.59 per funnel per 2 wk, SE ± 0.18) and 16-funnel trap (mean = 0.46 per funnel per 2 wk, SE ± 0.18) (Table 2).

Seasonality

Xyleborus glabratus were trapped throughout the period of the study from Mar 2010 - Dec 2011. During the winter months of Nov, Dec and Jan very few beetles were trapped with trap catches ranging from 0.5-3.3 per trap per 2 wk. The greatest numbers of beetles were trapped in early Apr 2010 and in early Mar 2011 with trap catches ranging from 42.9 to 49.9 per trap per 2 wk, respectively. During the period of the study, 3 peaks of trap catches were observed, i.e., in Apr 2010, Oct 2010 and Mar 2011. Trap catches of beetles declined from Mar 2011 to Dec 2011 (Fig. 4).

Manuka Lure Aging

Age of the lure had a significant effect on the numbers of *X. glabratus* trapped (F =17.34; df = 3, 11; P = 0.0002). The highest numbers of beetles were caught when fresh lures were used (mean = 9.5 per trap per 2 wk, SE ± 2.7). There were no significant differences between the traps catches when the lures were 2, 4 and 6 wk old (Table 3).

Trap Color

Color had no significant effect on catch per trap of *X. glabratus* (F = 0.87; df = 5, 29; P = 0.5153). Nevertheless the black colored traps caught the most beetles (mean = 1.1 per trap per 2 wk, SE ± 0.5), and the transparent traps caught the least (mean = 0.5 per trap per 2 wk, SE ± 0.2).

Discussion

Daylight flight of *X. glabratus* started in the late afternoon for a period of 3 h from about 1600-1900 h DST, ending at sunset. A similar pattern of unimodal behavior in midday was observed in the bark beetle *Ips typographus L.* and *Pityogenes chalcographus* L. in Sweden (Byers 1983). In contrast, bimodal flight with peaks in early morning and soon after dusk have been observed for *Orthotomicus erosus* and *Pityogeges calcara-*

tus (Mendel et al. 1991). High flight activity in low light was recorded for *Gnathotrichus retusus* (Lee) (Liu & Mclean 1993) and *G. sulcatus* (Lee) (Rudinsky & Schneider 1969). This suggests that flight pattern is species specific for the Scolytinae. It is probably also a function of interaction of 3 environmental cues: light intensity, temperature and humidity (Rudinsky & Schneider 1969; Liu & Mclean 1993). The unimodal flight behavior of *X. glabratus* may be considered a species-specific phototactic response to decreasing average solar radiation and decreasing average temperatures in the late afternoon. Whether solar radiation and temperature are the sole or primary factors that influence the flight behavior of *X. glabratus* would require additional data from repeated experiments during a wider range of environmental conditions.

Hanula & Sullivan (2011) reported that 85% of *X. glabratus* were trapped at a height of 1.5 m above the ground using sticky traps. We found similar results using a different type of trap (ladder-like trap) and experimental design. The maximum numbers of *X. glabratus* were caught at a height 35-100 cm above the ground, with beetle captures decreasing as the trapping height increased. We suggest that traps for *X. glabratus* should be placed between 0.35 m and 1 m from the ground in order to optimize trapping results.

More *X. crassiusculus* were caught more in traps at 0.5 m than at 1.7 and 3.0 m, whereas more *Xylosandrus germanus* were caught in traps at height 0.5 m and 1.7 m than at 3.0 m (Reding et al. 2010). *Ips duplicatus* (Sahlberg) were trapped significantly more in window-slot traps at a 1.5 m above the ground compared with traps at ground level and at 3.5 m above the ground (Chen et al. 2010). More *Ips typhographus* were trapped at 0.7 m than at heights ranging from 1.5 to 11.5 m using semiochemical lures (Byers et al. 1989). Thus, it appears that many Scolytinae fly relatively close to the ground.

In South Carolina, Hanula et al. (2008) and in Georgia, Hanula et al. (2011) detected peak activities of *X. glabratus* during Sep, with low activity in Jan and Feb. In Florida, peaks in beetle catches were observed in Mar-Apr 2010, Sep-Oct 2010 and Feb-Apr 2011, suggesting 2 major peaks of trap catches in a year. Small peaks in beetle catches were observed from May-Aug 2010. However, it is suggested that decrease in beetle catches might be a function of combination of several factors, i.e., age of the manuka lure, temperature, rainfall frequency and scarcity/absence of hosts in the study areas. For instance, baits were changed every 4 wk before Oct 2010, after which baits were changed every 2 wk, based on the results of the manuka lure aging experiment. The low trap catches of *X. glabratus* observed in the cold mo of Dec and Jan can be related to low temperatures. It is possible that the second peak in trap catches during 2011 was not observed because most redbay and swampbay trees in the areas of study had already perished. For instance, during 2009 at the Ordway Swisher site, *X. glabratus* densities built up when there was a mixture of laurel wilt-symptomatic and asymptomatic trees. By 2010, all of the trees has wilted and were decaying. *Xyleborus glabratus* trap averaged 0.82/trap/2 wk over the total period of study (Jul 2010-Dec 2011). Trap catches decreased at all study sites from 2010 to 2011, due to exhaustion of host trees.

Higher numbers of *Xyleborus glabratus* were trapped in 8- , 12- and 16- funnel traps as compared with 4-funnel traps. In a similar comparison of 8- and 16- funnel trap baited with ethanol and (-) - α - pinene, greater numbers of *Xyleborus* spp. were trapped in the 8-funnel trap, whereas more *Ips grandicollis* and *Xyleborinus saxesenii* were trapped in the 16-funnel trap (Miller et al. 2009). Trap catches of *Trypodendron lineatum* increased with an increase in number of funnels per trap with 16 funnels trapping more than 12- , 8- and 4- funnel traps (Hoover et al. 2000). Results from these studies indicate that there is a relationship between funnel length and trap catches of various Scolytinae species. The number of *X. glabratus*

TABLE 2. NUMBERS OF *XYLEBORUS GLABRATUS* TRAPPED IN LINDGREN TRAPS WITH DIFFERENT NUMBERS OF FUNNELS IN ALACHUA COUNTY, FLORIDA FROM MAR 2010-NOV 2011.

Trap design	N	Mean ± SE of *X. glabratus*/trap/2 wk	Mean ± SE of *X. glabratus*/funnel/2 wk[a]	Cost of complete trap with wet cup[b] (US $)
4 Funnels	4	4.1 ± 2.1 b	1.1 ± 0.18 a	32.40
8 Funnels	4	7.0 ± 3.4 a	1.0 ± 0.18 a	43.28
12 Funnels	4	6.0 ± 3.2 a	0.59 ± 0.18b	52.37
16 Funnels	4	6.3 ± 3.3 a	0.46 ± 0.18 b	60.40

[a]Analyses were conducted on square roots of transformed data.
[b]Costs are based on prices of Synergy Semiochemicals Corp., British Columbia, Canada.
Means followed with same letter are not significantly different based on the Tukey- Kramer test for separating means ($P < 0.05$).

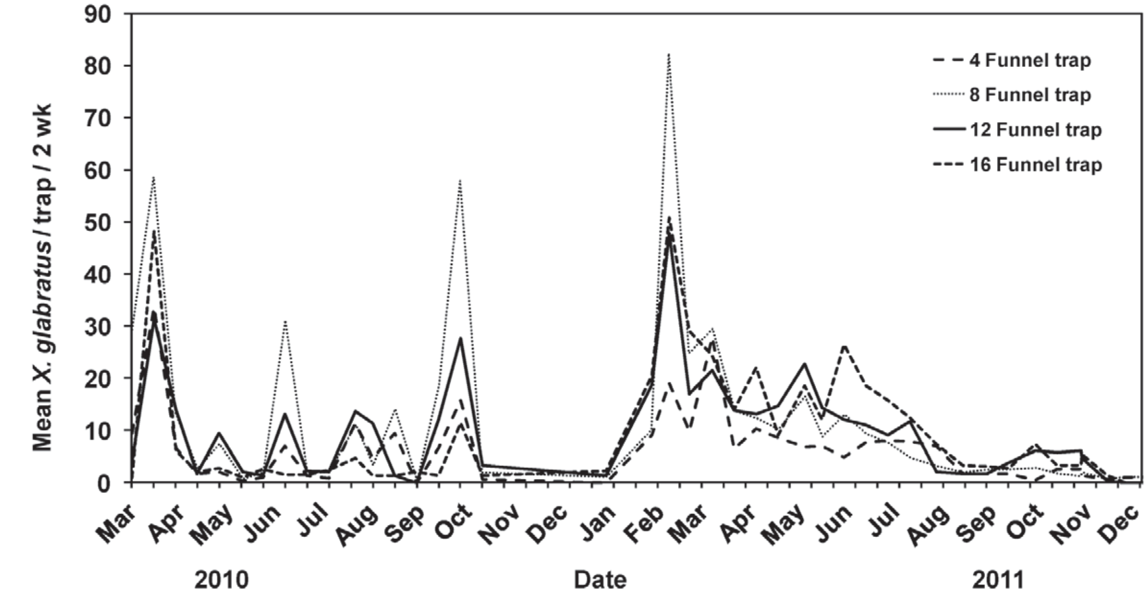

Fig. 4. Seasonality of *Xyleborus glabratus* in Florida. Mean *X. glabratus* numbers/trap/2 wk in 4 different kinds of trap, using manuka lure. Manuka baits were replaced monthly from Mar to Oct 2010 and biweekly from Oct 2010 to Dec 2011. Study was conducted at 4 different sites near Alachua County, Florida during Mar 2010-Dec 2011. Traps were serviced every 2 wk.

trapped per funnel was highest in 4-funnel and 8-funnel traps. Based on the economics of using funnel traps, the 4-funnel traps are the most economical (Table 2) However, the optimal trap design may mainly depend on our goals (e.g., for population dynamics, 4-funnel traps may be the best, but for monitoring the appearance of *X. glabratus* in new areas, the 8-funnel might be the best).

Trap color had no significant effect on capture of *X. glabratus* in nonbaited traps. This result agrees with the results of Hanula et al. (2011) in South Carolina and Georgia. In contrast, trap color impacted the capture of other scolytinae. In Florida, multifunnel traps colored black, blue, brown, gray, green, and red trapped more *Dendroctonus frontalis* Zimmermann than white and yellow traps (Strom & Goyer 2001). Significantly, higher numbers of *Ips typographus* and *Podendron lineatum* were trapped in pheromone -baited flight barrier traps than were transparent, black, green, grey or red brown as compared to white (Dubbel et al. 1985). More *Ips duplicatus* (Sahlberg) were trapped in window slot traps colored black or red compared to white or yellow (Chen et al. 2010).

Attractiveness of manuka bait decreases quickly with time in Florida, probably due to high temperatures and relative humidities. The temperature over the period of investigation from 16 Aug 2010-8 Oct 2010 averaged 24.6 °C, with maximum and minimum temperatures of 36.5 °C and 5.5 °C, respectively, and with relative humidity averaging 83% (fawn.ifas.ufl.edu). In our study, we found that manuka bait loses its attraction within 2 wk. Kendra et al. (2012) concluded that the maximum field life of manuka lures is 2-3 wk in Florida. Therefore, these lures should be replaced every 2 wk for optimal beetle catch.

To conclude, our studies suggest that for monitoring the spread of *X. glabratus* into new areas, the 8-funnel Lindgren funnel trap is optimal. Traps should be set at 35-100 cm above the ground for maximum probability of trapping *X. glabratus*. Manuka bait should be changed every other week, and trap color does not influence the catch of *X. glabratus*.

TABLE 3. NUMBERS OF *XYLEBORUS GLABRATUS* TRAPPED USING MANUKA LURES OF DIFFERENT AGES.

Aging interval in weeks	N	Mean ± SE of *X. glabratus*/trap/2 wk
0-2	4	9.5 ± 2.3 a
2-4	4	1.8 ± 0.8 b
4-6	4	1.5 ± 0.6 b
6-8	4	0.6 ± 0.4 b

Means followed by the same letter are not significantly different based on Tukey- Kramer test for difference of means ($P < 0.05$).

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