Spatiotemporal Distribution of Stink Bugs (Hemiptera: Pentatomidae) in Peach Orchards and Surrounding Habitat

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Spatiotemporal distribution of stink bugs (Hemiptera: Pentatomidae) in peach orchards and surrounding habitat

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Abstract

Stink bugs (Hemiptera: Pentatomidae) are economic pests of a variety of fruit crops across the southeastern USA, and damage by stink bugs to peaches is common. The landscape surrounding orchards may influence stink bug distribution and dispersal into this commodity, but such patterns may vary over the growing season. Accordingly, stink bug control should be targeted seasonally towards habitats that effectively reduce or prevent damage to peach. In this study, we used pheromone-baited traps to characterize distribution patterns of 2 stink bug species, *Euschistus servus* (Say) and *Euschistus tristigmus* (Say) (both Hemiptera: Pentatomidae), in peach orchards and surrounding habitat over 2 seasons at 3 sites in central Georgia, USA. In addition, we used Spatial Analysis by Distance Indices to identify significant aggregations of each species over the duration of the growing seasons. Adults captured in traps differed by species, and distribution patterns varied by habitat and wk sampled. *Euschistus servus* was commonly found in peaches, whereas *E. tristigmus* was not. Regardless of orchard or yr, adult *E. servus* tended to avoid woodland habitat, whereas *E. tristigmus* tended to prefer this habitat type. Both species increased later in the season in peach orchards with significant spatial aggregations of each detected at all orchards. However, the wk in which aggregations were detected varied by orchard and yr. Across all orchards, *E. servus* adults clustered mainly in peach trees adjacent to pecan, as well as pine, fallow, and kudzu habitat. Adult *E. tristigmus* aggregated primarily in woodland, pine, and pecan habitat. Seasonal distribution patterns of *E. servus* and *E. tristigmus* suggest that control measures may need to be implemented on a fine spatial scale across peach and non-crop habitats.

Key Words: pheromone-baited trap; *Euschistus servus*; *Euschistus tristigmus*; SADIE; landscape; habitat prevalence

Resumen

Las chinches hediondas (Hemiptera: Pentatomidae) son plagas económicas de una gran variedad de cultivos frutales, incluyendo los melocotones (duraznos), en el sureste de los Estados Unidos. Además, el campo alrededor de los huertos puede influir en la distribución y dispersión de las chinches hediondas en estas plantaciones, pero estos patrones pueden variar durante la temporada de crecimiento. En consecuencia, el control de las chinches hediondas debe dirigirse estacionalmente hacia los hábitats que reducen o previenen eficazmente el daño al durazno. En este estudio, utilizamos trampas cebadas con feromonas para caracterizar los patrones de distribución de 2 especies de chinches hediondas, *Euschistus servus* (Say) y *Euschistus tristigmus* (Say) (ambos Hemiptera: Pentatomidae), en huertos de duraznos y hábitats circundantes durante 2 temporadas en 3 sitios en el centro de Georgia. Además, utilizamos el "Análisis Espacial por Índices de Distancia" (AEID) para identificar agregaciones significativas de cada especie durante este período. Los adultos capturados en trampas difieren según la especie y los patrones de distribución varían según el hábitat y la semana muestreada. *Euschistus servus* se encontró comúnmente en melocotones, mientras que *E. tristigmus* no. Independientemente del huerto o el año, los adultos de *E. servus* tendían a evitar el hábitat de los bosques, mientras que *E. tristigmus* tendía a preferir este tipo de hábitat. Ambas especies aumentaron más tarde en la temporada en melocotones con agregaciones espaciales significativas en todos los huertos en que era detectada. Sin embargo, la semana en la que se detectaron las agregaciones varió según el huerto y el año. En todos los huertos, los adultos de *E. servus* se agruparon principalmente en los árboles de durazno adyacentes al pacana, así como en el hábitat de pinos, barbechos, y kudzu. Los adultos de *E. tristigmus* se agregan principalmente en el hábitat de bosques, pinos, y pacanas. Los patrones de distribución estacional de *E. servus* y *E. tristigmus* sugieren que es posible que sea necesario implementar medidas de control en una escala espacial fina en los hábitats de duraznos y no agrícolas.

Palabras Clave: trampa con cebo de feromonas; *Euschistus servus*; *Euschistus tristigmus*; SADIE; AEID; paisaje; prevalencia del hábitat

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Stink bugs (Hemiptera: Pentatomidae) are economic pests of row, horticultural, and orchard crops across the southeastern USA (McPherson & McPherson 2000). Moreover, stink bugs and associated feeding injury on peach fruit from these pests (i.e., catfacing) are common. Commercial peach production occurs in many southeastern states, but approximately 80% of regional production occurs in Georgia, USA, and South Carolina, USA. Combined, the 2 states produced 114,000 tons of peaches in 2019, with a production value of $123.7 million (nass.usda.gov). Two common pentatomids that attack southeastern peaches include native species *Euschistus servus* (Say) and *Euschistus tristigmus* (Say) (both Hemiptera: Pentatomidae) (Johnson et al. 2005). Despite geographic overlap between these 2 species, habitat partitioning may occur within southeastern agroecosystems for stink bugs and their egg parasitoids (Cottrell & Tillman 2015; Tillman 2016; Tillman & Cottrell 2016). Therefore, understanding species-specific distribution patterns in commercial peach orchards is important to inform management strategies that aim to reduce fruit damage.

The habitat within and surrounding peach orchards may influence stink bug distribution and dispersal into peaches, but such patterns may vary over the growing season. In central Georgia, most commercial peach cultivars are harvested from late May through early Aug. Many large peach orchards are comprised of contiguous blocks of several cultivars, each with different ripening dates. As a result, early ripening cultivars are located next to later ripening cultivars; commonly green fruit is available on some cultivars when others have been harvested. Stink bugs can exploit non-crop hosts in agricultural landscapes (Panizzi 1997; McPherson & McPherson 2000), as well as early maturing crops, where non-crop habitat can act as a source of individuals that later disperse into maturing crops (Panizzi 1997; Reay-Jones 2010; Olson et al. 2012; Tillman & Cottrell 2016; Babu et al. 2019). Ideally, stink bug control methods designed and implemented among surrounding habitats would lessen or prevent stink bug damage to peach. However, this requires an understanding of early season spatial and temporal movement of stink bugs among habitats surrounding peach orchards.

In this study, we tested the hypothesis that the distribution patterns of 2 native stink bugs, *E. servus* and *E. tristigmus*, in and around peach orchards varies by habitat type, season, and species. To test our hypothesis, we used pheromone-baited traps to capture the 2 stink bug species in peach orchards and surrounding habitat every wk for 2 seasons at 3 sites in central Georgia.

Materials and Methods

STUDY SITES

The study was conducted in and around 3 peach orchards each yr in central Georgia. In 2002, traps were set at Doles (32.4840°N, 82.9180°W), Holcomb (32.5890°N, 83.8120°W), and Cobb (32.5420°N, 83.8590°W) orchards. In 2003, traps were set again at Doles and Holcomb orchards, but Cobb was exchanged for Silver orchard (32.5280°N, 83.7730°W) due to the unforeseen removal of the former orchard by the grower. However, the habitat surrounding Silver was similar to Cobb, and consisted of peach trees surrounded by pine and pecan. The number of traps at each site varied, depending on the size of the target peach orchard and habitat surrounding the orchard (n = 45 traps at Cobb; n = 35 traps at Doles; n = 30 traps at Holcomb; and n = 35 traps at Silver). The distance between traps ranged from 94.4 to 161.8 m and the size of the sample area within each orchard was similar (Doles = 34.3 ha; Holcomb = 31.2 ha; Cobb = 48.6 ha; and Silver = 35.8 ha). Habitat surrounding peach orchards included woodland (natural assemblages of tree species and underlying vegetation), planted pine and pecan, fallow fields, kudzu, and blackberry patches. Commercial peach orchards were treated with insecticides per recommended management practices (Horton et al. 2003).

SAMPLING

For growers, visual assessment of stink bug population change in orchards are time consuming and difficult to complete and act upon quickly. Pheromone-baited traps allow for the capture of stink bug species in the field, and the development of this tool for sampling aids in management decisions. The male-specific aggregation pheromone, methyl (2*E*, 4*Z*)-2,4-decadienoate (MDD), a major component of the Nearctic *Euschistus* spp., attracts males, females, and nymphs of *E. servus* and other *Euschistus* spp. in the field (Aldrich et al. 1991). Traps rely on both the yellow-colored pyramidal base working in concert with the aggregation pheromone attractive to *Euschistus* spp. This system has been used in several studies that document abundance and movement of these *Euschistus* spp. in the southeastern USA (Cottrell et al. 2000; Cowell et al. 2015; Ni et al. 2019).

Stink bugs were sampled in focal orchards and surrounding habitat at all sites starting early in the season when all cultivars had similarly sized small green fruit (mid-Apr) and continued weekly for 15 wk through post-harvest (late Jul; see Fig. 2A, B for specific dates trap samples were collected in 2002 and 2003, respectively). Trapping was conducted using a stink bug-collecting device constructed from a 2.8-L clear plastic PET® jar (United States Plastic Corp., Lima, Ohio, USA) with a screw-cap lid (10.2 mm in diam) seated atop a 1.22-m-tall yellow pyramid base (Cottrell et al. 2000). The device was baited with an aggregation pheromone lure of *Euschistus* spp. purchased from Bedoukian Research, Inc. (Danbury, Connecticut, USA) based on the procedures described in Cottrell and Horton (2011). An insecticidal ear tag (10% λ-cyhalothrin and 13% piperonyl butoxide) (Saber™ Extra, Coopers Animal Health, Inc., Kansas City, Kansas, USA) also was placed in the jar to decrease stink bug escape (Cottrell 2001). Traps were established on 12 Apr 2002 and then on 9 Apr 2003. Thereafter, lures were changed on a weekly basis. Stink bugs in traps were identified, counted, and recorded in the laboratory. *Euschistus* spp. nymphs were collected in 2003 and identified to genus based on yr of rearing experience in our laboratory. Adults were identified using the taxonomic key of McPherson and McPherson (2000).

STATISTICAL ANALYSIS

We fit generalized linear mixed models to test whether the presence of *E. servus* and *E. tristigmus* adults varied by habitat type over time. Initially, we used R package lme4 (Bates et al. 2015) to test whether adult count data differed by species according to habitat type and season (family = Poisson; link = logit). We included time (1–15 wk during each yr; in 2002 = 19 Apr–26 Jul, and in 2003 = 16 Apr–23 Jul), habitat type (2 levels; peach or other), species (2 levels; *E. servus* and *E. tristigmus*) as fixed effects. We centered and scaled the continuous fixed effect (i.e., time) and tested for inclusion of 2-way interactions between habitat type and time, habitat type and species, time and species, as well as a 3-way interaction between habitat type, time, and species. Trap site nested within orchard, and wk nested within yr, each were included as a random effect. We were also interested in whether the distribution of stink bug nymphs in 2003 revealed patterns over the season and by habitat. For the nymph model we included time, habitat, and the interaction between time and habitat as fixed effects, and trap site nested within orchard as a random effect. Based on the Poisson distribution model, we tested for over-dispersion and found that the data for both models was indeed over-dispersed, and therefore violated assumptions of the model. Further exploration of count data indicated that only 58% of traps captured adult stink bugs and 37% of traps captured nymphs at any given time. Therefore, we tested whether adult and nymph stink bugs were captured in traps as our response variable (i.e., presence or absence) using a generalized linear mixed model (family = binomial; link = logit). Following Burnham and Anderson (2002), we used Akaike Information Criteria corrected for small sample sizes to guide model selection. We considered the best models as those with the lowest Akaike Information Criteria corrected score that accounted for approximately 95% of the Akaike Information Criteria corrected weights in the candidate model. Two models best fit the data describing the presence or absence of adult stink bugs in traps; both models included habitat, time, species, and the interaction between habitat and time as fixed effects (Akaike Information Criteria corrected = 5241.1; weight = 0.25). The other model also included the interaction between species and time (Akaike Information Criteria corrected = 5239.6; weight = 0.54). Two models best fit the data describing the presence or absence of nymph stink bugs in traps; 1 that included time as the only fixed effect (Akaike Information Criteria corrected = 1691.5; weight = 0.1) and the second that included habitat, time, and the interaction based on habitat and time (Akaike Information Criteria corrected = 1687.3; weight = 0.84). Based on candidate models, we used the package MuMIn (Bartoń 2018) to estimate model-averaged effect sizes as well as a 95% confidence interval for each fixed effect. If confidence intervals did not overlap with zero, then we considered the factor to influence if stink bugs were captured in pheromone-baited traps.

We analyzed spatial distribution patterns of *E. servus* and *E. tristigmus* using Spatial Analysis by Distance Indices (SADIEShell, version 2.0; Perry et al. 1999). For each orchard, we calculated a weekly aggregation index (I_a), where values indicate randomly arranged counts ($I_a = 1$), regularity ($I_a < 1$), or aggregation ($I_a > 1$), and calculated the probability (P_a) that groups of stink bugs aggregated more than expected (e.g., if $P_a = < 0.05$). To visualize the distribution of stink bugs captured at each orchard over time, we generated interpolated estimates of abundance from each trap site by wk. We used the inverse distance weighting tool (power = 2; variable = 20 points) in ArcGIS version 10.5 (Esri, Redlands, California, USA) to generate interpolated map images of *E. servus* and *E. tristigmus* count data. In the figure illustrations of orchard maps, traps were symbolized based on the habitat where they were located.

Results

In total, 29,064 *E. servus* and 3,671 *E. tristigmus* adults were captured across all sites. Adult stink bugs captured in pheromone-baited traps differed by species, and distribution patterns varied by habitat and wk sampled (Fig. 1; Table 1). *Euschistus servus* was present commonly in peach traps as well as the surrounding habitat (Fig. 1A), whereas *E. tristigmus* was far less likely to be present in traps located in peaches than any other habitat (Fig. 1A; Table 1). In general, the number of *E. servus* captured in traps over the 2002 season were greater than *E. tristigmus* (Fig. 2). In 2003, trap abundance was similar for both stink bug species until late May when *E. servus* became significantly greater. For both species, trap captures remained relatively low early in the season. The mean number of stink bugs captured per trap peaked around wk 8, and nymphs continued to increase as the season progressed with significantly more captures occurring in peach (early Jun; Figs. 1B, 2;

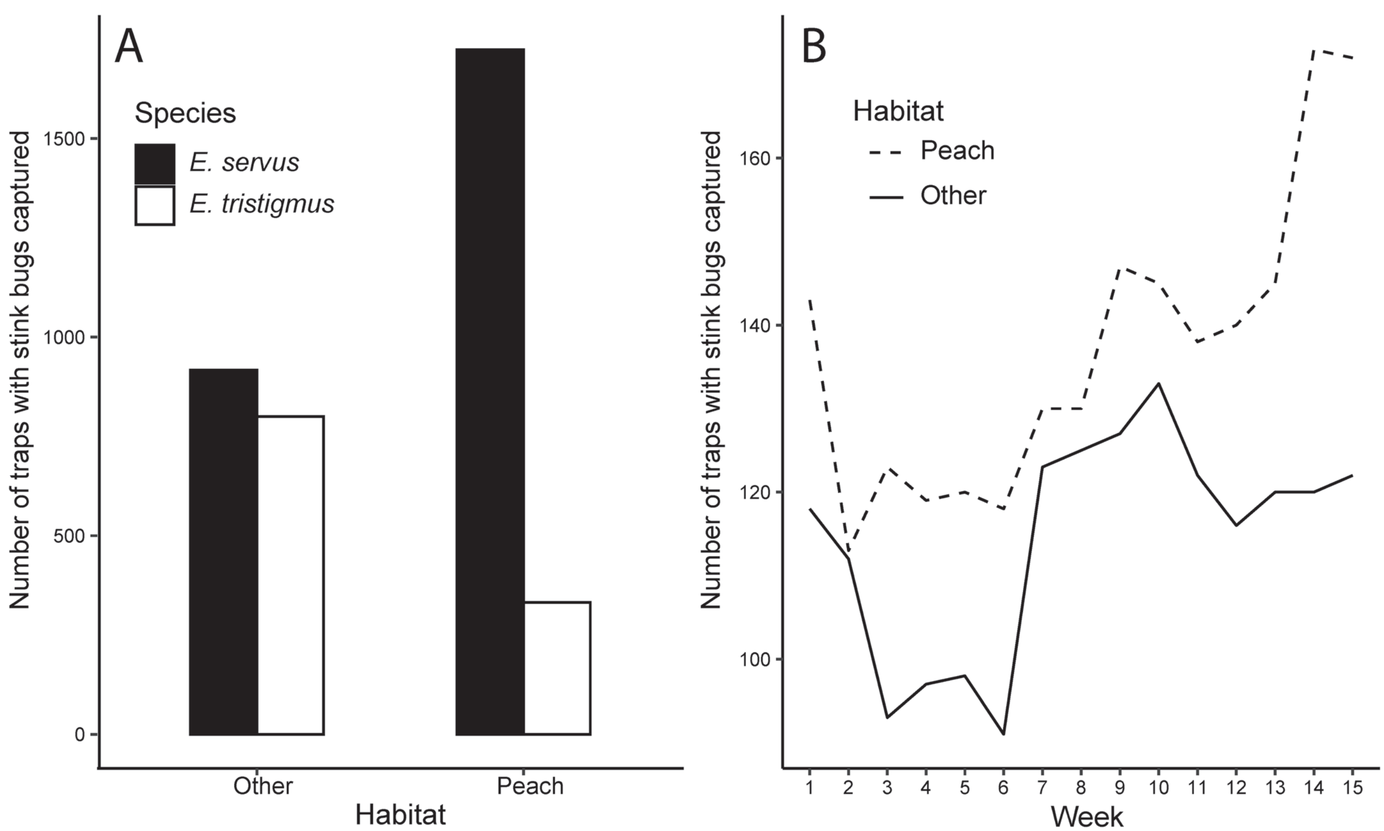

Fig. 1. Spatiotemporal distribution patterns of *Euschistus servus* and *Euschistus tristigmus*: (A) number of traps in which *E. servus* and *E. tristigmus* were present in peach and surrounding habitat; (B) number of traps in which stink bugs were present over the season in peach and surrounding habitat.

Table 1. Model-averaged fixed effect estimates and 95% confidence intervals for the number of pheromone-baited traps with adult stink bugs captured at 4 orchards in either peach or surrounding habitat in central Georgia, USA.

Parameter	Effect size	Lower 95% confidence interval[a]	Upper 95% confidence interval
Intercept	0.97	0.56	1.39
Species: *Euschistus tristigmus*	−0.47	−0.65	−0.29
Habitat: peach	2.70	2.33	3.08
Wk	0.24	0.01	0.48
Species × habitat	−4.85	−5.20	−4.51
Species × wk	−0.05	−0.21	0.10
Habitat × wk	0.54	0.38	0.69

[a]Parameter has an effect on adult stink bug capture if the confidence interval does not overlap with zero.

Table 2). In 2003, 3,616 *Euschistus* spp. nymphs were captured in traps with trap captures primarily occurring in woodland, pecan, and kudzu.

Significant spatial aggregations of *E. servus* or *E. tristigmus* were detected at all orchards sampled, but temporally varied by orchard and yr (Tables 3, 4). In 2002, clusters of *E. servus* were more variable over time, with aggregations detected early and later during the sample period at Doles and Cobb orchards (Doles wk 1–2, 13; Cobb wk 1, 9; Table 3). At Holcomb orchard, *E. servus* adults significantly aggregated throughout most of the sample period compared with *E. tristigmus* (Table 3). In 2003, aggregations of *E. servus* were detected later during weeks 6 to 14 consistently at all 3 orchards (Table 4). In contrast, *E. tristigmus* showed lower consistency in patterns of significant aggregation across all orchards sampled (Tables 3, 4). In 2002, *E. tristigmus* adults significantly aggregated at Cobb orchard across most of the season; however, no aggregations were detectable at Holcomb orchard that same yr (Table 3). Mid-sampling season aggregations of *E. tristigmus* were detected at Doles orchard in 2002 (wk 4–6, 8, 10; Table 3) and in 2003 (wk 4, 10, 11; Table 4).

Interpolated maps and Spatial Analysis by Distance Indices analysis suggest that aggregations of *E. servus* varied depending on habitat composition of each orchard (Fig. 3; Table 3). Across all orchards sampled, clusters of *E. servus* adults in peach were located primarily adjacent to pecan. However, clusters in peach next to pine, fallow fields (Holcomb), and kudzu (Doles) also were observed. At Doles, *E. servus* adults were captured primarily in planted peach, pecan, and pine habitats (Fig. 3; Table 3). At the beginning of the sample period (wk 1) in 2002, adults clustered in peach, pecan, and kudzu, although fewer adults were present in the same habitat the following yr. Both yrs, *E. servus* occurred throughout all habitats except for woodlands by mid-season (wk 8) and clustered in high numbers

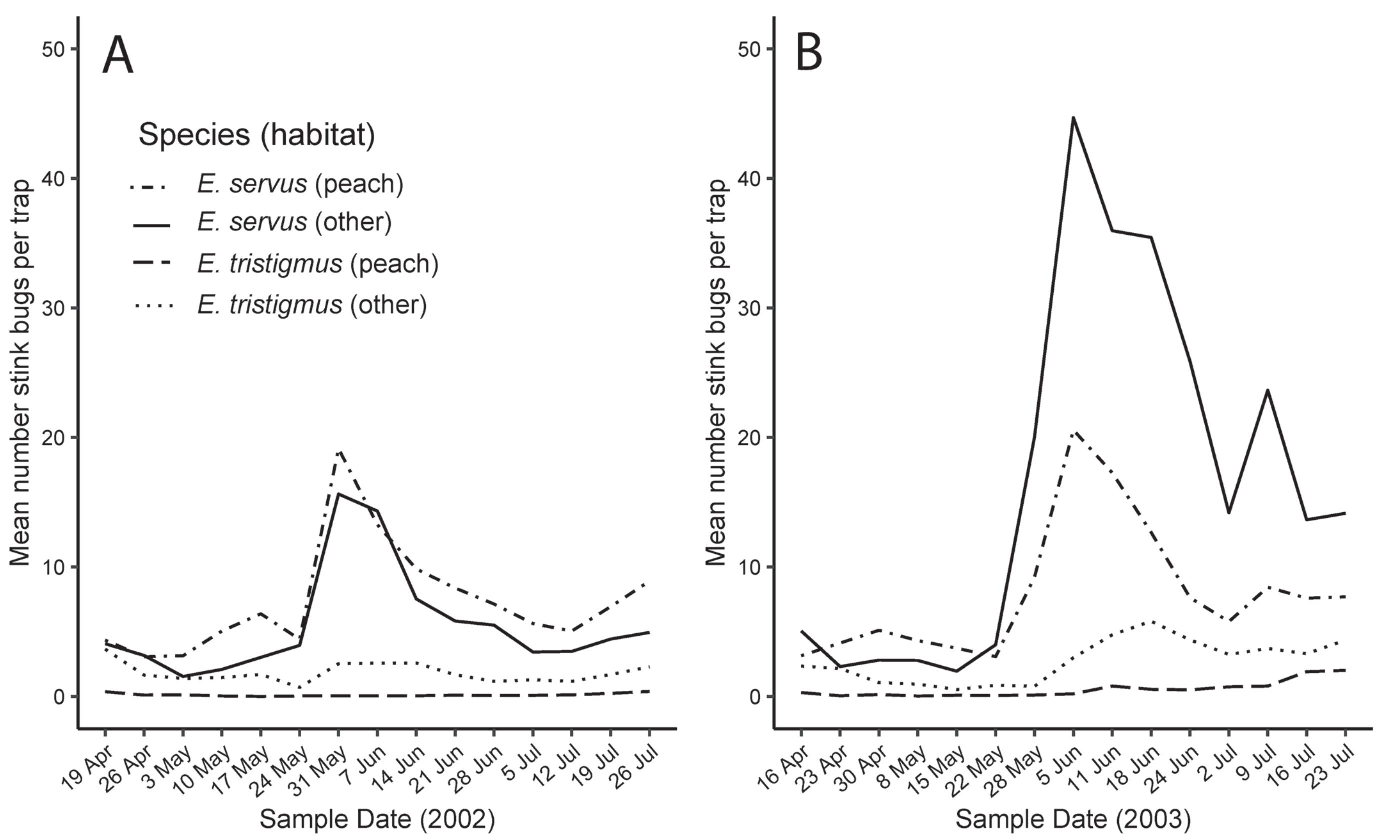

Fig. 2. Seasonal capture of *Euschistus servus* and *Euschistus tristigmus* in pheromone-baited traps; (A) mean number of *E. servus* and *E. tristigmus* per pheromone-baited trap in peach and non-crop habitat over time in 2002; (B) mean number of *E. servus* and *E. tristigmus* per pheromone-baited trap in peach and surrounding habitat over time in 2003.

Table 2. Model-averaged fixed effect estimates and 95% confidence intervals for the number of pheromone-baited traps with stink bug nymphs captured at 4 orchards in either peach or surrounding habitat in central Georgia, USA.

Parameter	Effect size	Lower 95% confidence interval[a]	Upper 95% confidence interval
Intercept	−0.72	−0.96	−0.47
Habitat: peach	0.07	−0.28	0.42
Wk	0.86	0.64	1.07
Week × habitat	0.33	0.10	0.63

[a]Parameter has an effect on adult stink bug capture if the confidence interval does not overlap with zero.

in peach and pecan in 2003. By wk 13 in 2002 and wk 11 in 2003, adults aggregated in peach and pecan (Supplemental Materials, Fig. 1). At Holcomb, the site with the greatest variety of habitat types, *E. servus* adults were captured in fallow fields and pecan as well as a few peach traps (Fig. 3; Table 3). In 2002, *E. servus* clustered in fallow fields and adjacent peach at the beginning of the season and in 2003 were present in pine adjacent to peach and a fallow field. At Holcomb, *E. servus* aggregated in high numbers in all habitats except woodland, where adults later dispersed into peach and pecan traps in 2002, then pecan and pine traps in 2003 by wk 12. At Cobb and Silver, adult *E. servus* were captured in peach, pecan, and pine, but clustered in peach and an adjacent pecan edge during wk 1 (Fig. 3; Table 3). The following yr at Silver, adults were present in pecan and pine edges. By mid-season, *E. servus* was distributed in high numbers throughout the Cobb site and aggregated along the pecan-peach edge during wk 9 (Supplemental Materials, Fig. 5). Similarly, at Silver, adults clustered in pecan and pine forest edges on wk 8 (Fig. 3; Table 3). By wk 12 at Silver, *E. servus* were present in peach, but mainly clustered in pecan and pine. At all orchards, the trap location with the highest densities varied wk by wk, with the largest number of adults captured in peach later in the season. Regardless of orchard or yr sampled, adult *E. servus* tended to avoid woodland habitat.

Aggregations of *E. tristigmus* adults typically clustered in traps located in non-peach habitat (Fig. 4; Table 4). At all orchards sampled, clusters of *E. tristigmus* adults were found in pine, woodland, and pecan. If adults were captured in peaches, traps often were directly adjacent to non-crop habitat located in pine (Cobb), woodlands, kudzu, and fallow fields (Doles and Holcomb), and pecan (Silver). In general, more individuals were captured in traps at the Holcomb site compared with the other locations, and trap abundance was greater at that site in 2003. *Euschistus tristigmus* were primarily captured in nearby woodland traps. At Doles on wk 1, *E. tristigmus* were captured in a woodland-kudzu edge both yr and in pecan in 2002 (Fig. 4; Table 4). Mid-season both yr, *E. tristigmus* were found along a woodland edge and clustered in a woodland-kudzu corner in 2002. Late season (wk 12) in 2002, *E. tristigmus* were collected in woodland and kudzu traps, and in 2003 along a woodland-peach edge. In 2002 at Holcomb, more *E. tristigmus* adults were captured throughout the site early in the season, compared with the following yr, where *E. tristigmus* clustered in the lower half of the site (Fig. 4; Table 4). On wk 8 in 2002, *E. tristigmus* were captured mostly in pecan and woodlands. The following yr, adults occurred throughout the site except for a few peach traps. In 2002, later season distributions of *E. tristigmus* varied with only a few adults captured in woodland, compared with the following yr, where adults distributed across the entire orchard. Early season at the 2 sites without woodland habitat, Cobb and Silver, *E. tristigmus* were found in pine and pecan edges (Fig. 4; Table 4). The next wk, at Silver, *E. tristigmus* clustered in pine (Supplemental Materials, Fig. 8). At Cobb, adults clustered in pine and pecan, whereas *E. tristigmus* clustered in 2 pine traps at Silver mid-season (Fig. 4; Table 4). On wk 12, *E. tristigmus* clustered in pine at Cobb, and at Silver in peach, pecan, and pine edges. At sites with woodland habitat, *E. tristigmus* always were captured in woodland traps, suggesting that *E. tristigmus* tended to prefer woodland habitat.

Table 3. *Euschistus servus* aggregation indices (I_a)[a] at 4 orchards in central Georgia, USA, over a 15-wk sample period in 2002 and 2003 based on Spatial Analysis by Distance Indices.

	Doles		Holcomb		Cobb	Silver
Week	2002	2003	2002	2003	2002	2003
1	1.55[§]	1.01	1.53[§]	1.11	1.73[§]	1.31
2	1.68[§]	1.09	1.36[§]	0.96	1.16	0.94
3	1.44	1.08	1.13	1.10	1.16	1.08
4	1.56	0.86	1.01	1.04	1.00	1.01
5	1.58	1.50	1.26	0.84	1.09	1.02
6	1.26	1.69[§]	1.53[§]	1.31	1.27	1.59[§]
7	1.35	1.68[§]	1.36[§]	1.45	1.29	1.34
8	1.16	1.73[§]	1.13[§]	1.57[§]	1.33	1.99[§]
9	1.18	1.73[§]	1.01[§]	1.53[§]	1.46[§]	1.86[§]
10	1.24	1.42	1.26[§]	1.52[§]	1.28	2.04[§]
11	1.44	1.60[§]	1.23	1.46[§]	0.9	2.07[§]
12	1.33	1.15	1.46[§]	1.62[§]	1.13	1.58[§]
13	1.48[§]	1.30	1.69[§]	1.49[§]	1.04	1.81[§]
14	1.25	1.26	1.73[§]	1.53[§]	0.87	1.85[§]
15	1.38	1.01	1.55[§]	1.33	1.07	1.01

[a]I_a values greater than 1 suggest clustering; [§]I_a values indicate $P_a < 0.05$.

Table 4. *Euschistus tristigmus* aggregation indices (I_a)[a] at 4 orchards in central Georgia, USA, over a 15-wk sample period in 2002 and 2003 based on Spatial Analysis by Distance Indices.

	Doles		Holcomb		Cobb	Silver
Week	2002	2003	2002	2003	2002	2003
1	1.38	1.14	1.17	1.36[§]	0.93	1.28
2	1.25	1.09	1.17	1.35[§]	1.00	1.58[§]
3	1.14	1.01	1.03	1.15	1.60[§]	0.89
4	1.64[§]	1.43[§]	1.26	1.31	1.30	1.37[§]
5	1.5[§]	1.22	0.94	1.16	1.39[§]	1.25
6	1.59[§]	1.21	1.06	1.13	1.16	0.97
7	1.19	1.07	0.87	1.12	1.25	0.89
8	1.88[§]	1.37	0.89	1.28	1.53[§]	1.43[§]
9	1.43	1.27	0.91	0.97	1.61[§]	1.05
10	1.65[§]	1.63[§]	0.94	1.04	1.56[§]	1.20
11	1.07	1.65[§]	1.04	0.83	1.37	1.21
12	1.37	1.13	0.93	1.01	1.38[§]	1.34
13	1.16	0.89	1.11	1.00	1.59[§]	1.13
14	1.25	1.06	1.00	0.81	2.17[§]	1.24
15	1.21	0.97	0.92	0.94	1.88[§]	1.14

[a]I_a values greater than 1 suggest clustering; [§]I_a values indicate $P_a < 0.05$.

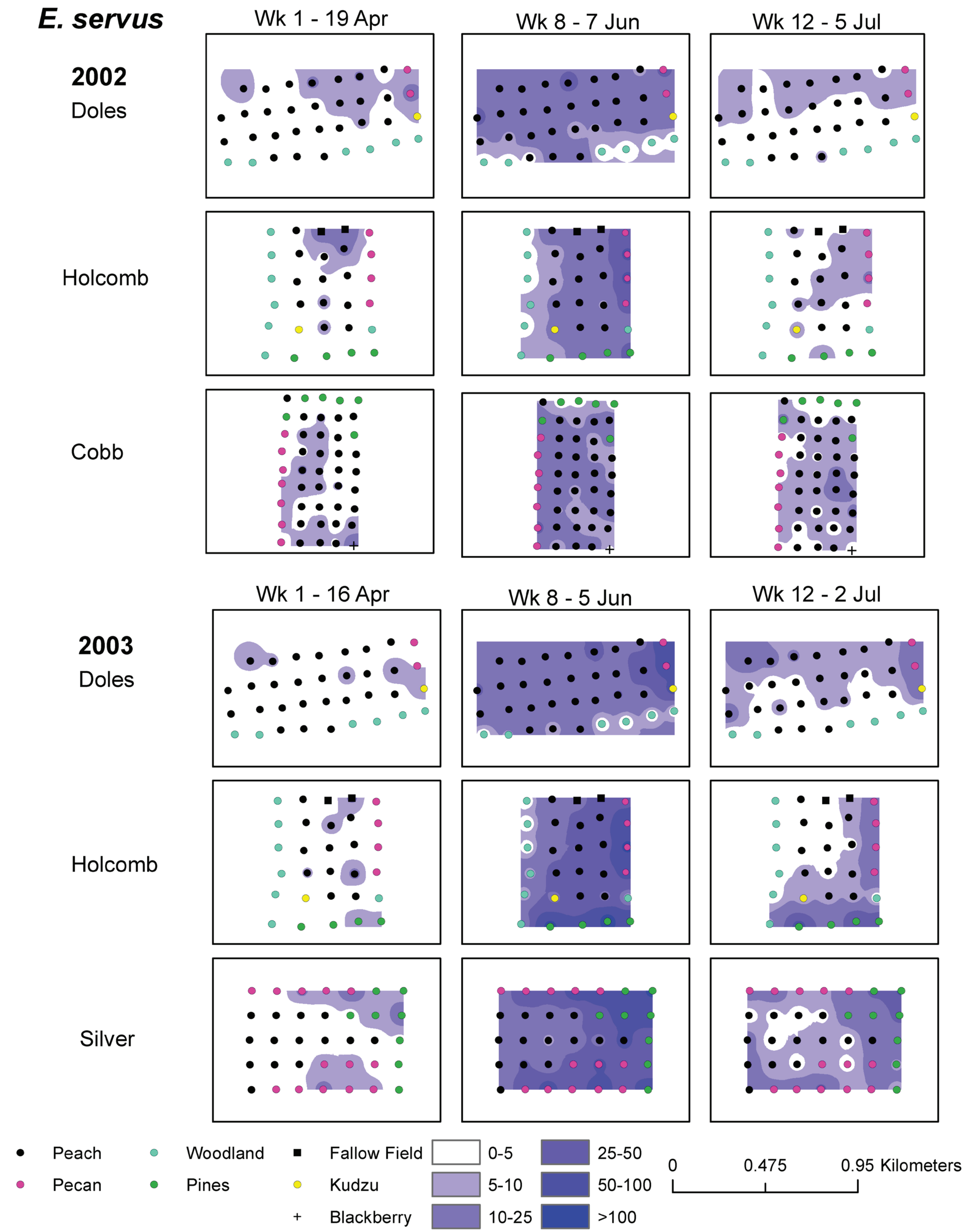

Fig 3. Interpolated maps of *Euschistus servus* adult distributions in peach orchards and surrounding non-crop habitat early season (wk 1), mid-season (wk 8), and late season (wk 12) in 2002 and 2003.

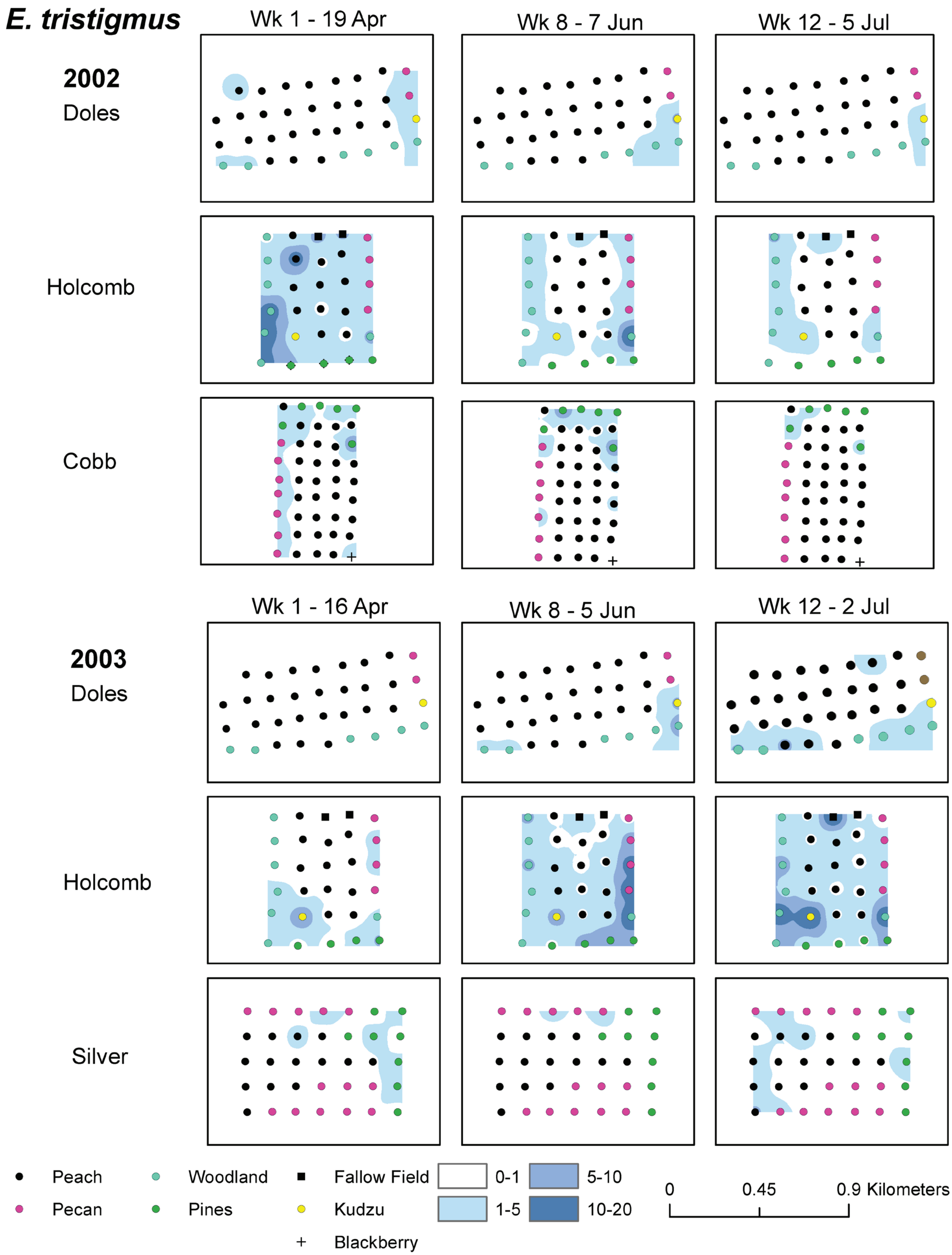

Fig 4. Interpolated maps of *Euschistus tristigmus* adult distributions in peach orchards and surrounding habitat early season (wk 1), mid-season (wk 8), and late season (wk 12) in 2002 and 2003.

Discussion

The spatiotemporal distribution patterns of *E. servus* and *E. tristigmus* adults in and around peach orchards differed. *Euschistus servus* were more likely to be captured in traps located in peach orchards than in traps in pine, pecan, fallow, blackberry, kudzu, and woodland habitats. *Euschistus tristigmus* were more likely to be captured in traps located in pine, pecan, fallow, kudzu, and woodland habitats than in peach orchard traps. This may explain why, in general, more *E. tristigmus* were captured at the Holcomb site, which had the greatest variety of non-crop habitat types. The number of stink bugs present in traps, as well as capture rates, increased as the season progressed. Although significant spatial aggregations of *E. servus* and *E. tristigmus* were detected at all orchards sampled, the wk in which these aggregations were detected varied by orchard and yr in which sampling took place. Over all orchards sampled, clusters of *E. servus* adults in peach occurred adjacent to pecan but also in pine, fallow, and kudzu habitats. *Euschistus tristigmus* adults clustered in pine, woodland, and pecan habitats, except for a few individuals that were captured in peach near woodland traps at 1 site in 2003. Both yr, the greatest total number of adult stink bugs captured occurred in early Jun and remained high until the end of the sampling period.

Despite broad spatial overlap between both stink bug species across habitats, at a finer scale *E. servus* were present mainly in peach habitat, whereas *E. tristigmus* was more likely to be found in woodland habitat in central Georgia. Over a 3-yr study in South Carolina, Jones and Sullivan (1981) determined that *E. servus* preferred to overwinter in open habitat (i.e., both well and poorly drained fields and kudzu), whereas *E. tristigmus* overwintered in woodland habitat, including woodland edge. Spring emergence for both species occurs from late Mar through Apr. Therefore, *E. servus* and *E. tristigmus* captured on the first wk of sampling in our study likely had emerged from areas proximal to the traps in which they were captured. This suggests that *E. tristigmus* may have overwintered in woodlands and *E. servus* did not. However, both species likely overwinter in peach. In a study across 18.1^2 km in Irwin County, Georgia, *E. servus* were more prevalent in crops and *E. tristigmus* were found over a larger range, commonly in non-crop habitat (P. G. Tillman, unpublished data). Moreover, corn is the most common early season host of *E. servus* (Tillman 2010). In contrast, early-season populations of *E. tristigmus* develop on non-crop hosts, such as elderberry, found in woodland edge (Tillman & Cottrell 2016). Prevalence of parasitoid species emerging from eggs of indigenous stink bug species is also primarily habitat specific, for example, *Anastatus* spp. (Hymenoptera: Eupelmidae) and *Trissolcus* spp. (Hymenoptera: Scelionidae) are more prevalent in woody habitats (woodlands and orchards) (Okuda & Yeargan 1988; Tillman 2016).

Stink bug management practices in peach generally are implemented in conjunction with plum curculio, *Conotrachelus nenuhar* Herbst (Coleoptera: Curculionidae); the latter is a key pest of southeastern peach (Horton et al. 2005). Plum curculio management relies solely on chemical insecticides to provide control from fruit set through harvest. Despite the applications of organophosphate and pyrethroid insecticides at 10 to 14 d intervals, *E. tristigmus* and especially *E. servus* adults have increased over time in the peach orchards. *Euschistus servus* were found to be less susceptible to some pyrethroids and organophosphates (Snodgrass et al. 2005). This suggests that other nonchemical management strategies may be needed for stink bug control in orchards. These could include addition of habitat such as wildflowers (Blaauw & Isaacs 2015) that provide needed resources that conserve and enhance natural enemy species. In addition, weeds in peach orchards may harbor stink bug natural enemies, and Coombs (2000) used specific timing of mowing the alley ways in pecan to conserve the stink bug parasitoid, *Trissolcus basalis* Wollaston (Hymenoptera: Scelionidae). Although both stink bug species overwinter in peach (Jones & Sullivan 1981), addition of physical barriers could prevent or slow stink bugs colonizing peach, especially those moving between pecan and peach orchards (Tillman et al. 2015; Cottrell & Tillman 2019).

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