Survey of Thysanoptera using colored sticky card traps in Florida, USA, olive groves

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Abstract

Olives are a potential emerging crop for the state of Florida, USA, and the pest arthropods in commercial groves in the state are under-studied. Thrips (order Thysanoptera) are an almost ubiquitous concern among specialty crop growers in Florida. Yellow and blue sticky card traps were used to survey the canopies of trees in 4 North Central Florida olive groves to determine thrips abundance and distribution over 2 growing seasons. Of the 16 species of thrips identified, most were *Frankliniella* spp., with Florida flower thrips, *Frankliniella bispinosa* (Morgan) (Thysanoptera: Thripidae), being the most abundant species for both yr. Yellow traps were more effective for most species of thrips, although several species were more abundant on blue traps. No consistent differences between yr existed. Although overall abundance of flower feeding thrips species coincided with flowering events in the olive orchards, there was insufficient flowering to make statistical correlations between the peak of thrips abundance and flowering events in the olive groves. The results of this study will be useful in informing future economic threshold analyses of Thysanoptera in Florida olive groves.

Key Words: thrips; flower pest; *Frankliniella bispinosa*; *Homalodisca vitripennis*; olives; *Olea europaea*

Resumen

Las aceitunas son un cultivo potencial emergente para el Estado de la Florida, EE. UU., y los artrópodos plagas en los bosques comerciales del estado están poco estudiados. Los trips (orden Thysanoptera) son una preocupación casi omnipresente entre los productores de cultivos especializados en la Florida. Se usaron trampas adhesivas amarillas y azules para examinar las copas de los árboles en 4 olivares del norte central de la Florida para determinar la abundancia y distribución de trips durante 2 temporadas de crecimiento. De las 16 especies de trips identificadas, la mayoría fueron *Frankliniella* spp., con el trips de flores de la Florida, *Frankliniella bispinosa* (Morgan) (Thysanoptera: Thripidae), siendo la especie más abundante para ambos años. Las trampas amarillas fueron más efectivas para la mayoría de las especies de trips, aunque varias especies fueron más abundantes en las trampas azules. No existieron diferencias consistentes entre los años. Aunque la abundancia general de especies de trips que se alimentan de las flores coincidió con los eventos de floración en los huertos de olivos, no hubo suficiente floración para hacer correlaciones estadísticas entre el pico de abundancia de trips y los eventos de floración en los olivares. Los resultados de este estudio serán útiles para informar futuros análisis de umbral económico de los Thysanoptera en los olivares de la Florida.

Palabras Claves: trips; plaga de flores; *Frankliniella bispinosa*; *Homalodisca vitripennis*; aceitunas; *Olea europaea*

Olives, *Olea europaea* L. (Oleaceae), are considered a potential small fruit crop for Florida, USA. Only within the last decade have olive trees been planted in large-scale, high-density groves in Florida. Globally, the most economically damaging arthropod pests affecting olive production include the olive fruit fly (*Bactrocera oleae* [Rossi]; Diptera: Tephritidae) (Ant et al. 2012), the olive moth (*Prays oleae* Bernard; Lepidoptera: Yponomeutidae) (Oliveira et al. 2012), and the olive psyllid (*Euphyllura olivina* [Costa]; Hemiptera: Liviidae) (Debo et al. 2011), none of which are pests in Florida olive or other crops at this time. In general, thrips are not considered to be primary pests of olive in the Mediterranean, which is considered the major olive-producing region of the world (Tzanakakis 2003). The exception is one localized species known to occasionally cause significant feeding damage to olive leaves in the Mediterranean region, *Liothrips oleae* (Costa) (Thysanoptera: Phlaeothripidae) (Canale et al. 2003; Haber & Mifsud 2007). *Liothrips oleae* has not been detected in Florida.

Thysanoptera are a large and diverse insect group with over 5,500 species and 275 species reported from Florida alone (Diffie et al. 2008). The major concern associated with thrips in Florida agriculture is the presence of species in the family Thripidae, arguably due to their role as vectors of plant *Tospoviruses* (Bunyaviridae) (Riley et al. 2011). Olives are not a known host for *Tospoviruses*, so other forms of plant injury such as thrips flower, fruit, and foliar feeding damage are likely more important. In other areas outside of the Mediterranean, thrips species besides *L. oleae* have been reported causing such damage to olive. *Thrips imaginis* Bagnall and *Frankliniella occidentalis* (Pergande) (both Thysanoptera: Thripidae) infestations of flowers in Australia were associated with scarred and misshapen fruit in olive groves (Spooner-Hart et al. 2007). *Frankliniella occidentalis* is considered the major thrips pest in California olives primarily due to its feeding damage to fruit (Daane et al. 2005). Although the diversity and abundance of thrips in Florida have been well studied (Chellemi et al. 1994; Childers & Naka-

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hara 2006; Frantz & Mellinger 2009; Cluever et al. 2016), their impact and abundance on olives in Florida remains unclear.

Visually attractive sticky card traps placed in fields are one of the most common and effective methods of monitoring for thrips in multiple agroecosystems such as blueberry (Liburd et al. 2009), nectarines and apple (Broughton & Harrison 2012), and avocado (Hoddle et al. 2002). The primary stimulus for attraction to the sticky card is color, and many studies have addressed the optimal trap color for the target pests (Hoddle et al. 2002; Chen et al. 2004; Demirel & Yildrum 2008; Liburd et al. 2009; Devi & Roy 2017; Prema et al. 2018). Blue, white, and yellow sticky cards were more attractive to pest thrips species of nectarine and apple orchards in western Australia compared to black, clear, and red (Broughton & Harrison 2012). In Florida, yellow and blue sticky cards were most effective for determining thrips abundance in an olive grove, whereas clear and white traps were not as effective (Allan & Gillett-Kaufman 2018). The objectives of this study were to further determine Thysanoptera species present throughout established Florida olive groves, and to examine the relationship between bloom and abundance.

Materials and Methods

FIELD SITES

Four North Central Florida olive groves were surveyed for this study. The survey was initiated in Mar 2017 and completed in Nov 2018 (Fig. 1). The northernmost grove was located near Live Oak, in Suwannee County, Florida, USA (30.2918°N, 83.1796°E) (Fig. 1). Planted in 2012, the Suwannee grove was located adjacent to pasture land and a chicken farm. It was 13.35 ha with an estimated tree density of 1,631 trees per ha. Prior its use for olive production, the land was used for pine logging, and most of the grove's perimeters were semi-natural pine forest. Four ha were sampled at the Suwanee grove. Inter-row spacing at this grove measured 3.96 m wide, and trees were spaced 1.52 m apart. At the start of the study, inter-row areas of Suwannee grove were predominantly bahiagrass (*Paspalum notatum* Flüggé; Poaceae) and became increasingly weedy throughout the study.

The Gilchrist grove was southwest of the Suwannee grove near Trenton, in Gilchrist County, Florida, USA (29.5923°N, 82.8426°E) (Fig. 1). Planted in 2013 adjacent to cattle farms, this grove was 39.25 ha with an estimated tree density of 1,794 trees per ha. Four hectares were sampled at the Gilchrist grove. The inter-row space was 3.66 m and trees were spaced at 1.83 m intervals. The inter-rows of Gilchrist were predominantly bahiagrass with weeds sometimes creeping into the inter-row.

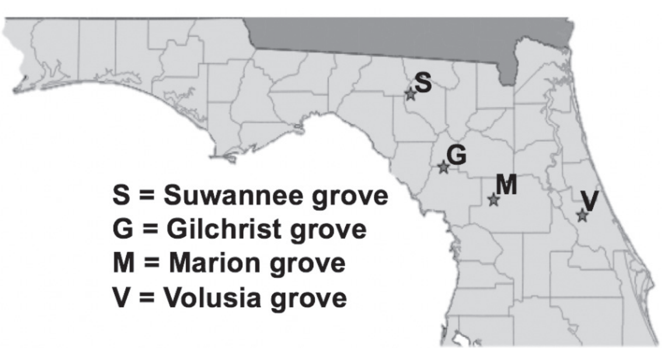

Fig. 1. Map of olive groves surveyed in North Central Florida. Stars represent locations of groves. "S" is a grove in Suwannee County, "G" is a grove in Gilchrist County, "M" is a grove in Marion County, and "V" is a grove in Volusia County. Map created using spatial data from USGS (2016).

Further south from Gilchrist was the Marion grove near Emathla, in Marion County, Florida, USA (29.2872°N, 82.2728°E) (Fig. 1). This grove was planted in 2013 adjacent to cattle farms, was 10.12 ha with an estimated tree density of 1,853 trees per ha. The inter-row spacing was 3.66 m wide with trees spaced 1.22 m apart. One hectare was sampled at the Marion grove. The inter-row areas at Marion grove were maintained as mowed bahiagrass.

Southwest of the Marion grove near De Leon Springs, in Volusia County, Florida, USA, was the Volusia grove (29.1303°N, 81.3071°E) (Fig. 1). The Volusia grove was planted in 2012 adjacent to pine trees and an abandoned citrus grove. It was 7.08 ha with an estimated tree density of 1,379 trees per ha. Trees were spaced 1.83 m apart. The Volusia grove was located on land previously used for pine logging. The inter-row areas were maintained as mowed bahiagrass.

All trees surveyed had been in the ground for 4 or 5 yr since planting. All trees were comprised of the primary olive cultivar 'Arbequina' (80 to 90%) and pollinizer cultivars 'Arbosana' and 'Koroneiki (5 to 10%) with the exception of the Marion grove which had pollinizer cultivars 'Mission' and 'Luca' (5 to 10%). Trees ranged from 1 to 2.5 m, with an average height of 2 m at the beginning of the survey. All groves used some form of tree support including PVC poles, wooden posts, wire trellising, and bamboo poles. All groves utilized drip irrigation from well water. Two groves maintained mowed grassy inter-rows, and 2 groves had inter-rows with a mix of bahiagrass and herbaceous weeds.

SAMPLING PROTOCOL

The groves in Suwannee, Gilchrist, and Volusia each consisted of 4-ha sampling areas which were divided into four 1-ha subplots for sampling. Within each subplot, 5 sampling locations were established (Fig. 2A). In Marion County, a single 1-ha sampling area was surveyed and designated as 1 subplot (which contained similar varieties as the other groves) and contained 5 sampling locations. Thus, for each date, 20 yellow and 20 blue traps were placed within the 4-ha sampling area in all groves except for the Marion grove which had 5 traps of each color in the 1-ha sampling area. Sampling locations within each subplot were classified according to their adjacency to other olive trees (Fig. 2B). Sampling locations were grouped into center sites (surrounded by olive trees), corner (surrounded on 2 sides by olives), edge of row (surrounded on 3 sides by olives) and end (end of a row, but not a corner).

Yellow and blue sticky card traps (Great Lakes IPM, Vestaberg, Michigan, USA) used for thrips sampling were plastic cards (15.2 cm × 29.5 cm) coated by the manufacturer with proprietary sticky material. At each sampling location within the subplots, 1 yellow and 1 blue sticky trap was hung in the tree canopy approximately 1 m above the ground with about 4 m between the traps. Colors selected for traps were based on a prior study in olive (Allan & Gillett-Kaufman 2018). Within each sampling location, the position of yellow and blue traps was switched when new traps were placed to avoid positional bias. When traps were collected, sticky surfaces were placed in transparent 16.5 cm × 14.9 cm plastic resealable sandwich bags (Publix, Lakeland, Florida, USA) before transportation back to the laboratory.

The survey was conducted from Feb 2017 to Nov 2018. Traps were replaced every 2 wk from late Feb until Apr (during potential bloom period) and every mo from Jun to Nov. Sticky card traps remained in the trees after placement during Nov sampling in 2017 and were collected in Feb 2018 to monitor for any occurrence of pest activity. Extreme weather and flooding caused by Hurricane Irma prevented sampling in the Volusia grove and delayed sampling of the Marion and Suwannee groves in Oct 2017. Collection of traps

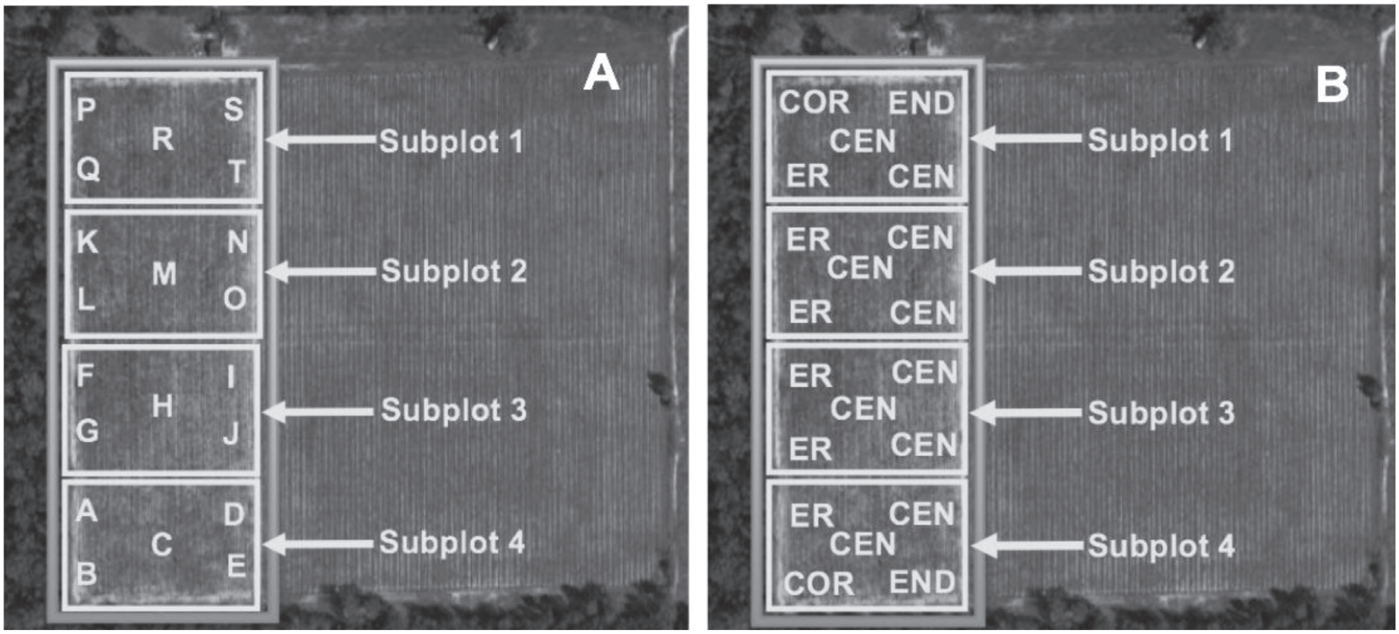

Fig. 2. Diagram of a Florida olive grove indicating sampling locations (A) and spatial identifiers (B) used for sampling design and analysis. The large rectangle represents a 4 ha area surveyed; each of the 4 white boxes represents a 1 ha subplot. Each letter represents a sampling location where yellow and blue sticky traps 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.

was delayed in the Marion grove to mid-Mar 2018 due to farm operations. Traps were removed from the Volusia grove at the growers request in early Jun 2018. Qualitative observations were made of budding, bloom, and fruit development on olive trees during each sampling visit (Fig. 3). Olive pollination is primarily wind-mediated, and olive inflorescence is limited to 7 to 10 d in some growing regions (Martin et al. 2005). Therefore, direct flower samples from olive groves were not taken to minimize pollination interference, and minimally disturb pollination and fruit set in the recently established groves.

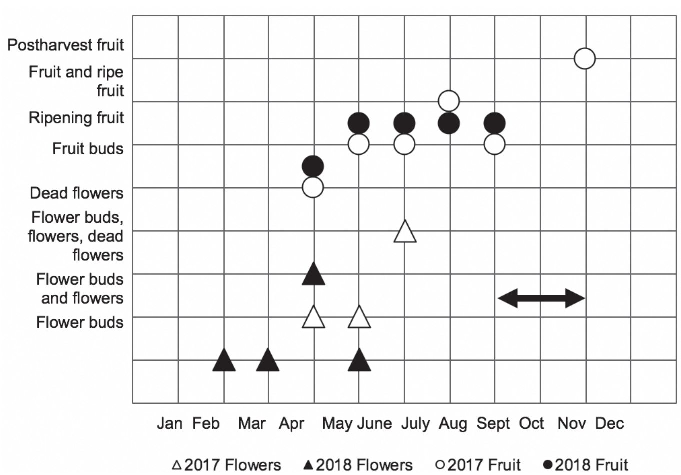

Fig. 3. Timeline of observed fruiting and flowering events of North Central Florida olive trees in both 2017 and 2018. The 2017 flowering and fruiting are represented by white symbols. The gap in 2017 fruiting visible in Sep is when Hurricane Irma prevented sampling efforts. The 2018 flowering and fruiting symbols are represented by black symbols. Triangles represent flowering events. Circles represent fruiting events. The black arrow represents the Florida harvest period. Specific flowering and fruiting events are listed on the y-axis, mo of observation are on the x-axis.

ARTHROPOD IDENTIFICATION

Arthropods on the sticky cards were identified and counted under 40× magnification using Heerbrugg (Heerbrugg, Switzerland), Bausch & Lomb (Rochester, New York, USA), AmScope (Irvine, California, USA), and Olympus (Shinjuku, Tokyo, Japan) brand dissecting microscopes. As the sticky card traps sometimes contained thousands of insects on one side of a card, 1 side of each card was selected at random for counting due to time constraints. A subsampling method similar to Liburd et al. (2009) was used. If cards exceeded 200 arthropods on 1 side, a transparent acetate sheet (10 cm × 13.5 cm) with a grid of 5 rows of 5 squares (each square was 2.54 × 2.54 cm) was placed over the sticky card for subsampling. One square from each row was randomly selected and divided into 4 smaller squares. If overall insect abundance exceeded 200 in 1 grid square, insects in 1 cell of the smaller square were counted, and the resulting number was then multiplied to account for the entire row.

Identifications of thrips on cards were based on key diagnostic features under 40× magnification of a dissecting microscope (Liburd et al. 2009) following Hoddle et al. (2012). Representative thrips were slide mounted and confirmed using the Thrips of California 2012 Lucid key (Hoddle et al. 2012). In some rare cases, identification of thrips to species on sticky traps was not possible due to the fragile state of the thrips in the sticky material. The time required for slide mounting large numbers of thrips and representative proportions of thrips from adjacent foliage was obtained and applied to the collection as stated in Rodriguez-Saona et al. (2010).

STATISTICAL ANALYSIS

Numbers of insects collected were divided by the number of traps to obtain numbers collected per trap collection. These numbers were averaged by yr, mo of deployment, location within the grove, and color of the sticky card, and corrected by number of traps for analysis. Comparisons between means were determined using PROC-GLM in SAS (vers. 9.3, SAS Institute, Cary, North Carolina, USA). Data were square root (× + 0.01) transformed before analysis due to the presence of zero count data. Comparisons of means by yr and sticky trap color were conducted with a paired *t*-test with unequal variance. Means separation using Tukey's Test ($P \leq 0.05$) was used for post-hoc analysis. Taxa with $n \leq 15$ were excluded from analysis. Excluded taxa included Phasmatodea, Trichoptera, *Neurothrips magnafemoralis* (Hinds) (Thysanoptera: Phlaeothripidae), *Echinothrips americanus* Morgan (Thysanoptera: Thripidae), *Frankliniella gossypiana* (Hood) (Thysanoptera: Thripidae), and *Leucothrips piercei* (Morgan) (Thysanoptera: Thripidae).

RESULTS

A total of 538,853 arthropods were counted on the blue and yellow sticky cards hung in the 4 sampled olive groves for 35,990 traps over the course of the study (Table 1). These collections included 2 orders of Arachnida and 13 orders of Insecta. Thysanoptera (202,732) was the most numerous order encountered on the cards, and represented 37.62% of trap catch and 16 species. The majority of Thysanoptera were in the family Thripidae (97.98%) with most phytophagous pest thrips in the genus *Frankliniella* (99.35%). These species included *Frankliniella bispinosa* (Morgan) (98.11%), *Frankliniella tritici* (Fitch) (1.34%), *Frankliniella fusca* (Hinds) (0.34%) (all Thysanoptera: Thripidae), *F. occidentalis* (Pergande) (0.19%), and 1 specimen of *F. gossypiana* (Hood). Other collected thrips in Thripidae included *Heliothrips haemorrhoidalis* (Bouché) (0.44%), *Microcephalothrips abdominalis* (Crawford) (0.10%), *Neohydatothrips floridanus* (Watson) (0.085%), *Thrips tabaci* Lindeman (0.011%), *L. piercei* (0.004%), and *E. americanus* (0.002%) (all Thysanoptera: Thripidae).

Thrips from the family Phlaeothripidae represented 2.02% of Thysanoptera collected, of which 98.1% were predatory thrips (Table 1). The most common Phlaeothripidae was *Karnyothrips flavipes* (Jones) (96.45%) with the remainder of the collection consisting of *Karnyothrips melaleucus* (Bagnall) (3.55%). Two species of phytophagous Phlaeothripidae were present, *Liothrips floridensis* (Watson) (1.079%), and *Haplothrips gowdeyi* (Franklin) (0.47%), along with 1 species of fungivorous Phlaeothripidae, *N. magnafemoralis* (0.147%) (all Thysanoptera: Phlaeothripidae).

Table 1. List and abundance of arthropods collected on yellow and blue sticky cards hung in north central Florida olive groves in 2017 and 2018. An asterisk (*) indicates phytophagous groups. A dagger (†) indicates predatory groups. A circled x (⊗) indicates fungivore/detritivore groups. A tilde (~) indicates groups that do not feed in the identified adult stage. Extended totals are listed by order.

Class	Order	Family	Species	Total	Extended Total
Arachnida	Acari				115
	Araneae †				1,675
Insecta	Blattodea ⊗				41
	Coleoptera				3,186
	Collembola ⊗				184
	Diptera				185,800
	Hemiptera				20,840
			Homalodisca vitripennis Germar*		353
	Hymenoptera				121,167
	Lepidoptera				324
	Neuroptera †				81
	Odonata †				23
	Orthoptera *				33
	Phasmatodea *				1
	Psocoptera ⊗				2,287
	Trichoptera ~				11
	Thysanoptera				202,732
		Phlaeothripidae		5	4,077
			Haplothrips gowdeyi Franklin *	19	
			Karnyothrips flavipes Jones †	3,861	
			Karnyothrips melaleucus Bagnall †	142	
			Liothrips floridensis Watson *	44	
			Neurothrips magnafemoralis Hinds ⊗	6	
		Thripidae			198,655
			Echinothrips americanus Morgan *	5	
			Frankliniella bispinosa Morgan *	193,650	
			Frankliniella fusca Hinds *	676	
			Frankliniella gossypiana Hood *	1	
			Frankliniella occidentalis Pergande *	383	
			Frankliniella tritici Fitch *	2,654	
			Heliothrips haemorrhoidalis (Bouché) *	878	
			Leucothrips piercei Morgan *	8	
			Microcephalothrips abdominalis Crawford *	207	
			Neohydatothrips floridanus Watson *	170	
			Thrips tabaci Lindeman *	23	
				Total	538,853

The wide range of non-target insects also collected on traps included Diptera, Hymenoptera, and Hemiptera and represented 34.50%, 22.50%, and 3.87%, respectively, of the overall trap catch (Table 1). None of the Diptera or Hymenoptera collected were species known to threaten olives. Of the 20,840 hemipterans collected, there were 353 glassy-winged sharpshooters, *Homalodisca vitripennis* Germar (Hemiptera: Cicadellidae), which is considered a potential pest species of olive.

Sticky card collection means were compared between yr of collection (Table 2). Overall thrips numbers did not differ between yr, nor did numbers of Thripidae, total *Frankliniella* spp., or the most predominant species, *F. bispinosa*. Several of the less common Thripidae and total Phlaeothripidae differed significantly between yr but no pattern in number by species, or between phytophagous or predatory species was consistent. Because there were few defined effects of yr of collection, data were combined between yr for subsequent analyses.

There were significant patterns of abundance in thrips collections between mo with a definite increase in Mar and Apr followed by a decrease in May (F = 141.83; df = 9, 2481; P < 0.0001). The same pattern was clear in both 2017 and 2018 with higher mean numbers collected in May in 2017 than in 2018. Thrips numbers again increased slightly in Oct 2017. Whereas the greatest numbers of thrips were collected in Apr followed by Mar, there were several patterns of abundance detected when examining individual species. Early season abundance (Feb, Mar) was high for *L. floridensis* (F = 5.33; df = 9, 2481; P < 0.0001), *F. occidentalis* (F = 15.15; df = 9, 2481; P < 0.0001), and *F. tritici* (F = 6.46; df = 9, 2481; P < 0.0001). Greatest abundance of Thripidae (F = 142.69; df = 9, 2481; P < 0.0001), *Frankliniella* spp. (F = 144.68; df = 9, 2481; P < 0.0001), and *F. bispinosa* (F = 137.11; df = 9, 2481; P < 0.0001) occurred in Apr. Within Phlaeothripidae the greatest abundance was in May and Jun (F = 23.02; df = 9, 2481; P < 0.0001) and consisted primarily of *K. flavipes* (F = 24.61; df = 9, 2481; P < 0.0001). Greatest abundance of *K. maleulucus* appeared in late summer and fall (F = 5.61; df = 9, 2481; P < 0.0001). Small peaks of abundance occurred in Oct for *K. melaleucus*, *F. tritici*, *H. haemorrhoidalis*, and *M. abdominalis*. Month of collection did not affect thrips species collected in very low numbers (*H. gowdeyi*: F = 0.69; df = 9, 2481; P = 0.716). While significantly different means were detected by ANOVA, the means comparison test failed to detect significant differences for monthly analysis of collections of *T. tabaci*, likely due to the higher statistical power of the ANOVA. Overall abundance of Hemiptera was greatest in Jun and then in Oct and Nov (F = 29.54; df = 9, 2481; P < 0.0001). In contrast, greatest numbers of *H. vitripennis* were collected in Jun and Jul (F = 6.90; df = 9, 2481; P < 0.0001). Traps left in the field from Nov 2017 to Feb 2018 did not show a significant increase in any groups.

The color of the sticky cards affected composition of insects collected (Table 3). Collections of overall thrips, Thripidae, combined *Frankliniella* spp., *F. bispinosa*, and *F. fusca* were not significantly different between trap colors. Yellow traps were more attractive for *H. gowdeyi*, *K. flavipes*, *M. abdominalis*, *N. floridanus*, and *T. tabaci* whereas blue traps were more attractive to *K. maleulucus*, *F. occidentalis*, and *F. tritici*. *Homalodisca vitripennis* had higher collections on yellow cards.

The spatial position of the sticky cards within the plots affected collections of some groups (Table 4). Overall, the end positions had the lowest numbers of Thysanoptera with a similar pattern seen for Thripidae, which was primarily comprised of *F. bispinosa*. While there was no overall pattern seen for Phlaeothripidae, larger numbers of *K. melaleucus* were present in the center and end positions. There was no overall pattern in Hemiptera; however, greater numbers of *H. vitripennis* were collected from corner positions.

When considering the timing of olive tree fruiting and flowering events in 2017 and 2018, flowering occurred for 3 mo in both yr, and it occurred approximately 2 mo earlier in 2018 than in 2017 (Fig. 3). Flower bud development initiated in late Feb 2018 and in Apr 2017. Flowering and fruiting were recorded as presence or absence in the groves. Flowering was observed more heavily in 2018 than 2017, with 11 incidences of flowers observed in 2017 and 41 incidences of flowers observed in 2018. Main fruiting events, such as fruit budding and development, were observed in the same timeframe in 2017 and 2018 and began in Apr (Fig. 3). Fruit presence and ripening were observed

Table 2. Comparison of yearly means (SE) of arthropods caught on yellow and blue sticky card traps hung in north central Florida olive groves in 2017 and 2018. N = total number of traps deployed each mo in both yr. Data analyzed with a t-test (P ≤ 0.05). Values followed by an asterisk (*) indicate significant statistical differences.

	Mean (SE) per trap collection			
Group	2017	2018	*t*	*P*
Thysanoptera	80.322 (5.439)	83.562 (7.197)	0.75	0.4580
Phlaeothripidae	1.626 (0.144)	1.667 (0.136) *	2.95	0.0030
Haplothrip gowdeyi	0.002 (0.002)	0.015 (0.004) *	3.53	0.0004
Karnyothrips flavipes	1.565 (0.144) *	1.546 (0.134)	2.51	0.0120
Karnyothrips melaleucus	0.020 (0.007)	0.105 (0.013) *	7.40	< 0.0001
Liothrips floridensis	0.030 (0.008) *	0.002 (0.001)	3.51	0.0005
Thripidae	78.696 (5.440)	81.895 (7.195)	0.86	0.3950
Frankliniella spp.	78.133 (5.442)	81.43 (7.189)	0.69	0.4890
Frankliniella bispinosa	77.764 (5.442)	78.493 (7.083)	1.30	0.1930
Frankliniella fusca	0.130 (0.031)	0.454 (0.229)	0.38	0.7070
Frankliniella occidentalis	0.001 (0.001)	0.350 (0.059) *	8.41	< 0.0001
Frankliniella tritici	0.237 (0.067)	2.132 (1.017) *	4.54	< 0.0001
Heliothrips haemerhorrhoidales	0.363 (0.035)	0.342 (0.028)	0.74	0.4620
Microcephalothrips abdominalis	0.057 (0.016)	0.117 (0.022) *	4.16	< 0.0001
Neohydatothrips floridanus	0.118 (0.016) *	0.006 (0.003)	7.39	< 0.0001
Thrips tabaci	0.016 (0.005) *	0.000 (0.000)	3.17	0.0020
Hemiptera	8.867 (0.481)	7.489 (0.383)	0.93	0.3530
Homalodisca vitripennis	0.077 (0.009)	0.225 (0.023) *	6.38	< 0.0001
N	1,390	1,090		
df	1, 2,417			

Table 3. Comparison of trap color on mean (SE) of arthropods captured on yellow and blue sticky cards hung in north central Florida olive groves in 2017 and 2018. *N* = total number of traps deployed each mo in both yr. Data analyzed with a paired *t*-test ($P \leq 0.05$). Values followed by an asterisk (*) indicate statistically significant differences.

	Mean number (SE) per total traps collected			
Group	Yellow	Blue	*t*	*P*
Thysanoptera	49.396 (3.439)	114.096 (7.980)	0.75	0.4550
Phlaeothripidae	2.828 (0.191) *	0.460 (0.037)	2.95	0.0032
Haplothrips gowdeyi	0.010 (0.004) *	0.005 (0.002)	3.53	0.0004
Karnyothrips flavipes	2.729 (0.191) *	0.384 (0.034)	2.51	0.0120
Karnyothrips melaleucus	0.056 (0.008)	0.059 (0.011) *	7.40	< 0.0001
Liothrips floridensis	0.028 (0.009)	0.007 (0.002)	3.51	0.1450
Thripidae	46.568 (3.422)	113.636 (7.978)	0.86	0.3910
Frankliniella spp.	45.938 (3.417)	113.226 (7.977)	0.69	0.4890
Frankliniella bispinosa	45.117 (3.417)	111.052 (7.909)	1.30	0.1930
Frankliniella fusca	0.163 (0.051)	0.383 (0.198)	4.59	0.7070
Frankliniella occidentalis	0.056 (0.012)	0.252 (0.051) *	8.41	< 0.0001
Frankliniella tritici	0.602 (0.121)	1.538 (0.889) *	4.54	< 0.0001
Heliothrips haemorrhoidalis	0.392 (0.033)	0.317 (0.033)	0.74	0.4620
Microcephalothrips abdominalis	0.095 (0.016) *	0.072 (0.021)	4.16	< 0.0001
Neohydatothrips floridanus	0.121 (0.017) *	0.016 (0.004)	7.39	< 0.0001
Thrips tabaci	0.018 (0.006) *	0.000 (0.000)	3.17	0.0020
Hemiptera	13.716 (0.581)	2.806 (0.141)	0.93	0.3533
Homalodisca vitripennis	0.282 (0.022) *	0.002 (0.001)	6.38	< 0.0001
N	1,240	1,240		
df	1, 2,417			

from May until Aug, and was similarly higher in 2018 than in 2017 with 24 incidences of fruiting observed in 2017 and 95 incidences of fruiting observed in 2018. Fruit was observed on trees in areas outside of sampling areas as late as Oct 2018. There were not enough incidents of flowering to statistically analyze the effect of flowering on Thysanoptera abundance during the growing season. Although no significant correlations could be made, the abundance of thrips occurred earlier and higher in 2018, similar to the earlier and heavier flower set in 2018 (Figs. 3, 4). The decline in thrips abundance from Apr to May was more pronounced in 2018 than 2017, which aligned with evidence of flowering being present through the mo of May 2017. There were very few insects collected while olive trees are dormant in Florida, between the mo of Nov to early Feb. Peak abundance of thrips coincided with flowering events of both yr with Apr always the highest, followed by Mar (Fig. 4).

Discussion

Flower-infesting thrips in the genus *Frankliniella* were the most common thrips collected in olive groves, with *F. bispinosa* as the most abundantly encountered species. This species is present throughout the southeastern states of Florida, Georgia, and Alabama (Funderburk et al. 2007; Diffie et al. 2008; Tillman et al. 2017), and in Florida has similarly been the most encountered thrips species (Childers & Nakahara 2006; Liburd et al. 2009; Cluever et al. 2016; Allan & Gillett-Kaufman 2018). In a survey of 7 different mid-Central Florida citrus orchards, *F. bispinosa* was the most abundant thrips species encountered, representing 32.15% of the total thrips collected from the tree canopy and vines and ground cover plants present in the orchards (Childers & Nakahara 2006). In citrus, this species is associated with premature flower drop resulting in yield loss of fruit (Childers & Achor 1991). Similarly, in 2 Central Florida rabbiteye and southern highbush blueberry fields, 95% of Thysanopteran pests were *F. bispinosa* (Liburd et al. 2009). Flower thrips are considered to be pests not only of blueberry flowers, but of developing fruit as well. In Australia, 2 species of Thripidae, plague thrips, *T. imaginis*, and western flower thrips, *F. occidentalis*, are considered responsible for flower infestations resulting in scarred and misshapen fruit (Spooner-Hart et al. 2007). *Frankliniella occidentalis* was considered the major thrips pest in California olives where it caused damage by feeding on leaves, young shoots, and fruit (Daane et al. 2005).

The peak abundance of *Frankliniella* species occurred in Apr of both yr, which coincided with flowering and initial fruit budding in olive trees. Due to relatively few flowering observations overall, it was not possible to make direct statistical correlations between flower presence in the olive groves with peak presence of pest flower thrips. Correlations of thrips abundance was done measuring collections of thrips in olives during the general pre-bloom, bloom, and post-bloom inflorescence events by Allan and Gillett-Kaufman (2018). They found that peak collections of thrips coincided with bloom in early Apr in a Florida olive grove and was lowest during the post-bloom period. It is probable that the flower thrips are moving from surrounding flowering plants into the groves, or from flowering plants in the inter-row areas to the olive trees. The pest species *T. imaginis* and *F. occidentalis* of Australian olive are thought to feed on understory flowering weeds and flowers adjacent to olive groves, and then move into the olive groves beginning in spring (Spooner-Hart et al. 2007). *Thrips imaginis* is found more commonly in Australian olive flower trap samples than on sticky card traps. Additionally, some pest thrips species are known to feed more on maturing fruits and foliage of plant hosts. An olive-specific thrips species, *L. oleae*, is currently known to be established only throughout the Mediterranean and eastern Africa (Haber & Mifsud 2007). This species is commonly found in olive groves in the Mediterranean; however, it is considered only an occasional pest that causes limited economic injury through formation of semi-circular leaf galls leading to leaf deformation (Havber & Mifsud 2007). No such evidence of *L. oleae* characteristic galls were observed during this survey. Floral damage from

Table 4. Effect of trap location within the plot on mean (SE) number of insects collected on yellow and blue sticky traps hung in north central Florida olive groves in 2017 and 2018. *N* = total number of traps deployed each mo in both yr. Data were analyzed between locations with an ANOVA followed by Tukey's test for means separation ($P \leq 0.05$). *P* values followed by an asterisk (*) indicate significant difference between locations. Means with the same letter are not significantly different.

	Mean number (SE) per total traps collected					
Group	Center	Corner	End	Edge Row	*F*	*P*
Thysanoptera	89.398 (6.416) a	89.455 (18.118) ab	64.317 (8.711) b	78.296 (7.652) ab	3.89	0.009 *
Phlaeothripidae	1.821 (0.173) a	1.172 (0.152) a	1.633 (0.244) a	1.608 (0.185) a	0.96	0.410
Haplothrips gowdeyi	0.013 (0.005) a	0.000 (0.000) a	0.002 (0.002) a	0.007 (0.003) a	1.84	0.138
Karnyothrips flavipes	1.692 (0.172) a	1.119 (0.150) a	1.551 (0.242) a	1.560 (0.185) a	0.39	0.760
Karinyothrips maleulucus	0.091 (0.015) a	0.023 (0.010) b	0.056 (0.016) ab	0.027 (0.007) b	6.25	0.0003 *
Liothrips floridensis	0.022 (0.008) a	0.018 (0.012) a	0.021 (0.008) a	0.011 (0.007) a	0.66	0.577
Thripidae	87.578 (6.414) a	88.282 (18.114) ab	62.683 (8.700) b	76.688 (7.657) ab	4.05	0.007 *
Frankliniella spp.	86.983 (6.412) a	87.841 (18.113) ab	62.193 (8.698) b	76.219 (7.654) ab	4.02	0.007 *
Frankliniella bispinosa	85.690 (6.380) a	83.179 (17.748) ab	61.284 (8.694) b	75.419 (7.641) ab	4.21	0.006 *
Frankliniella fusca	0.345 (0.199) a	0.562 (0.427) a	0.292 (0.200) a	0.045 (0.012) a	1.41	0.238
Frankliniella occidentalis	0.215 (0.051) a	0.088 (0.039) a	0.072 (0.029) a	0.148 (0.050) a	1.46	0.224
Frankliniella tritici	0.733 (0.260) a	4.013 (3.477) a	0.544 (0.191) a	0.608 (0.174) a	0.80	0.492
Heliothrips haemorrhoidalis	0.394 (0.041) a	0.310 (0.059) a	0.322 (0.049) a	0.337 (0.040) a	0.40	0.757
Microcephalothrips abdominalis	0.102 (0.019) a	0.068 (0.026) a	0.065 (0.034) a	0.075 (0.029) a	1.60	0.188
Neohydatothrips floridanus	0.080 (0.014) a	0.054 (0.018) a	0.088 (0.030) a	0.048 (0.013) a	1.06	0.365
Thrips tabaci	0.017 (0.007) a	0.006 (0.005) a	0.001 (0.001) a	0.005 (0.003) a	1.52	0.206
Hemiptera	8.202 (0.539) a	9.010 (0.813) a	8.648 (0.883) a	7.808 (0.480) a	1.27	0.284
Homalodisca vitripennis	0.094 (0.014) b	0.185 (0.034) a	0.164 (0.030) ab	0.176 (0.024) ab	4.32	0.005 *
N	1,000	308	428	744		
df	3,2415					

Thysanoptera may be overlooked due to the presence of the olive bud mite, *Oxyenus maxwelli* (Keifer) (Acari: Eriophyidae), that feeds on floral buds and can prevent flowering and fruit set if present in high enough numbers. While the olive bud mite was detected in Florida previously (Allan & Gillett-Kaufman 2018), it was not detected in the current survey. Pressure from local populations of flower thrips are likely of greatest concern for Florida olive growers.

The rather sharp drop in overall flower thrips pest groups after Apr and after major flowering events may indicate that the thrips are not feeding on other important parts of the plant such as fruit during the remainder of the growing season in Florida. This may be due to the relatively few instances of flowering and fruiting in the olive groves which reflects the comparatively young age of the groves, and grove response to unseasonably severe cold weather in early spring in both yr of the study. As a result of the low flowering, it was difficult to quantify any significant or direct correlation between thrips abundance, flowering, and any feeding damage effects on subsequent fruiting. As groves mature, the continued monitoring of abundance of *Frankliniella* species within the groves is needed to determine if the thrips move into olive groves during the short 7 to 10-d flowering period, or if they are abundant on surrounding flowering weeds and other vegetation coinciding with olive flowering. The establishment of a correlation between olive flowering and flower thrips damage could lead to the determination of economic thresholds of *Frankliniella* species that could warrant control to prevent subsequent fruit damage. Several studies in Florida agroecosystems show a strong relationship between bloom periods and thrips abundance (Chellemi et al. 1994; Frantz & Mellinger 2009; Liburd et al. 2009; Osekre et al. 2009; Allan & Gillett-Kaufman 2018).

Other *Frankliniella* species collected included species that feed on flowers as well as leaves. Polyphagous species included *F. fusca*, important as a pest of field crops in the southeastern USA (Reitz et al. 2003), and *F. gossypiana* which is associated with a range of flower species but not recorded as a pest (Hoddle et al. 2012). Both *F. occidentalis* and *F. tritici* are relatively common species on wild plant species in Florida and the southeastern USA with economic damage to many crops reported from *F. occidentalis* (Chellemi et al. 1994; Reitz 2008). *Franlinkiella tritici* has been associated with crop damage, particularly roses (Reitz 2008). Seasonal abundance of these species in Florida differ, with high abundance of *F. tritici* in late spring and late summer, *F. bispinosa* in Jun and Jul, and *F. occidentalis* in late Feb and Apr (Chellemi et al. 1994).

Other thrips species collected in this study on olive and considered phytophagous from family Thripidae included *E. americanus*, *H. haemorrhoidalis*, *L. piercei*, *M. abdominalis*, *N. floridanus*, *T. tabaci*, and multiple species from the genus *Frankliniella*, including *F. fusca*, *F. gossypiana*, *F. occidentalis*, and *F. tritici*. Of these species, *N. floridanus* is not considered a pest in Florida (Childers & Nakahara 2006). Although the remainder of these species are considered plant pests, none have previously been documented as feeding or reproducing on olives in the southeastern United States.

Phytophagous thrips species collected from Phlaeothripidae included *H. gowdeyi*, *L. floridensis*, and *N. magnafemoralis*. *Haplothrips gowdeyi* is a generalist pest of flowers (Nakahara & Hilburn 1989) and reportedly more abundant on ground cover and citrus tree canopies in Florida (Childers & Nakahara 2006). *Liothrips floridensis* is specific to camphor trees, known from Florida (Yothers 1924), and more recently has been established in California (Hoddle et al. 2012). Presumably in the current study, thrips were associated with camphor trees in adjacent wooded areas. Of note, this species was collected only on sticky traps, not in tree branch tap samples or brush samples from tree trunk bark collected in addition to sticky card traps during this survey, indicating that they are not residing in the olive trees but captured in flight around the trees. The less common species, *N. magnafemoralis*, has been reported from citrus in Florida where they have not been associated with damage, and are classified fungal feeders (Childers & Nakahara 2006). These species do not appear to pose a threat to olive trees.

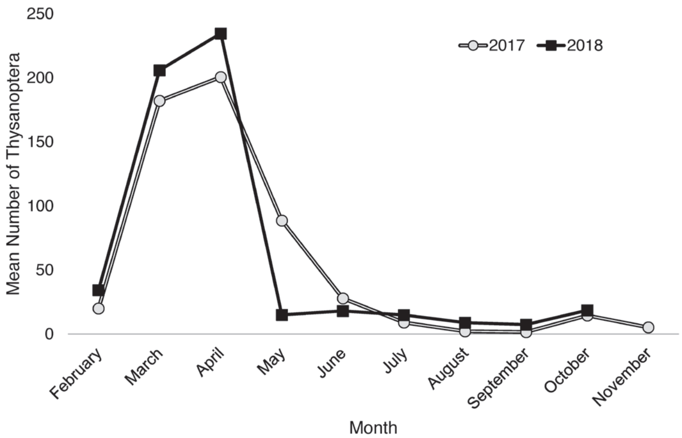

Fig. 4. Mean thrips abundance per mo in 2017 and 2018 and in both yr combined found on yellow and blue sticky card traps in 4 north central Florida olive groves.

Predatory thrips are known to be generalists feeding on multiple insect or mite species, or specialists feeding on particular insect or mite species (Lewis 1973). Predatory thrips identified in the survey included 2 specialized predators, *K. flavipes* and *K. melaleucus*. The species that was less common in this study, *K. melaleucus*, preferentially feeds on soft scale insects (Coccidae) (Pitkin 1976), of which 3 were collected from brush sampling techniques and hundreds were observed in the same olive groves surveyed for this study. The more abundant predatory species, *K. flavipes*, feeds specifically on *Saissetia* soft scales (Hemiptera: Coccidae), *Asterolecanium* pit scales (Hemiptera: Asterolecaniidae), *Parlatoria* armored scales (Hemiptera: Diaspididae), *Pseudaonidia duplex* Cockerell (Hemiptera: Diaspididae), whiteflies (Hemiptera: Aleyrodidae), and mites (Acari) (Pitkin 1976). Tree branch tap sampling and collection of tapped insects from a canvas beat sheet and observation data from the same collection sites revealed an abundance of *Saissetia* soft scale, likely serving as a food source for *K. flavipes*. Additionally, *N. magnafemoralis* was the only fungivore identified and presumably feeds on lichen commonly observed on olive tree bark. A previously reported predatory thrips species from olive, *Leptothrips pini* (Watson) (Thysanoptera: Phlaeothripidae), was not found in our survey (Allan & Gillett-Kaufman 2018). None of the predatory species reported here are new to the state and have been documented in other Florida agroecosystems such as citrus (Childers & Nakahara 2006) and blueberry (Liburd et al. 2009).

Although there were significant differences between yr of collection for some arthropods, there was no difference between yr for the abundant flower pest, *F. bispinosa*, indicating that populations of these potentially serious flower pests are fairly stable from yr to yr. There were 2 major periods of abundance of thrips, in the spring and early summer, and there was a smaller peak of abundance in Oct. The most abundant thrips in Thripidae included the flower-associated thrips, *Frankliniella* species, *F. bispinosa*, *F. occidentalis*, *F. tritici*, and *N. floridanus*, with highest populations during peak flowering mo (Mar, Apr). The small late season peak in abundance observed in Oct was similar to Childers and Nakahara (2006) collections of *F. bispinosa* in Florida citrus. They noted an increase of *F. bispinosa* in Nov, and that *F. bispinosa* was capable of producing multiple generations per yr (Childers & Nakahara 2006). The most common predatory thrips, *K. flavipes*, was most abundant during mo following flowering (May, Jun), possibly showing a lag in population increase after feeding on flower-associated arthropods. Several less common thrips species, *K. melaleucus*, *H. haemorrhoidalis*, *L. piercei*, *M. abdominalis*, and *T. tabaci* reached maximum populations in Oct. These are polyphagous species most likely associated with plant species adjacent to the olive trees or in the inter-row areas and may reflect a new late-season generation. The glassy-winged sharpshooter, *H. vitripennis*, was most abundant in Jul and Jun of both yr. This is similar to a study done in Florida grape in 2001 to 2002 where the abundance of *H. vitripennis* was highest in late Jun and Jul, but were comparatively absent thereafter (Andersen et al. 2005). Additionally, Krugner et al. (2009) found that even under continuous deficit irrigation, populations of *H. vitripennis* peaked in Florida citrus groves in Jul, with the populations beginning to increase in Jun.

When considering the different colors of traps, blue appears better suited to assess *F. bispinosa* abundance in olive groves. This finding is consistent with other surveys of Thysanoptera (Chen et al. 2004; Allsopp 2010; Allan & Gillett-Kaufman 2018). Other less abundant *Frankliniella* species were found to be significantly higher on blue sticky traps; however, other genera of phytophagous thrips were more abundant on yellow sticky cards. The potential pest *H. vitripennis* was found primarily on the yellow sticky cards. *Homalodisca vitripennis* is known to be attracted to yellow (Tipping et al. 2004), and both yellow sticky cards (Blackmer et al. 2006) and traps (Northfield et al. 2009) have been used to collect this insect.

The consistent presence of glassy-winged sharpshooters in Florida olive groves may pose a threat. They are known vectors of the bacterial plant pathogen *Xylella fastidiosa* subspecies *fastidiosa* Wells et al. (Xanthomonadaceae), that causes Pierce's disease of grape (*Vitis vinefera* L.; Vitaceae), which is native to Florida and allows for only resistant strains of grape to be grown successfully (Hopkins 1989). While *H. vitripennis* is native to the southeastern USA where some native grape varieties resistant to Pierce's disease of grape exist (Mortensen et al. 1977), it was first reported in 1997 in southern California where it is now established and considered a major pest of viticulture in the state costing millions in losses annually (Tumber et al. 2014). The causal agent *X. fastidiosa* is xylem-limited, and infection spreads between plants by xylem-feeding Hemipteran insect vectors (Purcell & Finlay 1979; Hopkins 1989). Recently, a strain of the disease, *Xylella fastidiosa* subsp. *pauca* (Xanthomonadaceae) strain CoDiRO (Complesso del Disseccamento Rapido dell'Olivo), was introduced to Italy in infected ornamental plants from Costa Rica (Luvisi et al. 2017). Subsequently the pathogen was then found causing Olive Quick Decline Syndrome in olive groves in southeastern Italy. The disease causes desiccation of twigs, which begins in the olive crown and progresses down throughout the canopy, leaving the tree with a scorched appearance (Martelli et al. 2016). Affected trees may continue to put out new foliage known as suckers; however, the foliage desiccates, and secondary pathogens and insect pests begin to move in and colonize the dying trees (Martelli et al. 2016). This pathogen, *X. fastidiosa* subsp. *pauca*, is spread by various Auchenorrhynchan xylem-feeding insects such as cicadas (Hemiptera: Cicadidae), spittlebugs (Hemiptera: Cercopidae, Aphophoridae), and leafhoppers (Hemiptera: Cicadellidae).

The strain *X. fastidiosa* subsp. *pauca* strain CoDiRO has not been reported in the USA in olive growing regions; however, there have been identifications of multiple subspecies of *X. fastidiosa* in California olive trees (Krugner et al. 2014; Martelli et al. 2016). Three subspecies and 1 clade of *X. fastidiosa* has been cultured from California olive, but are not thought to be correlated with disease or symptoms of leaf scorch. Krugner et al. (2014) reported that *H. vitripennis* is capable of transmitting *X. fastidiosa* subsp. *fastidiosa* and *X. fastidiosa* subsp. *multiplex* to olive at low efficiency. Additionally, *H. vitripennis* is known to be highly mobile (Turner & Pollard 1959; Blackmer et al.

2006) and phytophagous. While it has host species from 37 families in Florida, most Florida collections occur from *Citrus* spp. (Hoddle et al. 2003). The glassy-winged sharpshooter was frequently collected on yellow sticky cards, indicating that it is active in the sampled olive groves. If the *X. fastidiosa* subsp. *pauca* strain CoDiRO pathogen becomes introduced to Florida, it is highly possible that *H. vitripennis* can serve as a suitable vector. With the presence of an effective vector already present in Florida olive, the threat exists of spread of this serious pathogen throughout olive growing regions in the southeast.

Thysanoptera most commonly encountered in this study were predominantly *F. bispinosa*. The population abundance of these thrips was highest during bloom in Florida olive groves, indicating these thrips may pose the most significant threat to successful pollination in heavy yr of flowering in Florida olive. The use of blue colored sticky card traps is recommended for monitoring for *F. bispinosa* in Florida olive when flower formation is first observed, and the use of yellow sticky cards is recommended for additional thrips species monitoring and monitoring for the potential pest *H. vitripennis* in Florida olive. Further investigation to determine the impact of flower-feeding thrips damage to blossoms on subsequent olive yields in Florida olive groves is warranted.

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