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Survey of Florida olive groves during olive fruit development: monitoring for stink bugs and olive fruit flies

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Abstract

Olives, *Olea europaea* L. (Oleaceae), are an emerging commercial crop in Florida; however, potential arthropod threats during olive tree establishment and fruit development remain uncharacterized. Two potential pests that may threaten olive fruit production directly are native and invasive pentatomid stink bugs, which are important pest species of many crops in the southeast, and the invasive olive fruit fly, *Bactrocera oleae* (Gmelin) (Diptera: Tephritidae),which is not known to be established in Florida. Monitoring for stink bugs during fruit maturation was done using dual funnel tube traps baited with stink bug lures. Yellow sticky card traps baited with food and pheromone lures were used to monitor for the olive fruit fly. Both trap types were placed in tree canopies in 4 North Central Florida olive groves during the anticipated fruit development period for 2 growing seasons. Whereas neither of the invasive species targeted (*Halyomorpha halys* Stål [Hemiptera: Pentatomidae] or *B. oleae*) were detected, several other potential pests were identified including brown stink bugs (*Euschistus* spp.; Hemiptera: Pentatomidae), glassy winged sharpshooters, *Homalodisca vitripennis* Germar (Hemiptera: Cicadellidae), and grasshoppers. No fruit damage attributable to arthropod pests was detected although fruit production was very low with limited samples. These results contribute to awareness of potential pests that may jeopardize olive fruit production and aid in the future studies to develop effective monitoring activities for Florida growers.

Key Words: Pentatomidae; *Bactrocera oleae*; *Olea europaea*; *Halyomorpha halys*; *Homalodisca vitripennis*; trapping

Resumen

La aceituna, *Olea europaea* L. (Oleaceae), es un cultivo comercial emergente en la Florida; sin embargo, las posibles amenazas de artrópodos durante el establecimiento del olivo y el desarrollo de la fruta no han sido caracterizadas. Dos plagas potenciales que pueden amenazar directamente la producción del olivo son las chinches pentatómidas nativas e invasoras, que son importantes especies de plagas de muchos cultivos en el sureste de Estados Unidos, y la mosca invasora del olivo, *Bactrocera oleae* (Gmelin) (Diptera: Tephritidae), que no se sabe si está establecida en la Florida. Se realizó el control de las chinches hediondas durante la maduración de la fruta utilizando trampas de tubo de embudo doble cebadas con señuelos para chinches hediondas. Se usaron trampas amarillas de tarjetas adhesivas cebadas con comida y señuelos de feromonas para monitorear la mosca del olivo. Se colocaron ambos tipos de trampas en las copas de los árboles en 4 olivares del centro norte de Florida durante el período de desarrollo anticipado de la fruta durante 2 temporadas de crecimiento. Si bien no se detectó ninguna de las especies invasoras enfocadas (*Halyomorpha halys* Stål [Hemiptera: Pentatomidae] o *B. oleae*), se identificaron varias otras plagas potenciales, incluidas las chinches hediondas pardas (*Euschistus* spp.; Hemiptera: Pentatomidae), chicharrita de alas cristalinas, *Homalodisca vitripennis* Germar (Hemiptera: Cicadellidae) y saltamontes. No se detectaron daños en la fruta atribuibles a plagas de artrópodos, aunque la producción de fruta fue muy baja con muestras limitadas. Estos resultados contribuyen a la conciencia de las plagas potenciales que pueden poner en peligro la producción de aceitunas y ayudan en los estudios futuros para desarrollar actividades de monitoreo efectivas para los productores de la Florida.

Palabras Clave: Pentatomidae; *Bactrocera oleae*; *Olea europaea*; *Halyomorpha halys*; *Homalodisca vitripennis*; reventado

Olives for olive oil production are a major agricultural commodity with global olive oil production reaching an estimated 3,314 metric tons from 2017 and 2018 alone (International Olive Council 2019). Motivated by increasing market prices for high quality olive oil (Metzidakis et al. 2008), growers and researchers are evaluating the possibility of growing intensive-scaled commercial olive groves in the southeastern US. Olives are considered an ideal crop because the trees are resilient and tolerant of drought and nutrient poor conditions (Erel et al. 2013). Olive trees require a winter chilling period of at least 450 h below 7.5 °C to stimulate spring flowering and fruiting, making the subtropical climate of North Central Florida, USA, the most ideal part of Florida for olive production (Gutierrez et al. 2009). Recently, the acreage planted with olives in Florida has increased dramatically yet only the potential for damage from thrips through blossom damage has been examined (Allan & Gillett-Kaufman 2018; Phillips et al. 2020).

Olive flowers are prone to damage from a wide range of insect pests (Tzanakakis 2003; Daane et al. 2005; Spooner-Hart et al. 2007). Damage from arthropod pests can create wounds on fruit that leave it susceptible to further damage from pathogen colonization. Identification of fruit pests and timely use of control measures is crucial to keep the cost of olive production low and the quality of olives produced high.

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Two groups of arthropods that potentially may threaten olive fruit development in Florida are phytophagous stink bugs and olive fruit flies, *Bactrocera oleae* (Gmelin) (Diptera: Tephritidae). Florida olive growers have observed stink bugs feeding on olive fruit (Gillett-Kaufman et al. 2017), and here we seek to characterize the species present and when damage is occurring. The southeastern US provides an ideal environment for many species of pest stink bugs (Hemiptera: Pentatomidae) that are highly mobile and polyphagous (McPherson & McPherson 2000). While phytophagous stink bugs may feed on all structures of plants, the damage is particularly noticeable on fruit (McPherson & McPherson 2000). Generalist plant-feeding stink bugs often will overwinter and feed on available uncultivated plant species suitable for growth and development, and upon reaching adulthood easily move into a preferred cultivated species (Panizzi 1997). Stink bugs are well documented pests of various crops in Florida including soybean (Panizzi & Slansky 1985), rice (Cherry & Nuessly 2010), tomato (Schuster 1977), and various cruciferous crops such as broccoli and mustard (White & Brannon 1933; Ludwig & Kok 2001). The symptoms caused by stink bug feeding may lead to loss of marketability, plant death, and inability to harvest the plants.

Pentatomids are not often considered primary pests of olive, despite their and other phytophagous Heteroptera presence in olive grove surveys (Tzanakakis 2003; Cotes et al. 2011; Kacar & Dursun 2015). In Australia, the southern green stink bug, *Nezara viridula* L. (Hemiptera: Pentatomidae), has been documented to cause direct damage to olive fruit due to feeding with its piercing-sucking mouthparts (Spooner-Hart et al. 2007). Stink bug damage to olive fruit can lead to a loss of marketable fruit, especially if populations become elevated (Tzanakakis 2003; Cotes et al. 2011; Kacar & Dursun 2015). It is unknown which species of native or invasive pentatomids are present in Florida olive groves and causing potential damage to susceptible developing fruit. One stink bug species of considerable concern is the invasive brown marmorated stink bug, *Halyomorpha halys* Stål (Hemiptera: Pentatomidae), which is prolific in the northeastern US (Hoebeke & Carter 2003; Leskey et al. 2012). This polyphagous and highly mobile pest native to Asia (Weber et al. 2017) is expanding rapidly throughout the US with the first capture in Florida from peaches in 2016 (Penca & Hodges 2018). The trait of *H. halys* as a successful invader makes it a potential concern for new olive groves, and has been recently observed causing damage in established olive groves (Damos et al. 2019).

The olive fruit fly is a host-specific key pest to all cultivars of *Olea europaea* L. (Oleaceae) in well-established olive producing regions of the world (Bueno & Jones 2002; Daane & Johnson 2010; Kakani et al. 2010). The olive fruit fly oviposits directly into ripening fruit where larvae hatch, feed on the fruit, and eventually exit to pupate in the soil. Exit wounds left by the larvae result in increased entry points and susceptibility of fruit to pathogens (Malheiro et al. 2015). Global olive loss due to insect pests has been estimated to be USD $800 million annually, with *B. oleae* as the most injurious fruit pest, causing direct damage and up to a catastrophic 100% loss of yield (Bueno & Jones 2002). In the US, the economic threshold for *B. oleae* for olives to be harvested for the processing of table olives is 0% infestation, and the commonly used European threshold for oil producing cultivars is a 10% infestation rate (Devarenne & Vossen 2007). As a listed pest for fruit fly exclusion and detection surveillance by the USDA Animal and Plant Health Inspection Service (APHIS) program, the species is of concern to plant health officials at the state and federal level (USDA 2019). The olive fruit fly has been intercepted but not established in Florida, making it an important olive pest to monitor (FDACS 2014). The continued exclusion of this important pest would mean growers would not need to use chemical controls necessary to maintain acceptable infestation levels, and would allow for Florida to have the unique capacity to produce organic olive oil.

The objective of this study was to monitor for both established and invasive arthropod fruit pests of potential concern for olive fruit development in the areas of commercial olive plantings in Florida. Because phytophagous stink bugs and the olive fruit fly are considered potential pests, trapping was targeted towards these groups.

Materials and Methods

FIELD SITES

The study was completed in commercial olive groves in 4 olive groves in North Central Florida with 1 grove in each of Suwannee, Gilchrist, Marion, and Volusia counties with the grove referred to by county location. Specific details of field sites were provided by Phillips et al. (2020). Plots were selected for cultivar similarity and were predominately 'Arbequina' (80 to 90%). Each plot in Suwannee, Gilchrist, and Volusia counties was 4 ha and Marion County was 1 ha due to other cultivars planted in other areas of the grove. At the beginning of the study, trees in the Marion and Gilchrist groves had been in the ground for 4 yr, and the trees in the Suwannee and Volusia groves had been planted for 5 yr. The Volusia and Suwannee groves were surrounded by semi-natural pine forest, and the Volusia grove was located near an abandoned citrus orchard. The Gilchrist grove was located close to a cattle operation and watermelon plantings. The Marion grove was located tangentially to cattle and horse operations, with small plantings of ornamentals, muscadine grape, and peaches located on the property near the olive groves.

SAMPLING PROTOCOL

Each ha within a plot was designated as a subplot and contained 3 sampling locations (Fig. 1A) with 1 in the center of the plot and 1 on the north and south edges of the plot. There was a total of 12 sampling locations at each grove except for Marion which had 3. Both olive fruit fly traps and stink bug traps were deployed at each of these sampling locations. Sampling locations also were given spatial identifiers within the groves (Fig. 1B) and these were designated as the center (surrounded by olive trees), corner (on the corner of the plot with 2 sides adjacent to olive trees), edge (edge of the plot with olive trees on 3 sides) and end (end of row, not a corner and with olive trees on 3 sides).

Trapping for stink bugs and olive fruit flies was conducted during anticipated fruit development to coincide with early fruit development when the fruit is most vulnerable, which was from late Apr to Oct in 2017 and 2018. The main cultivar surveyed, 'Arbequina,' is grown for its fruit that is pressed for oil, making the fruit the most valuable part of the tree. Traps initially were placed in Apr and checked or replaced each mo through Sep and removed in Oct. Hurricane Irma caused delayed deployment of Sep traps in 2017 in the Marion and Suwannee groves, and prevented final trap deployment in the Volusia county grove in 2017. Trapping did not occur during winter mo when olive trees were dormant. Traps were removed from Volusia County in Jun 2018 following a grower request.

Each trap was deployed for a total of 3,816 trap d in the Suwannee grove, 3,588 trap d in the Gilchrist grove, 2,388 trap d in the Volusia grove, and 942 trap d in the Marion grove.

STINK BUG TRAPS

Dual funnel stink bug traps (Trécé®) (Great Lakes IPM, Vestaburg, Michigan, USA) were hung on 2 trees approximately 1.4 m from the ground in the 3 sampling locations per subplot for a total of 2 traps per

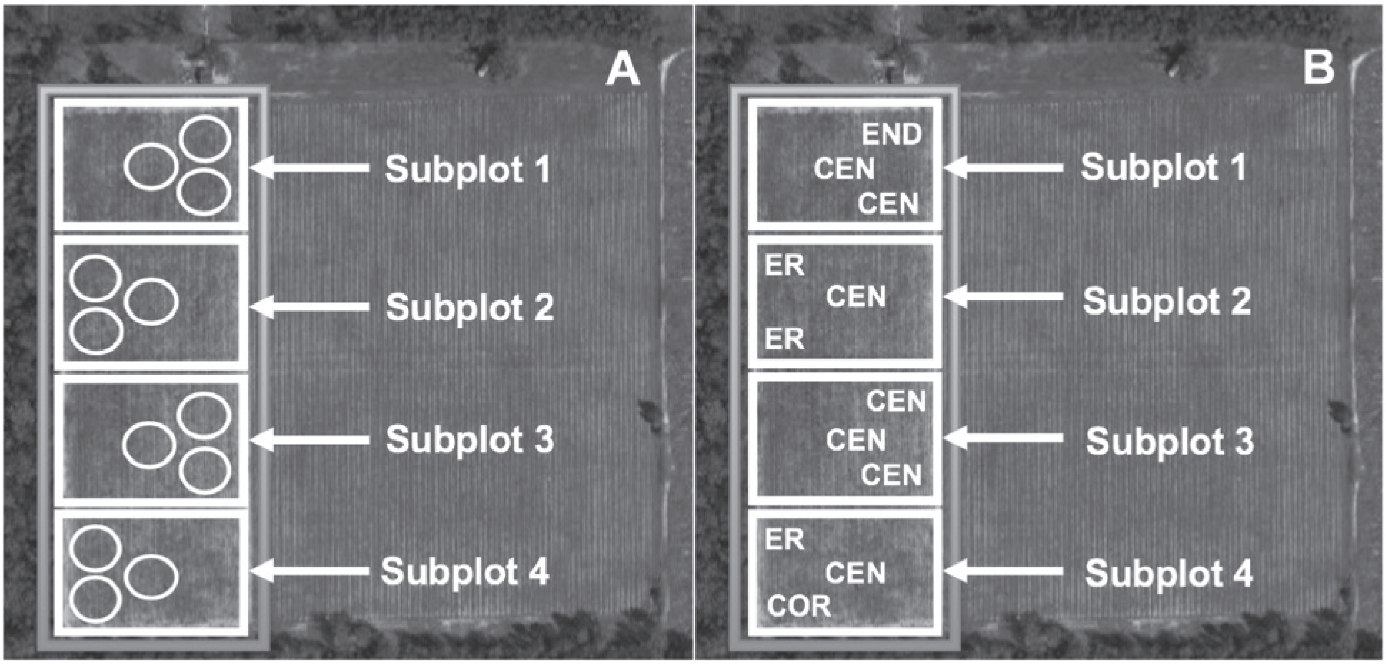

Fig. 1. Diagram of (A) trap locations in Florida olive groves, and (B) spatial identifiers used to characterize the locations for analysis. The large rectangle represents a 4-ha area surveyed; each white box represents a 1-ha subplot. Each circle represents a sampling location where 1 baited olive fruit fly trap and 2 dual funnel stink bug traps, 1 baited for the brown marmorated stink bug and 1 baited for the consperse stink bug were placed during each sampling visit. Spatial identifiers for sampling sites included: COR = corner site, CEN = center site, ER = edge of the grove site and bordered by olive trees on 3 sides of the tree, END = site located at the end of a row, but not a corner. Image from Google Maps.

sampling location and 6 traps per subplot (Brennan et al. 2013). In each sampling location, the 2 traps contained separate lures: 1 trap contained a rubber Pherocon® *Euschistus conspersus* Uhler (Hemiptera: Pentatomidae) (consperse stink bug) aggregation pheromone lure cap similar to Brennan et al. (2013), and the second trap contained 2 Pherocon® rubber lures (Great Lakes IPM, Vestaburg, Michigan, USA), 1 with aggregation pheromones for *H. halys* and *Plautia stali* Scott (Hemiptera: Pentatomidae) (oriental stink bug), and 1 with aggregation pheromones for *Chinavia hilaris* Say (Hemiptera: Pentatomidae) (green stink bug). While the concentration and diffusion rate of the lures was proprietary information, lures were reported to be effective for up to 12 wk, with the dual funnel traps considered usable for approximately 6 mo (Weber et al. 2017). The pheromones for *H. halys*, *P. stali*, and *C. hilaris* were deployed in the same dual funnel trap because components of the *P. stali* and *C. hilaris* lures are attractive to *H. halys* without negative interactions (Weber et al. 2017) and have a synergistic effect in attracting *H. halys* (Weber et al. 2014). Lures were replaced once a mo, and traps were checked and emptied during each lure change. Damaged or missing traps were replaced as needed. Pest pentatomids and other known hemipteran pests, as well as other arthropods of potential pest status, were collected and identified to species from the traps. Organisms were held in 50 mL centrifuge tubes (Fisherbrand™, Fisher Scientific, Hampton, New Hampshire, USA) with 70% ethyl alcohol for transportation and storage in the laboratory. Arthropods were identified to order or family, and species when possible using keys by Triplehorn and Johnson (2005) and Key to the Florida Pentatomidae (Joseph Eger, unpublished), and a Heerbrugg compound microscope (Heerbrugg, Switzerland) at 40× magnification.

OLIVE FRUIT FLY TRAPS

One Trécé Pherocon® AM/NB *B. oleae* yellow sticky trap with a sex pheromone lure and ammonium bicarbonate food bait (Great Lakes IPM, Vestaburg, Michigan, USA) was hung approximately 1.4 m from the ground on a different tree but in the same sampling location at the 3 sampling locations in each subplot from Apr to Sep 2017 and 2018. Traps were hung so the short end of the panels were parallel to the branches. Distances between olive fruit fly traps and stink bug traps were not consistent in all groves due to the high variation of pruning and tree height among the groves. Sticky traps were collected and replaced each mo and collected traps were placed in clear plastic resealable bags (Publix, Lakeland, Florida, USA) for processing in the laboratory. Occasionally traps were damaged or missing and these traps were replaced as needed. Due to time constraints, each sticky card was thoroughly counted on only 1 side, and the other side was quickly scanned for any tephritid fruit flies. All counting was done under 40× magnification with a Heerbrugg compound microscope. Organisms on the sticky cards were identified to order except for Thysanoptera. Further identification to genus and species was completed, when possible, if they were a known or suspected pest.

STATISTICAL ANALYSIS

Counts of arthropods collected monthly from traps were averaged for analysis by yr, mo of trap deployment, spatial position within the grove, and by the 2 types of lure combinations used in the stink bug traps, and divided by total traps deployed in the selected timeframe or with a specific stink bug lure combination. The effect of yr was determined by averaging monthly collection totals for each yr and comparing means by yr with a paired *t*-test with unequal variance. The effect of stink bug lure on collections was determined by averaging totals for each trap lure type and comparing means by yr with a paired *t*-test with unequal variance. The effect of mo of collection was determined by combining data for both yr and obtaining means for each mo. Spatial comparisons of means and means of different mo were compared for each taxon by 1-way ANOVA (Proc-GLM, SAS, SAS Institute, Cary, North Carolina, USA) followed by means separation by Student-Newman-Keuls test ($P \leq 0.05$). Statistical comparisons were conducted in SAS (version 9.3). All data were square root (× + 0.01) transformed before analysis due to the presence of zero count data.

Results

STINK BUG TRAPS

A total of 330 insects from 9 orders were collected from all stink bug traps after 11,379 trap d (Table 1). The majority of insects collected from stink bug traps were Hemiptera (66.96%), of which 51.13% were Pentatomidae, and 47.96% were Reduviidae. Of the Pentatomidae, individuals from the genus *Euschistus* were most abundant (69.91%), with *Euschistus servus* Say (Hemiptera: Pentatomidae) being the most abundant identified species (21.51%). A total of 8 species of stink bugs were identified including predatory *Podisus maculiventris* Say (Hemiptera: Pentatomidae). Three species of assassin bugs were collected, of which most were *Apiomerus crassipes* F. (Hemiptera: Reduviidae) (68.86%) with low collections of *Arilus cristatus* L. (Hemiptera: Reduviidae) (3.77%) and *Zelus longipes* L. (Hemiptera: Reduviidae) (2.83%). The remaining 33% of arthropods collected represented a broad range from Araneae, Blattodea, Coleoptera, Diptera, Hymenoptera, Lepidoptera, Neuroptera, and Orthoptera.

In general, there was little difference between yr in arthropod numbers collected from stink bug traps. Significantly more Hemiptera were collected in 2017 (t = 2.03; df = 1, 839; P = 0.043), and similarly there were higher numbers of *E. servus* collected in that yr (t = 2.08; df = 1, 839; P = 0.037). The most Reduviidae were collected in 2017 (t = 1.98; df = 1, 839; P = 0.048). All other groups were not significantly different between yr ($P > 0.05$). Seasonal patterns were not evident for most arthropods other than those from Hemiptera (Table 2). The plant pest pentatomid, *E. servus*, had the highest collections in Apr, and the predatory reduviids *A. cristatus* and *A. crassipes* had peak populations in May and Jun, respectively (Table 2). Overall, total Hemiptera and Reduviidae had the highest collections in Jul, and no taxa were most frequently collected in Aug and Sep (Table 2). Taxa other than Hemiptera did not differ by mo of collection ($P > 0.05$) and are not presented in Table 2.

Trap lures affected the collection of 3 Hemipteran groups and overall Hemiptera (Table 3). Overall numbers of Hemiptera, Reduviidae, and *A. crassipes* were more abundant in traps baited with the combination of green and brown marmorated stink bug lures, whereas *Euschistus quadrator* Rolston (Hemiptera: Pentatomidae) was more abundant in traps baited with the consperse stink bug lure (Fig. 2). There was no effect of spatial position of the stink bugs traps on collection of any Hemiptera taxa ($P > 0.05$).

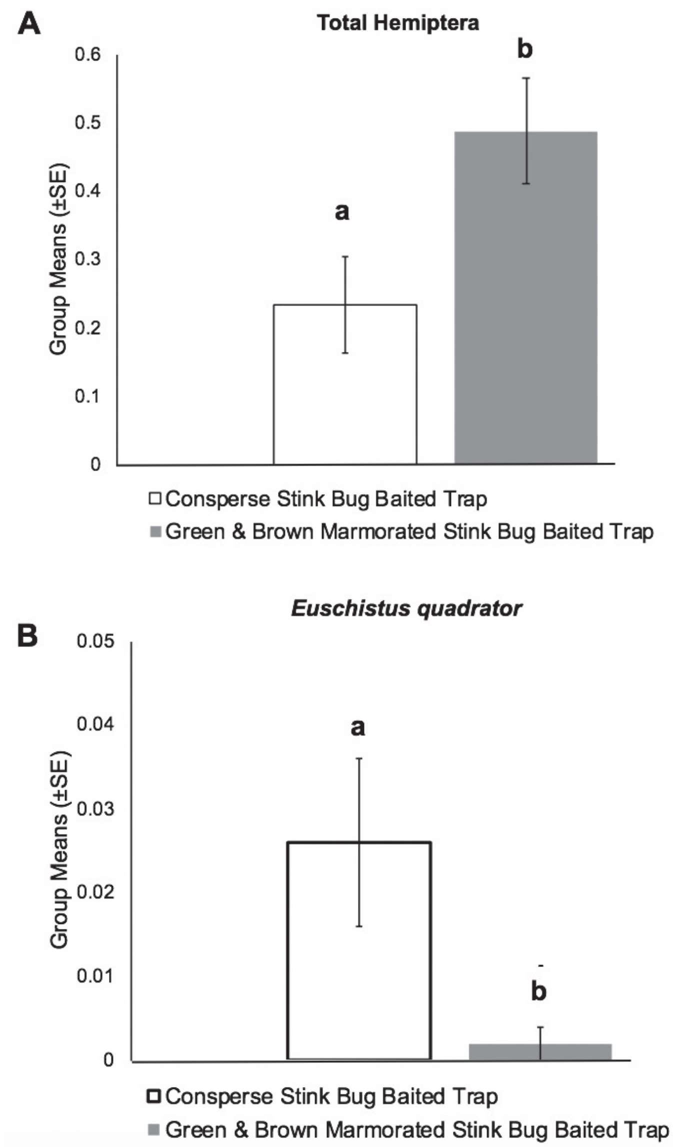

Fig. 2. Comparison of type of stink bug on total monthly collection (mean ± SE) from 2017 and 2018 of (A) Hemiptera, and (B) *Euschistus quadrator* Rolston. Lures consisted of either a consperse stink bug lure or a combination of green stink bug and brown marmorated stink bug lures. Statistical comparisons were made with a paired t-test ($P \leq 0.05$); means with different letters are significantly different.

OLIVE FRUIT FLY TRAPS

A total of 113,237 insects from 11 orders were identified on the olive fruit fly cards after 10,701 trap d (Table 1). Of these, the majority were Diptera (77.86%), followed by Hymenoptera (14.17%), and Hemiptera (5.26%). A total of only 7 flies in the family Tephritidae were found (Table 1), and none of these were olive fruit flies, *B. oleae*. Two of the identifiable tephritids were in the genus *Paramyiolia* (Diptera: Tephritidae), which are considered occasional root pests in Florida (G. J. Steck, FDACS DPI, Taxonomic Entomologist, Diptera Curator [Tephritidae], personal communication). The most abundant potential pest species identified from olive fruit fly traps was the glassy winged sharpshooter, *Homalodisca vitripennis* Germar (Hemiptera: Cicadellidae), which represented 0.09% of the collections. Of these collections, 15% and 58% came from Marion and Suwanee groves, respectively.

Three taxa, Coleoptera (t = 0.0325; df = 1, 300; P = 0.0325), Diptera (t = 5.60; df = 1, 300; $P < 0.0001$), and glassy-winged sharpshooters (t = 6.62; df = 1, 300; $P < 0.0001$) had significantly higher means in 2018. All other groups collected were not significantly different by yr ($P > 0.05$). There were seasonal differences with many groups, such as Lepidoptera, Coleoptera, and Psocoptera collections being higher in Apr and May than the following mo. Collections of Diptera peaked in Jul with overall higher collections in summer mo than in Apr and May, and both Hemiptera and *H. vitripennis* collections were highest in Sep (Table 4).

The spatial position of traps in groves affected 3 taxa, with Coleoptera collections slightly higher in center positions (F = 4.26; df = 3, 380; $P < 0.006$), Hymenoptera collections lowest at end of row positions (F = 6.29; df = 3, 380; $P < 0.0004$), and Diptera collections highest in corner positions (F = 2.71; df = 3, 380; $P < 0.045$).

Table 1. List and abundance of insects collected in lure-baited stink bug traps and lure-baited olive fruit fly traps from North Central Florida olive groves in 2017 and 2018. Lower Classification Total columns indicate the number of arthropods identified to Family, Genus, or Species, Order. Total columns indicate the number of arthropods identifiable to Order, with the sum of the 2 columns comprising the Totals at the bottom of the table. An asterisk (*) indicates phytophagous groups, a dagger (†) indicates predatory groups, and the symbol (⊗) indicate groups not considered major ecological potential plant pests or arthropod predators. Specimens indicated as not identified were those not easily identified or those not in important families.

Order	Family	Scientific name	Stink bug trap lower classification total	Stink bug trap order total	Olive fruit fly trap lower classification total	Olive fruit fly trap order total
Blattodea⊗	Not identified			4		1
Coleoptera	Not identified					2,147
	Scarabaeidae	*Anomala flavipennis* Burmeister*	1			
		Phyllophaga prununculina Burmeister*	1			
Dermaptera⊗	Not identified					1
Diptera	Not identified		2	1		88,164
	Culicidae⊗		5			
	Tephritidae				7	
		Bactrocera oleae (Gmelin)*			0	
	Sciomyzidae⊗		1			
Hemiptera	Not identified			1		5,859
	Cicadellidae	*Homalodisca vitripennis* (Germar)*			100	
	Coreidae	*Acanthocephala terminalis* Dallas*	1			
	Pentatomidae		1			
		Euschistus quadrator Rolston*	13			
		Euschistus servus Say*	17			
		Euschistus tristigmus Say*	6			
		Euschistus spp.*	43			
		Loxa flavicollis Drury*	2			
		Murgantia histrionica Hahn*	4			
		Nezara viridula Linnaeus*	3			
		Oebalus pugnax Fabricius*	2			
		Podisus maculiventris Say†	22			
	Reduviidae		4			
		Apiomerus crassipes Fabricius†	73			
		Arilus cristatus Linnaeus†	4			
		Zelus longipes Linnaeus†	25			
Hymenoptera	Not identified			5		16,046
	Formicidae†		10			
	Ichneumonidae†		1			
	Vespidae		1			
		Polistes exclamans Viereck⊗	2			
		Polistes fuscatus Fabricius⊗	1			
		Polistes metricus Say⊗	7			
Lepidoptera	Not identified			1		140
	Erebidae	*Mocis latipes* Guenée* pupae	2			
Neuroptera†	Chrysopidae†	larvae†	1			1
Odonata†						1
Orthoptera	Not identified		21	21		5
	Acrididae*	adults, immatures, parts*	11			
	Tettigoniidae*	adults, immatures, parts*	10			
Psocoptera⊗	Not identified					765
			Total	330	Total	113,237

Discussion

Potentially invasive targeted stink bug fruit pest species were not collected during this survey. While not detected, these species could pose a future threat to Florida olive. The brown marmorated stink bug was documented causing over 80% damage to olive fruits in northern Greece (Damos et al. 2019), showing the importance of continued monitoring for these potentially important olive pests.

Several stink bug species were present consistently in the olive orchards, although overall numbers were low. Of the 8 species of phytophagous stink bugs identified, most individuals were *Euschistus* spp. which are known for their ability to damage vegetation and fruits (Bun-

Table 2. Effect of collection mo on mean (SE) numbers of Hemiptera collected from stink bug traps baited with either consperse stink bug lures or brown marmorated stink bug plus green stink bug lures in 2017 and 2018. *N* = number of traps collected each mo in both yr. Data were analyzed among mo by ANOVA followed by mean separation with a Student-Newman-Keuls test ($P \leq 0.05$). Means with the same letter are not significantly different. *P* values followed by an asterisk (*) indicate statistical differences.

	Mean (SE) trap collection per mo							
Group	Apr	May	Jun	Jul	Aug	Sep	F	*P*
Hemiptera	0.462 (0.160) a	0.218 (0.063) a	0.442 (0.134) a	0.727 (0.192) a	0.220 (0.080) a	0.028 (0.021) b	3.93	0.002*
Euschistus quadrator	0.006 (0.006) a	0.006 (0.006) a	0.006 (0.006) a	0.053 (0.027) a	0.008 (0.008) a	0.009 (0.009) a	2.16	0.057
Euschistus servus	0.071 (0.024) a	0.026 (0.013) b	0.000 (0.000) b	0.000 (0.000) b	0.000 (0.000) b	0.000 (0.000) b	5.76	< 0.0001*
Euschistus tristigmus	0.000 (0.000) a	0.013 (0.013) a	0.000 (0.000) a	0.000 (0.000) a	0.030 (0.030) a	0.000 (0.000) a	0.83	0.529
Euschistus spp.	0.147 (0.147) a	0.039 (0.022) a	0.013 (0.009) a	0.068 (0.047) a	0.015 (0.011) a	0.000 (0.000) a	0.55	0.739
Loxa flavicollis	0.006 (0.006) a	0.006 (0.006) a	0.000 (0.000) a	0.000 (0.000) a	0.000 (0.000) a	0.000 (0.000) a	0.68	0.641
Murgantia histrionica	0.000 (0.000) a	0.006 (0.006) a	0.000 (0.000) a	0.008 (0.008) a	0.000 (0.000) a	0.000 (0.000) a	0.77	0.568
Nezara viridula	0.000 (0.000) a	0.006 (0.006) a	0.006 (0.006) a	0.008 (0.008) a	0.000 (0.000) a	0.000 (0.000) a	0.54	0.745
Oebalus pugnax	0.000 (0.000) a	0.006 (0.006) a	0.006 (0.006) a	0.000 (0.000) a	0.000 (0.000) a	0.000 (0.000) a	0.68	0.641
Podisus maculiventris	0.006 (0.006) a	0.000 (0.000) a	0.000 (0.000) a	0.000 (0.000) a	0.000 (0.000) a	0.000 (0.000) a	0.88	0.496
Reduviidae	0.096 (0.025) ab	0.039 (0.018) b	0.192 (0.065) ab	0.280 (0.079) a	0.068 (0.036) b	0.009 (0.009) b	4.62	0.0004*
Apiomerus crassipes	0.045 (0.019) a	0.000 (0.000) a	0.160 (0.056) b	0.250 (0.072) b	0.060 (0.035) a	0.000 (0.000) a	6.55	< 0.0001*
Arilus cristatus	0.000 (0.000) b	0.026 (0.013) a	0.000 (0.000) b	0.000 (0.000) b	0.000 (0.000) b	0.000 (0.000) b	3.57	0.003*
Zelus longipes	0.006 (0.006) a	0.006 (0.006) a	0.000 (0.000) a	0.000 (0.000) a	0.000 (0.000) a	0.009 (0.009) a	0.64	0.672
N	156	156	156	132	132	108		
df	5,839							

dy & McPherson 2000; Leskey & Hogmire 2005; Brennan et al. 2013). The brown stink bug, *E. servus*, is a well-documented pest of many crops including cotton, tomatoes, southern peas, and okra, and is the cause of the most severe damage of other crop pests in the genus *Euschistus* (Rolston & Kendrick 1961; Bundy & McPherson 2000). Similarly, *E. quadrator* and *Euschistus tristigmus* Say (Hemiptera: Pentatomidae) are broadly polyphagous and occasionally cause severe damage. While all *Euschistus* spp. stink bugs prefer to feed on fruits and reproductive structures of crops and wild hosts, they may feed on stems and leaves (McPherson & McPherson 2000).

Other stink bug species collected were few in number and considered incidental, possibly related to preferred host plant vegetation surrounding or within the groves rather than the olive trees. The southern green stink bug, *N. viridula* is highly polyphagous with feeding reported on over 30 plant families (Panizzi 1997). In the province of Bresica, Italy, 21 individuals of *N. viridula* were collected in 2 olive groves from alfalfa *Medicago sativa* L. (Fabaceae) and common calamint *Calamintha selvatica* Bromf. (Lamiaceae) (Limonta et al. 2004), and there was no indication if *N. viridula* damaged fruit or trees. In Australian olive systems, *N. viridula* is considered a pest and causes feeding damage to fruit (Spooner-Hart et al. 2007). The low numbers collected in the current survey suggests they may be present in Florida olive while seeking out more suitable adjacent plant hosts. Other than *N. viridula*, pentatomids are not considered major pests in other olive growing regions of the world. Other Heteroptera species reported as olive pests are in Lygaeidae, Miridae, and Tingidae, with the mirid plant

Table 3. Effect of lure type on collection of Hemiptera (mean per mo [SE]) collected in dual funnel stink bug traps baited with either consperse stink bug lures or brown marmorated stink bug plus green stink bug lures in 2017 and 2018. *N* = number of traps collected per yr. Data analyzed with a paired *t*-test ($P \leq 0.05$). *P* values followed by an asterisk (*) indicate statistical differences.

	Monthly mean (SE) per trap collection			
Group	Consperse stink bug lure traps	Green + brown marmorated stink bug lure traps	*t*	*P*
Hemiptera	0.233 (0.070)	0.488 (0.078)	3.24	0.001*
Euschistus quadrator	0.026 (0.010)	0.002 (0.002)	2.52	0.012*
Euschistus servus	0.021 (0.009)	0.014 (0.006)	0.53	0.596
Euschistus tristigmus	0.014 (0.011)	0.000 (0.000)	1.39	0.167
Euschistus spp.	0.081 (0.057)	0.019 (0.009)	0.92	0.358
Loxa flavicollis	0.000 (0.000)	0.005 (0.003)	1.42	0.157
Murgantia histrionica	0.000 (0.000)	0.005 (0.003)	1.42	0.157
Nezara viridula	0.000 (0.000)	0.007 (0.0040	1.74	0.083
Oebalus pugnax	0.005 (0.003)	0.000 (0.000)	1.42	0.157
Podisus maculiventris	0.002 (0.002)	0.000 (0.000)	1.00	0.318
Reduviidae	0.026 (0.009)	0.207 (0.037)	5.11	< 0.0001*
Apiomerus crassipes	0.012 (0.007)	0.162 (0.033)	4.91	< 0.0001*
Arilus cristatus	0.007 (0.004)	0.002 (0.002)	1.00	0.317
Zelus longipes	0.000 (0.000)	0.007 (0.004)	1.74	0.083
N	420	420		
df	1,839			

Table 4. Effect of collection mo on mean (SE) numbers of insects collected from olive fruit fly traps in North Central Florida olive groves in 2017 and 2018. Data were analyzed among mo by ANOVA followed by mean separations with Student-Newman-Keuls test ($P \leq 0.05$). *N* = total number of olive fruit fly traps hung each mo over the course of the study. Means with the same letter are not significantly different. An asterisk (*) indicates $P < 0.05$. NS = not significant.

	Mean (SE) per mo							
Group	Apr	May	Jun	Jul	Aug	Sept	F	*P*
Coleoptera	11.449 (2.184) a	7.641 (1.337) a	3.47 (0.785) b	2.394 (0.521) b	2.53 (0.559) b	3.852 (0.842) b	11.49	*
Diptera	98.064 (11.413) b	148.885 (14.694) b	282.849 (27.148) a	364.894 (33.670) a	256.212 (20.643) a	342.259 (51.255) a	24.52	*
Bactrocera oleae	–	–	–	–	–	–	–	–
Hemiptera	14.654 (2.309) b	8.077 (0.899) b	17.182 (5.528) b	20.000 (4.748) b	11.530 (2.718) b	31.926 (8.339) a	4.85	*
Homalodisca vitripennis	0.090 (0.037) b	0.244 (0.069) b	0.182 (0.057) b	0.333 (0.095) b	0.212 (0.088) b	0.963 (0.247) a	7.63	*
Hymenoptera	39.180 (2.961) a	48.641 (5.295) a	41.924 (2.887) a	44.879 (4.388) a	37.333 (3.522) a	37.148 (2.816) a	1.50	NS
Lepidoptera	0.718 (0.117) a	0.513 (0.094) ab	0.349 (0.076) bc	0.106 (0.038) c	0.136 (0.052) c	0.185 (0.093) c	8.75	*
Orthoptera	0.000 (0.000) a	0.026 (0.018) a	0.030 a (0.021) a	0.015 (0.015) a	0.000 (0.000) a	0.000 (0.000) a	0.95	NS
Psocoptera	5.140 (0.940) a	2.128 (0.294) b	1.424 (0.264) bc	0.530 (0.115) c	0.7121 (0.164) c	0.815 (0.214) c	15.0	*
N	78	78	66	66	66	27		
df	5,380							

bug *Closterotomus trivialis* A. Costa (Hemiptera: Miridae) found most often in the Mediterranean growing region (Spooner-Hart et al. 2007; Kalaitzaki et al. 2012; Kacar & Dursun 2015).

Trapping for stink bugs often involves attractive visual components such as yellow pyramid traps; however, these were not chosen for this study due to concerns about unwanted vicinity effects (Wallingford et al. 2018) and inadvertently attracting pests from outside the groves. Lure selection was devised to monitor for pentatomid pests already present in Florida, namely genus *Euschistus*, and for the potentially invasive highly polyphagous pest, *H. halys*. Traps baited for the consperse stink bug collected *E. quadrator* in greater numbers than in traps baited with lures for the green stink bug and brown marmorated stink bugs; however, the latter collected other *Euschistus* spp., so use of both combinations of lures can provide more comprehensive monitoring of *Euschistus* spp. in Florida olive groves.

A large number of the solely predatory group Reduviidae were collected in the survey. Higher trap catches of total Reduviidae and *A. crassipes* in the green/brown marmorated stink bug traps may indicate that these predators were attracted to prey in the traps, or because the larger plastic lures in the traps provided a suitable substrate for egg-laying and niche for ambushing prey. Incidental collections in stink bug traps included Coleoptera, Diptera, Blattodea, Lepidoptera, and Hymenoptera.

No *B. oleae* were detected in this survey and this agrees with its lack of detection in other Texas, Georgia, and Florida crops. The threat of introduction is present because olive branches and fruit infested with *B. oleae* larvae imported from California have been intercepted by the Florida Department of Agriculture and Consumer Services, Department of Plant Industry (FDACS DPI) at state interdiction stations (FDACS 2014). In a nursery setting, potted trees imported from infested areas could contain pupae in the soil, and potentially be moved to various areas throughout the state. If infested fruit or soil was introduced into a Florida olive system, it is likely the entire grove would quickly become infested if a reproducing population established. For this reason, ongoing monitoring for *B. oleae* is crucial to ensure that this highly destructive olive pest does not establish or spread in Florida and adjacent olive-growing regions.

An unexpectedly abundant insect collected in olive groves was the glassy winged sharpshooter, *H. vitripennis*. This species is known to be attracted to yellow (Tipping et al. 2004), and can be readily collected on yellow sticky cards (Blackmer et al. 2006) or traps (Northfield et al. 2009). This species uses a broad range of host plants and often switches hosts during its lifetime (Mizell et al. 2008). Additionally, *H. vitripennis* are strong fliers and may disperse considerable distances to new host plants (Blackmer et al. 2006). The presence of these insects on the olive fruit fly traps indicated their presence in the vicinity of the olive trees, presumably as they move in search of preferred host plants. Prior observations of Florida olive documented this species from olive vegetation (Gillett-Kaufman et al. 2017). The main concern with *H. vitripennis* is that it is a known vector of *Xylella fastidiosa* Wells et al. (Xanthomonadales: Xanthomonadaceae), a bacterial plant pathogen associated with a range of diseases in multiple crops (Hopkins 1989). In Italy, the causal agent of Olive Quick Decline Syndrome is *X. fastidiosa* subsp. *pauca* strain CoDiRO, which is not yet present in the US. It is important to screen at points of entry of Florida for the possible introduction of the disease via infected plant material or vectors to prevent the pathogen's establishment in the state (Luvisi et al. 2017). The higher collections of sharpshooters in Marion and Suwanee groves may be related to the nearby commercial and wild muscadine grape, which are host plants.

The most abundant arthropod taxa collected on the olive fruit fly traps were Diptera, presumably due to the attractive yellow color (Prokopy & Owens 1983) and ammonium bicarbonate food lure (Heath et al. 2009). Temporally, very few groups of organisms collected in the stink bug traps or olive fruit fly traps had significantly different collections between yr. This could reflect the fact that the groves sampled recently are entering an established, fruit-bearing stage and not much fruit was present in the groves to attract fruit pests into the groves. Generally, there were more arthropods collected in 2018 compared to 2017, possibly due to the disruptive effect of Hurricane Irma in 2017, and more fruiting observed in 2018.

Different seasonal patterns of insect abundance in groves were observed with different traps. Stink bug traps detected a peak of phytophagous Pentatomidae earlier in the season (Apr), whereas olive fruit fly traps detected an increased number of potential olive pests in the order Diptera, and the glassy-winged sharpshooter later in the growing season (Jul to Sep, and Sep, respectively). A survey of olive fruit flies using yellow sticky cards in Crete, Greece, found that populations in *B. oleae* peaked in Jul, with another increase in abundance with cooler fall temperatures more suitable for growth and reproduction (Neuenschwander 1982), which was similar to the overall pattern observed in the Diptera collected in this survey. Stink bug traps detected some early peaks in individual predatory Hemiptera species, likely due to an emergence of adults, with the overall predatory group Reduviidae most numerous later in the summer mo. The higher collections of *A. crassipes* in the mo of Jun and Jul in this survey than other mo were similar to findings of *A. crassipes* in a southern Illinois black walnut system (McPherson & Weber 1990). Overall, both trap types detected a higher presence of predatory organisms later in the summer mo.

Position of traps in the groves affected abundance of arthropods collected in olive fruit fly traps. Coleoptera were collected less at the edge of groves compared to center positions. If bark or sap beetles become problematic, this may indicate that monitoring in the middle of the grove may be the best place to begin monitoring and management efforts. Collections of Diptera were highest at corner positions than any other spatial positions within the grove. This indicates that placing olive fruit fly cards at the corner of Florida olive groves may be the best location to target monitoring for the invasive *B. oleae*. Other tephritids have shown patterns of aggregation during monitoring experiments, including those in the genus *Anastrepha* Schiner (Diptera: Tephritidae) (Nicácio et al. 2019) and the genus *Bactrocera* Macquart (Diptera: Tephritidae) (Vargas et al. 1990), and typically are associated with presence of food sources.

In conclusion, no olive-specific pests were identified in this survey; however, several species with potential as pests were present but not causing damage; these included multiple species of stink bugs, 2 species of scarab beetles, grasshoppers, long horned grasshoppers, and *H. vitripennis*. As trees become more established and productive in Florida, the potential remains that some of these species may play a role in defoliation, potential root damage by larvae, and fruit loss via feeding damage and scarring. The high presence of natural enemies and predators observed in the olive agroecosystems may contribute to natural management of pest populations. Whereas *B. oleae* and *H. halys* were not detected in this study, continued surveillance is advisable to detect and rapidly respond to their potential establishment in Florida.

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