Phytoseiidae on Citrus in Florida Dooryard, Varietal, and Commercial Trees between 1951 and 2014, and Species Recommendations for Evaluation in Citrus Under Protective Screen (CUPS)

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Phytoseiidae on citrus in Florida dooryard, varietal, and commercial trees between 1951 and 2014, and species recommendations for evaluation in citrus under protective screen (CUPS)

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Abstract

A survey of the mite fauna on citrus was conducted in 550 dooryard trees including 25 varietal trees in Florida, USA, during 2009 to 2014 in the following counties: Broward, Charlotte, Collier, Dade, Indian River, Lee, Manatee, Martin, Palm Beach, Pinellas, Polk, St. Lucie, and Sarasota. One abandoned block of trees was sampled in Highlands County. Seventeen species of Phytoseiidae were identified from 1,982 slide-mounted mites collected from these trees. *Euseius ennsi* Ueckermann, Moraes & Childers, *Euseius ovalis* (Evans), *Neoseiulus loxus* (Schuster & Pritchard), *Phytoseius coheni* Swirski & Shechter, *Typhlodromalus jucundus* (Chant), and *Typhlodromina johnsoni* (Mahr) were new records on Florida citrus. *Amblyseius largoensis* (Muma) was the most abundant species with 854 of the phytoseiids followed by *E. ovalis*, *Euseius mesembrinus* (Dean), *E. ennsi*, and *Iphiseioides quadripilis* (Banks) (all Mesostigmata: Phytoseiidae) with 418, 388, 81, and 68 mites, respectively. *Amblyseius largoensis* was the most frequently collected phytoseiid from 220 of the 550 dooryard and varietal trees, followed by *E. ovalis* from 97 trees. A total of 787 commercial citrus trees were sampled in Florida from 2009 to 2014 in De Soto, Hardee, Hendry, Highlands, Indian River, Okeechobee, Palm Beach, Polk, and St Lucie counties. One *T. jucundus* was collected from these trees. *Amblyseius largoensis* and *E. ovalis* are recommended for evaluation as general predators of mite and insect pests in enclosed structures of citrus under protective screen (CUPS). Both mites have broad host ranges and are known mite predators, including some insect pests. Both species appear to have some degree of pesticide tolerance and use supplemental plant pollens such as *Quercus virginiana* Mill. (Fagaceae) or *Typha* spp. L. (Poaceae). Differences in phytoseiid species in this study and from earlier sampling for mites on citrus in Florida from 1986 to 2003 by the first author, a horticultural mineral oil (HMO) field study during 1994 to 1996, M. H. Muma from 1951 to 1975, and Denmark and Evans (2011) are included for comparison. A combined total of 60 phytoseiid species are reported on Florida citrus for the period of 1951 to 2014.

Key Words: Phytoseiidae; Mesostigmata; citrus; biological control; integrated mite control; citrus under protective screen (CUPS)

Resumen

Se realizó un estudio de la fauna de ácaros en los cítricos en 550 árboles de patio, incluidos 25 árboles varietales en la Florida, EE. UU., durante el 2009 a 2014 en los siguientes condados: Broward, Charlotte, Collier, Dade, Indian River, Lee, Manatee, Martin, Palm Beach, Pinellas, Polk, St. Lucie, y Sarasota. Se muestreó un bloque de árboles abandonado en el condado de Highlands. Se identificaron diecisiete especies de Phytoseiidae (Mesostigmata: Phytoseiidae) a partir de 1.982 ácaros montados en portaobjetos recolectados de estos árboles. *Euseius ennsi* Ueckermann, Moraes & Childers, *Euseius ovalis* (Evans), *Neoseiulus loxus* (Schuster & Pritchard), *Phytoseius coheni* Swirski & Shechter, *Typhlodromalus jucundus* (Chant) y *Typhlodromina johnsoni* (Mahr) eran nuevos registros sobre los cítricos en la Florida. *Amblyseius largoensis* (Muma) fue la especie más abundante con 854 de los fitoseiidos, seguida de *E. ovalis*, *Euseius mesembrinus* (Dean), *E. ennsi* e *Iphiseioides quadripilis* (todos Mesostigmata: Phytoseiidae) con 418, 388, 81, y 68 ácaros, respectivamente. *Amblyseius largoensis* fue el fitoseido recolectado con mayor frecuencia de 220 de los 550 árboles de patio y varietales, seguido por *E. ovalis* de 97 árboles. En este mismo estudio se muestrearon un total de 787 árboles de cítricos comerciales en la Florida entre el 2009 y 2014 en los condados de De Soto, Hardee, Hendry, Highlands, Indian River, Okeechobee, Palm Beach, Polk, y St. Lucie. De estos árboles se recolectó un individuo de *T. jucundus.* Se recomiendan *Amblyseius largoensis* y *E. ovalis* para evaluación como depredadores generales de plagas de ácaros e insectos en estructuras cerradas de cítricos bajo una pantalla protectora. Ambos ácaros tienen un amplio rango de hospedadores y son depredadores de ácaros conocidos, incluidas algunas plagas de insectos. Ambas especies parecen tener cierto grado de tolerancia a los pesticidas y consumen pólenes de plantas suplementarias como *Quercus virginiana* Mill. (Fagaceae) o *Typha* spp. L. (Poaceae). Se incluyen las diferencias en las especies de fitoseidos de este estudio y los muestreos anteriores de ácaros en los cítricos en Florida

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entre 1986 y 2003, un estudio de campo de aceite mineral hortícola durante el 1994 a 1996, estudios hechos por MH Muma desde el 1951 a 1975 y los registros de Denmark y Evans (2011) para comparación. Se informa un total combinado de 60 especies de fitoseidos sobre los cítricos de la Florida durante el período de 1951 a 2014.

Palabras Clave: Phytoseiidae; Parasitiformes; citricos; control biológico; control integrado de ácaros; cítricos bajo pantalla protectora

Numerous species of predaceous mites in the family Phytoseiidae have been reported on citrus in different countries in North, Central, and South America, especially in Florida, where citrus is an important crop (Muma & Denmark 1970; Muma 1975; Denmark & Evans 2011). Denmark and Evans (2011) compiled a work dealing with 428 phytoseiid species in 54 genera found in North America and Hawaii, including species found on citrus. Knowledge of the phytoseiid species complex on both dooryard and commercial citrus, as well as the identity of potential biological control agents, need to be updated continually in Florida. Concerns about exotic arthropod pest introductions, as well as improved understanding of mite diversity within these different environments, are important. Also, developing a more sustainable pest mite control program for citrus that relies less on broad spectrum pesticides with minimal effects on non-target beneficial arthropods remains a goal.

Here we report on the Phytoseiidae found on dooryard, varietal block, and commercial citrus between 2009 and 2014. Results of this survey are compared with previous collections of phytoseiid mites on Florida citrus by Muma and Denmark (1970), Muma (1975), Childers and Denmark (2011), Denmark and Evans (2011), and unpublished records of phytoseiid species collected by the first author from commercial citrus growing areas primarily in central Florida between 1986 and 2003 where fungicides, acaricides, or horticultural mineral oils (HMOs) were evaluated. This time occurred prior to establishment of the Asian citrus psyllid, *Diaphorina citri* Kuwayama (Hemiptera: Liviidae). Asian citrus psyllid is a key pest on Florida citrus and was first detected on 2 Jun 1998 by Susan Halbert (Florida Division of Plant Inspection, Gainesville, Florida, USA) on dooryard citrus trees in Broward, Martin, and St. Lucie counties in Florida (Halbert 1998, 2005). *Candidatus* Liberibacter asiaticus, the bacterial disease thought to cause citrus greening, remains a serious challenge to researchers worldwide (Dewdney et al. 2018–2019).

Citrus greening leads to a progressive reduction in tree vigor and, ultimately, premature death of the tree. Florida citrus production has been progressively and negatively affected by this disease since about 2006. Singerman (2019) reported production costs rose from $2,995 in 2003/2004 to $4,633 in 2017/2018 per ha for processed oranges in southwest Florida. Production costs per box went from just under $3.00 in 2003/2004 to over $15 in 2017/2018. The citrus bearing ha in Florida have decreased from 274,782 in 2003/2004 to 162,684 in 2017/2018 (Singerman 2019). Significant citrus tree losses have occurred in commercial blocks as well as in dooryard citrus trees. However, there are no published data available on estimated dooryard citrus tree losses. As more non-pesticide control strategies are developed for Asian citrus psyllid, a shift back to improved integrated mite and insect control approaches on Florida citrus should follow.

A new technology for growing citrus in Florida is evolving. Two methods are being used increasingly by Florida citrus growers to protect their trees from Asian citrus psyllid and citrus greening. The first method is citrus under protective screen (CUPS). Mesh size used to cover these enclosures prevents Asian citrus psyllid from accessing the trees, thus preventing citrus greening. Initially, this was the sole purpose for using the screening. Startup costs are high but production of high-quality fruit (i.e., color, size, internal quality, yield) have been achieved (Schumann et al. 2017, 2018–2019, 2020). Fruit quality and yield are greater than conventionally grown trees due to shading effects of the screen enclosures, whereas commercially grown trees are exposed to the elements as well as Asian citrus psyllid and greening (Schumann et al. 2020). A multi-disciplinary approach is needed to identify optimal fungicides and insecticides for use in an Integrated Pest Management (IPM) System within citrus under protective screen that is effective in disease and insect control without creating flaring of pest mite or insect species. The results of this study are expected to be fundamental for the establishment of new strategies of citrus production with optimal use of selected phytoseiid species.

A second method is the use of individual protective screen covers designed for use in excluding Asian citrus psyllid on newly planted trees in orchard settings. The original idea was to provide more time for tree growth and to extend production of these trees versus non-covered newly planted trees exposed to Asian citrus psyllid and citrus greening. Alferez et al. (2019, 2020) found individual protective screen covered trees had denser canopies, larger leaf area, higher leaf chlorophyll, and trees flushed earlier. Neither Asian citrus psyllid nor citrus greening were detected in individual protective screen covered trees while trees without individual protective screen covers had both the insect vector and citrus greening.

Materials and Methods

The first author sampled 550 dooryard citrus trees, including 18 trees at the Division of Plant Industry Varietal block in Winter Haven, Polk County, Florida, USA, and 7 trees at the Fruit & Spice Park in Homestead, Dade County, Florida, USA. One block of about 0.4 ha of 'Tahiti' lime trees also was sampled at the Tropical Research & Education Center in Homestead. John Williams Park in Hollywood, Florida, USA, was sampled 10 times between 2009 and 2014 because this was the location where *Diptilomiopus floridanus* Craemer & Amrine (Eriophyoidea: Diptilomiopidae) was first discovered on citrus (Childers et al. 2017; Craemer et al. 2017). The number of dooryard citrus trees sampled in the following Florida counties were: Broward (129), Charlotte (20), Collier (23), Dade (27), Indian River (11), Lee (37), Manatee (18), Martin (38), Palm Beach (68), Pinellas (59), Polk (32), St. Lucie (20), and Sarasota (67). One abandoned sweet orange block was sampled in Highlands County. More trees were sampled in Broward County because this was the area where the new rust mite on citrus was first discovered.

Beginning in 2009 and continuing through 2014, sample trees were selected randomly from lists of homeowner dooryard citrus locations compiled from previous dooryard citrus tree surveys. Dooryard citrus trees were sampled on the east coast from 2009 to 2012 and on the west coast in 2013. A few trees from both coastal counties were resampled during 2014. Because a new eriophyoid mite, *D. floridanus* was found originally on citrus in an eastern coastal habitat, many of the dooryard citrus locations selected for sampling were within about 10 to 15 km of either the east or west coasts. After a dooryard site was located from the list, all citrus trees were sampled at that location. Additional citrus trees within an area of several blocks were located and sampled. Usually 2 or 3 locations would be sampled in that area before moving on to another known address having 1 or more dooryard citrus trees.

An alcohol wash method was used to extract mites from leaves, twigs, and fruit of individual dooryard citrus, varietal citrus, and commercial citrus trees (Childers & Denmark 2011; Childers et al. 2017). Dooryard trees that were sampled varied substantially in age and vigor. Many dooryard and varietal block trees showed visual degrees of infection associated with citrus greening.

In moderate to large citrus trees, 8 to 12 clusters of leaves and associated twigs from within and around each tree were clipped with pruning shears and dropped individually into a 5 L bucket containing about 250 mL of 80% ethanol. In smaller trees (2–3 yr old) or trees less than 2 m in height, 4 to 6 clusters of leaves and associated twigs were taken. Fewer than 15 trees of this smaller size were sampled during the survey. Occasionally, 2 to 4 fruit from a tree were included with the leaf samples or processed individually. All samples were immediately washed in 80% ethanol. The leaves and twigs from each sample were discarded and the rinsate from that tree was transferred into a labeled glass jar for processing later. Wet leaves and twigs would be hit against the inside edge of the bucket with tongs to dislodge droplets of alcohol.

Samples from at least 787 commercial citrus trees in Florida were taken between May 2009 and Apr 2014 in De Soto, Hardee, Hendry, Highlands, Indian River, Okeechobee, Palm Beach, Polk, and St. Lucie counties. All commercial blocks sampled followed the recommended guidelines for arthropod and disease control (Dewdney & Timmer 2011; Rogers et al. 2011a, b). Three blocks of sweet orange trees were sampled in the Bowling Green vicinity, Hardee County, on 12 May 2010. Each block was about 4 ha and 10 leaves from each of 10 trees were collected from the inner and outer canopy.

The 3 nearest commercial orange, tangelo, and grapefruit orchards in the greater Hollywood–Ft. Lauderdale area at that time were 2 Southern Gardens orchards, about 48 and 8 km south-southwest of Clewiston in Hendry County, and a former citrus planting in Loxahatchee in Palm Beach County. At Southern Gardens, twenty-four 4-ha blocks of sweet oranges were selected randomly and sampled on 11 to 12 May 2009. Ten leaves from each of 5 trees per block were collected at random in each of the 24 selected blocks. Four fruit were collected separately and at random from 5 different trees per block. The same sampling method was repeated on 16 to 17 Aug 2010. Another Southern Garden site about 60 km south-southwest of Clewiston was sampled on 10 to 11 May 2010. A total of twenty-four 4 ha blocks of sweet orange varieties were sampled by collecting 10 leaves from each of 5 randomly selected trees in each block. At the Loxahatchee site, 5 leaves from each of 5 trees of tangelos were sampled on 11 May 2010. The same sampling procedure was used in 5 grapefruit blocks as well. On 16 Aug 2010, 20 leaves from each of 4 trees in 6 blocks each of tangelo and grapefruit at the same location were collected at random per block. A total of 22 blocks of sweet orange, 2 blocks of tangerines, 1 block of tangelos, and 1 block of grapefruit were sampled by company scouts between Aug 2009 and Aug 2012, and leaves and fruit were collected and washed in 80% ethyl alcohol. Numbers of leaves or fruit per tree or number of trees sampled in Highlands, Indian River, Okeechobee, Palm Beach, Polk, and St. Lucie counties during 2009 to 2012 by independent scouts were not recorded. All samples were immediately washed in 80% ethanol as stated above and the rinsate per sample was placed in an individual labeled glass jar.

The genus and species names for all Phytoseiidae reported in this paper have been updated based on current revisions for this mite family (Denmark & Evans 2011). The 2 authors included all genus-species combinations from previous studies to avoid confusion. The scientific names of the citrus species sampled for mites in this study follow Hodgson (1967).

The following pesticides were applied to the varietal block trees at the Citrus Arboretum in Winter Haven, Florida, USA, during 2012 as part of their citrus tree maintenance program: 30 Mar: Danitol® (Valent USA Corp., Walnut Creek, California, USA) + Citru-film® (Helena Holding Co., Wilmington, Delaware, USA); 10 May: Kocide® (E. I. DuPont de Nemours & Co., Inc., Wilmington, Delaware, USA); 11 Jun: Danitol® + Citru-film®. The commercial citrus blocks were sprayed on a regular basis primarily for Asian citrus psyllid, pest mites, and disease control (Dewdney & Timmer 2011; Rogers et al. 2011a, b).

Insecticide fogging for mosquito control in John Williams Park, Hollywood, Broward County, Florida, USA, occurred prior to some of the sampling dates. The insecticides used and application dates were not available. Mosquito problems were quite evident in the park during some of the sampling dates. We suspect absence of mite species was due to the mosquito fogging during those times. Also, the pesticides used at the Fruit & Spice Park in Homestead were not available.

Results and Discussion

Seventeen species of Phytoseiidae were identified from 550 dooryard and varietal block citrus trees in Florida between 2009 and 2014 of which 7 are new records for Florida citrus including 1 new species (Table 1).

Amblyseius largoensis (Muma): This mite was the most frequently collected phytoseiid from 220 of 550 dooryard and varietal block trees as well as the most abundant species with 854 of the 1,982 phytoseiids identified from those trees (Tables 1–3). *Amblyseius largoensis* was the only phytoseiid species collected from 103 of the 550 citrus trees sampled, with the remaining 117 trees having *A. largoensis* and 1 or more other phytoseiid species. Florida counties with the highest incidence of *A. largoensis* were: Broward, Palm Beach, Sarasota, Pinellas, and Lee (Table 2). Citrus species with the most trees with *A. largoensis* were: sweet orange (206), lemon (165), Key lime (113), and 'Tahiti' lime (120) (Table 3).

Amblyseius largoensis is found mostly in humid tropical and subtropical areas of the world including at least 75 countries (Rodriguez et al. 1981; Demite et al. 2016; Gomez-Moya et al. 2018). This mite occurs in California, Florida, Hawaii, and Louisiana (Denmark & Evans 2011). *Amblyseius largoensis* is a generalist predator with a Type IIIb lifestyle (McMurtry et al. 2013). The mite can feed on a wide range of plant pollens (Saito & Mori 1975; Tanaka & Kashio 1977). Most *A. largoensis* larvae died before reaching the deutonymph stage when reared on pollen of citrus or lily, *Lilium longifolorum* Thunb. (Liliales: Liliaceae) (Tanaka & Kashio 1977). Yue and Tsai (1996) assessed the development, survivorship, and reproduction of *A. largoensis* with 4 plant pollens and found that live oak, *Quercus virginiana* Miller (Fagaceae), was the most suitable of the 4. This phytoseiid feeds on the eriophyid mites: *Aceria guerreronis* Heifer, and citrus rust mite,

Table 1. Number of identified phytoseiid mite species from 544 dooryard and varietal block citrus trees in Florida between 2009 and 2014.

Species	Number of mites identified	Percentage of total
Amblyseius largoensis	854	43.0
Euseius ennsi	81	4.0
Euseius mesembrinus	388	20.0
Euseius ovalis	418	21.0
Galendromus helveolus	5	0.3
Iphiseiodes quadripilis	68	3.0
Neoseiulus loxus	1	0.05
Paraseiulella elliptica	20	0.9
Phytoscutus sexpilis	1	0.05
Phytoseius coheni	1	0.05
Typhlodromalus jucundus	4	0.2
Typhlodromalus peregrinus	9	0.6
Typhlodromina arborea	41	2.0
Typhlodromina conspicua	3	0.05
Typhlodromina johnsoni	60	3.0
Typhlodromina subtropica	21	1.0
Typhlodromina sp.	3	0.2
Typhlodromips dentilis	4	0.2
Total	1,982	

Table 2. Number of dooryard and varietal block citrus trees with phytoseiid species by county in Florida between 2009 and 2014.

Species	Dade	Broward	Palm Beach	Martin	St. Lucie	Indian River	Collier	Lee	Charlotte	Sarasota	Manatee	Pinellas	Polk	Highlands	Totals
Total trees per county	27	129	68	38	20	11	23	37	20	67	18	59	32	1	550
Amblyseius largoensis	13	32	31	11	6	1	15	24	6	36	6	28	11	0	220
Euseius ennsi	0	5	2	1	1	0	1	7	0	5	2	2	0	0	26
Euseius mesembrinus	0	6	0	0	0	0	0	0	8	14	0	12	15	0	55
Euseius ovalis	0	19	12	5	4	0	14	6	0	6	0	27	4	0	97
Galendromus helveolus	0	4	0	0	0	0	0	0	0	0	0	0	0	0	4
Iphiseiodes quadripilis	1	1	2	3	4	0	2	6	5	7	1	4	1	0	37
Neoseiulus loxus	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Paraseiulella elliptica	0	10	0	0	0	1	0	0	0	0	0	0	0	0	11
Phytoscutus sexpilis	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Phytoseius coheni	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Typhlodromalus jucundus	0	0	0	1	1	0	0	0	0	0	0	0	1	0	3
Typhlodromalus peregrinus	0	3	1	0	0	0	0	3	0	0	0	1	1	0	9
Typhlodromina arborea	1	9	1	1	0	0	1	0	0	0	0	0	0	0	13
Typhlodromina conspicua	0	0	0	0	3	0	0	0	0	0	0	0	0	0	3
Typhlodromina johnsoni	0	7	4	1	0	0	1	0	0	0	0	3	1	1	18
Typhlodromina subtropica	0	5	0	0	1	0	0	1	0	4	0	4	0	0	15
Typhlodromina sp.	0	0	1	0	0	0	0	0	0	2	0	0	0	0	3
Typhlodromips dentilis	0	0	0	0	1	0	0	0	0	0	0	0	2	0	3

Phyllocoptruta oleivora (Ashmead) (both Trombidiformes: Eriophyidae); spider mites: *Eotetranychus sexmaculatus* (Riley), *Eutetranychus orientalis* (Klein), *Panonychus citri* (McGregor), *Oligonychus punicae* (Hirst), *Tetranychus cinnabarinus* (Boisduval), and *Tetranychus pacificus* (McGregor) (all Trombidiformes: Tetranychidae); broad mite: *Polyphagotarsonemus latus* (Banks) (Trombidiformes: Tarsonemidae); false spider mites: *Brevipalpus yothersi* Baker, *Raoiella indica* Hirst (both Trombidiformes: Tenuipalpidae), and various species of lepidopterans, thrips, whiteflies, and scale insects (Ehara 1962; Kamburov 1971; Tanaka & Kashiro 1977; Rodriguez & Ramos 2004; Galvão et al. 2007; Carrillo et al. 2010; Rodriguez et al. 2013; Melo et al. 2015; De Alfaia et al. 2018). In this study, a slide-mounted *A. largoensis* was observed with a species of Winterschmidtiidae (Acari: Astigmata) in its chelicerae from Broward County. This phytoseiid was found in 11 of 22 leaf and twig samples from dooryard citrus trees that also had this acarid mite present.

Amblyseius largoensis was the most abundant predator associated with *R. indica* on various palms including coconut and the only phytoseiid found throughout the yr on palms in Florida (Carrillo et al. 2010). This phytoseiid was shown to have high survival rates, shorter developmental times, and reproductive rates when fed solely on *R. indica*.

Muma (1964a) collected 2,110 phytoseiids from citrus in Florida between 1960 and 1962 with only 1.5% identified as *A. largoensis* from citrus leaf samples in 3 counties: Monroe, St. Lucie, and Sarasota. Muma (1955) previously had described this species from Key lime (*Citrus aurantifolia* [Christm.]; Rutaceae) in Key Largo, then deleted *A. largoensis* from mites associated with citrus in Florida without explanation (Muma 1975).

Amblyseius largoensis was collected only from sweet orange fruit in 1 of 7 commercial citrus orchards on reduced spray programs using horticultural mineral oils and sampled between Aug 1994 and Jan 1996 in Lake, Polk, and De Soto counties in central and south central Florida (Childers & Denmark 2011). No *A. largoensis* were collected from 82 ground cover plant species that were sampled monthly for 1 yr in 5 of the 7 citrus orchards. Herbicides were applied in the 2 remaining orchards.

Two totally different habitats were sampled in the 7-orchard study (Childers & Denmark 2011) and this survey of dooryard citrus trees. Most of the dooryard citrus trees sampled had a ground cover of 1 or more grasses versus the diverse complex of volunteer ground cover plants present in the 7 citrus orchard study (Childers & Denmark 2011). In the dooryard study, *A. largoensis* was the only species of *Amblyseius* collected from the dooryard citrus trees compared with 6 species of *Amblyseius* in the 7 citrus orchard study. This phytoseiid has increased substantially in recent yr both in species numbers and the mite's distribution on citrus within Florida counties.

Euseius ennsi Ueckermann, Moraes & Childers: This is a newly described species on Florida citrus (Ueckermann et al. 2020). A total of 81 mites were identified from dooryard citrus trees in 9 counties (Tables 1–4). Two species, *Euseius sibelius* (DeLeon) and *Euseius urceus* (DeLeon) (both Mesostigmata: Phytoseiidae), were included incorrectly in the key of *Euseius* species found on Florida citrus by Ueckermann et al. (2020) because neither has been found on citrus in Florida to date. One female *Euseius victoriensis* (Womersley) (Mesostigmata: Phytoseiidae) was collected on 29 Mar 2011 from *Pouteria* Aubl. (Sapotaceae) in Pompano Beach, Broward County, Florida, USA, by W. C. Welbourn (2011). This is the only Florida Division of Plant Inspection record for this phytoseiid species. There is incomplete information provided by Denmark and Evans (2011) for this mite about its occurrence based on collection records, releases, or recoveries on or from Florida citrus.

Euseius mesembrinus (Dean): McCoy and Rakha (1985) first reported this mite on Florida citrus. This phytoseiid occurs in Louisiana, Texas, and Mexico (Denmark & Evans 2011). A total of 388 mites were identified from 57 trees in 5 counties (Tables 1–4). *Euseius mesembrinus* was the third most abundant phytoseiid species from dooryard or

Table 3. Number of phytoseiid species collected from dooryard and varietal block citrus trees in Florida between 2009 and 2014.

Phytoseiidae	Key lime	Sourorange	Pomelo	Kumquat	Lime	Cocktai tree	Sweet lime	Lemon	Ponderosa lemon	Rangpur lime	Calamondin	Temple	Grapefruit	Tangerine	Tangelo	Sweet orange	Rough lemon	Trifoliate orange	Red lime	Citrus sp.	Totals
Amblyseius largoensis	113	35	2	0	120	2	11	165	23	0	0	0	84	25	66	207	1	0	0	0	854
Euseius ennsi	5	4	0	0	9	0	0	18	0	0	0	0	3	8	20	13	1	0	0	0	81
Euseius mesembrinus	23	6	0	0	12	0	11	89	4	0	0	0	65	26	25	122	0	5	0	0	388
Euseius ovalis	58	9	3	0	25	1	6	120	8	0	0	0	50	8	27	103	0	0	0	0	418
Galendromus helveolus	0	3	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	5
Iphiseiodes quadripilis	12	2	0	0	10	0	0	4	0	0	0	0	6	7	9	18	0	0	0	0	68
Neoseiulus loxus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Paraseiulella elliptica	0	13	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	20
Phytoscutus sexpilis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Phytoseius coheni	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Typhlodromalus jucundus	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	0	0	0	0	4
Typhlodromalus peregrinus	0	0	0	0	3	0	0	3	0	0	0	0	1	0	0	1	0	1	0	0	9
Typhlodromina arborea	0	19	0	0	5	0	0	3	1	0	0	0	0	1	3	5	0	0	0	4	41
Typhlodromina conspicua	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	3
Typhlodromina johnsoni	0	0	0	0	5	0	0	18	0	0	0	0	0	0	2	34	0	0	1	0	60
Typhlodromina subtropica	1	2	0	0	0	0	0	11	0	0	0	0	3	0	4	0	0	0	0	0	21
Typhlodromina sp.	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	3
Typhlodromips dentilis	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	1	0	0	0	0	4
Total																					1,982

Table 4. Phytoseiidae collected from Florida citrus between 1951 and 2014.

Phytoseiid species	2009–2014 Dooryard and varietal citrus	2009–2014 Commercial citrus	Childers and Denmark 2011	Denmark and Evans 2011	Childers citrus on modified to no spray programs 1986–2003	Muma; Muma and Denmark 1951–1975
Amblydromalus limonicus (Garman & McGregor)			X			X
Amblyscutus grandis (Banks)						X
Amblyseiella setosa Muma				X		X
Amblyseius aerialis (Muma)			X	X	X	X
Amblyseius herbicolus Chant			X	X	X	X
Amblyseius largoensis (Muma)	X		X	X		X
Amblyseius multidentatus (Chant)			X	X	X	
Amblyseius sp. near *multidentatus*			X			
Amblyseius obtusus (Koch)			X			
Athiasia cesi (Muma)				X	X	X
Athiasia imbricata Muma & Denmark					X	X
Athiasia morgani (Chant)					X	
Chelaseius vicinus (Muma)			X			X
Clavidromus transvaalensis (Nesbitt)					X	X
Euseius ennsi Ueckermann, Moraes & Childers	X					
Euseius hibisci (Chant)			X	X		X
Euseius mesembrinus (Dean)	X		X	X	X	
Euseius ovalis (Evans)	X					
Galendromus annectans (DeLeon)						X
Galendromus flumensis (Chant)			X		X	
Galendromus gratus (Chant)			X			
Galendromus helveolus (Chant)	X		X	X	X	X
Iphiseoides quadripilis (Banks)	X		X	X	X	X
Neoseiulus californicus (McGregor)				X		
Neoseiulus gracilis (Muma)				X		X
Neoseiulus ilicis Denmark & Evans				X		
Neoseiulus loxus (Schuster & Pritchard)	X					
Neoseiulus marinellus (Muma)						X
Noeledius iphiformis (Muma)				X		X
Orientalis rickeri (Chant)				X	X	X
Paraseiulella corna (DeLeon)						X
Paraseiulella elliptica (DeLeon)	X			X		X
Phytoscutus sexpilis Muma	X		X	X	X	X
Phytoseiulus macropilis (Banks)			X		X	X
Phytoseius chanti Denmark					X	
Phytoseius coheni Swirski & Shechter	X					
Proprioseiopsis asetus (Chant)					X	
Proprioseiopsis detritus (Muma)			X		X	X
Proprioseiopsis dorsatus (Muma)			X	X	X	X
Proprioseiopsis lepidus (Chant)						X
Proprioseiopsis mexicanus (Garman)			X	X	X	
Proprioseiopsis ovatus (Garman)				X		
Proprioseiopsis rotundus (Muma)			X	X	X	X

Table 4. (Continued) Phytoseiidae collected from Florida citrus between 1951 and 2014.

Phytoseiid species	2009–2014 Dooryard and varietal citrus	Commercial citrus	Childers and Denmark 2011	Denmark and Evans 2011	Childers citrus on modified to no spray programs 1986–2003	Muma; Muma and Denmark 1951–1975
Proprioseiopsis solens (DeLeon)			X	X		X
Proprioseiulus paxi (Muma)						X
Proprioseius meridionalis Chant				X		
Tenorioseius macrosetae (Muma)			X			X
Typhlodromalus jucundus (Chant)	X	X				
Typhlodromalus peregrinus (Muma)	X		X	X	X	X
Typhlodromina arborea (Chant)	X					
Typhlodromina conspicua (Garman)	X			X		X
Typhlodromina johnsoni (Mahr)	X					
Typhlodromina subtropica Muma & Denmark	X		X	X	X	X
Typhlodromips arenillus Denmark & Muma						X
Typhlodromips deleoni (Muma)			X	X		X
Typhlodromips dentilis (DeLeon)	X		X	X	X	X
Typhlodromips dillus (DeLeon)			X			X
Typhlodromips mastus Denmark & Muma			X			
Typhlodromips simplicissimus (DeLeon)			X	X		X
Typhlodromus pyri Scheuten				X		
Total species	17	1	29	30	23	37

varietal block trees in this survey. This phytoseiid was the most abundant species collected from both within tree canopies in a 7 citrus orchard study and from ground cover plants between Sep 1994 and Jan 1996 in Collier, Polk, and Lake counties in Florida (Childers & Denmark 2011). Five of the 7 orchards were treated with horticultural mineral oils only foliar sprays. Prior to the 2011 study, several of these citrus orchards had been on pesticide spray programs. Urban encroachment around these orchards required the use of less toxic sprays, such as horticultural mineral oils.

Euseius mesembrinus fed and reproduced when provided with pollen of either *Bidens pilossa* L. (Asteraceae) or *Malephora crocea* (Jacq.) (Aizoaceae), 3 spider mite species including all stages of *Tetranychus urticae* Koch, *Eutetranychus banksi* (McGregor), and the larval and nymphal stages of *Panonychus citri* (McGregor) (all Trombidiformes: Tetranychidae) (Abou-Setta & Childers 1987, 1989). Yue et al. (1994) evaluated the effects of 9 plant pollens on development, survivorship, and reproduction of *E. mesembrinus* in the laboratory. Most significant were the 30.8 and 30.4 eggs per female produced on single diets of ice plant, *M. crocea*, or live oak, *Q. virginiana* pollens, respectively. Ice plant thrives in more arid climates of South Africa and California, and is difficult to maintain in the humid climate of Florida whereas live oak is found commonly in most of Florida. There was 100% mortality of *E. mesembrinus* females when provided with a sole diet of *P. oleivora* (Abou-Setta & Childers 1989). There are no records of this phytoseiid feeding and reproducing on citrus rust mites or other eriophyoid species.

Euseius mesembrinus was never collected in Florida by Muma or Denmark prior to 1970 to 1975, and appears to have been introduced into Florida citrus from Texas (Abou-Setta et al. 1991). This phytoseiid also appears to be an indicator species of limited pesticide usage on citrus in Florida based on its frequent occurrence in commercial citrus orchards between 1986 and 2003, and its occurrence in the varietal citrus block at the Division of Plant Industry in Winter Haven and John Williams Park where pesticides were applied.

Euseius ovalis (Evans): This is a new species found on Florida citrus and not previously reported in Florida prior to 2009 (Tables 1–4). *Euseius ovalis* has been collected in Taiwan, Malaysia, Brazil, Mexico, and the USA in Hawaii and Louisiana (Nguyen & Shih 2010; Denmark & Evans 2011). A total of 418 mites were identified from 97 dooryard citrus trees in 9 of 14 counties sampled during this study. *Euseius ovalis* was the second most abundant phytoseiid identified from dooryard citrus trees with the most positive trees at 27, 19, 14, and 12 from Pinellas, Broward, Collier, and Palm Beach counties, respectively.

Euseius ovalis is a generalist predator with a type IV lifestyle (McMurtry et al. 2013). Pijnakker et al. (2016) found the pollen of the little leaf cattail, *Typha angustifolia* L. (Poales) to be an acceptable supplemental food source for *E. ovalis* and 3 other phytoseiid species. The pollen is applied before pest buildup in glass house crops of vegetables or flowers following release of the phytoseiid predator(s). The pollen is stored frozen and then defrosted shortly before use. The authors did not mention pre-freezing requirements for the pollen. This food supplement is applied every 2 wk at 500 g per ha using a pollen applicator. Use of the supplemental pollen eliminates the need for repetitive releases of the phytoseiids.

Initial sampling of dooryard citrus occurred in Pinellas County on 19 Jun 2013. Among the trees sampled was a single lemon tree at 1 of several homes in Redington Beach, Florida, USA. Large numbers of both eriophyoid mites *P. oleivora* and *D. floridanus* were collected from leaves and twigs of this lemon tree. Many phytoseiids were collected in that sample with 26 *E. ovalis* identified from slide-mounted mites. No other phytoseiid species were identified in that sample. On 4 Jan 2014, large numbers of both *P. oleivora* and *D. floridanus* were in a sample of leaves and twigs from the same tree. A second sample was taken on 14 Apr 2014 and no eriophyoid mites were present. However, there were large numbers of phytoseiids in the sample. The slide-mounted subsample had a single species with 27 *E. ovalis*. No indications of fungal pathogens in the eriophyoid mites were observed in the slide-mounted mites in any of the samples.

Euseius ovalis feeds on the broad mite, and reduced populations at ratios up to 1:100 (Hariyappa & Kulkarni 1989). Multiple species of spider mites in the genera *Eotetranychus*, *Eutetranychus*, *Panonychus*, *Oligonychus*, and *Tetranychus* on several crops were fed upon by *E. ovalis*, and the developmental times compared (Shih et al. 1993; Chang et al. 1995; Nguyen & Shih 2010; Liyaudheen et al. 2014).

Galendromus helveolus (Chant): Five mites were collected from 3 citrus species in Broward County (Tables 1–4). These were the only specimens collected during this survey. This phytoseiid fed and reproduced on diets of *P. citri*, *E. banksi*, *T. urticae*, and *E. sexmaculatus*. Females of *G. helveolus* (Mesostigmata: Phytoseiidae) fed and survived for 10 d on *P. oleivora* but could not produce eggs when provided only with this eriophyid mite (Caceres & Childers 1991).

Galendromus helveolus was collected from inner and outer citrus leaves, twigs, and fruit with a total of 315 mites from within the trees versus 7 from ground cover plants (Childers & Denmark 2011). Only 2 of the 86 ground cover plant species (*B. pilosa* and *Desmodium tortuosum* [Sw] DC; Fabaceae) had very low numbers of *G. helveolus* (Childers & Denmark 2011). This phytoseiid was found commonly in commercial citrus orchards between 1986 and 2003.

Iphiseoides quadripilis (Banks): A total of 68 mites were identified in this study from 1,982 slide-mounted phytoseiids (Tables 1–4). This mite was collected from 37 dooryard trees on 8 citrus species in 12 counties. *Iphiseoides quadripilis* is found on citrus throughout the yr in Florida. The host range includes: *E. banksi*, *P. citri*, and the eggs and crawlers of *Chrysomphalus aonidum* (L.), *Lepidosaphes beckii* (Newman), and *Lepidosaphes gloverii* (Packard) (all Hemiptera: Diaspididae) (Muma 1971). *Iphiseoides quadripilis* was reared successfully in the laboratory on single diets of *M. crocea* or *Quercus* sp. pollens and eggs, and motile stages of *E. banksi* (Villanueva & Childers 2007). Starved *I. quadripilis* females and deutonymphs would feed on pink citrus rust mites, but not the citrus rust mite in arenas containing both species. Neither eriophyid species was a suitable prey for completion of development by *I. quadripilis*. Muma and Denmark (1970) reported that *I. quadripilis* was found commonly on citrus. A total of 830 *I. quadripilis* were collected from inner leaves compared with 1,365 on outer leaf samples from the same trees in the 7 citrus orchard study using horticultural mineral oils (Childers & Denmark 2011).

Neoseiulus loxus (Schuster & Pritchard): This is a new species record for Florida citrus. One mite was collected on 12 Jun 2013 on 'Tahiti' lime in Lee County. This phytoseiid has been collected from several non-citrus plants in Florida and from several other states (Denmark & Evans 2011).

Paraseiulella elliptica (De Leon): A total of 20 mites were identified from sour orange trees in John Williams Park in Broward County and a lemon tree in Indian River County, Florida, USA. Denmark and Evans (2011) reported that *P. elliptica* was widespread in Florida and found on many plants including citrus.

Phytoscutus sexpilis Muma (Mesostigmata: Phytoseiidae): A single mite was collected on a tangelo tree in Sarasota County with the chelicerae attached to a species of Winterschmidtiidae (Acari: Astigmata). Muma (1961) reported that *P. sexpilis* fed on acarid mites. This phytoseiid has been collected from citrus in Florida many times (Denmark & Evans 2011).

Phytoseius coheni Swirski & Schechter: This is a new state record for this species on citrus. A single specimen was identified from a sour orange tree in Broward County. Swirski and Shechter (1961) described *P. coheni* from pomelo in Hong Kong, and this phytoseiid was collected previously from *Annona* in Miami, Dade County, Florida, USA (Denmark & Evans 2011).

Typhlodromalus jucundus (Chant): This is a new species on Florida citrus. A total of 4 mites were identified from lemon, sweet orange, and Key lime trees on 12 and 15 Jun 2012 and 11 Jul 2013 in Martin, St. Lucie, and Polk counties, respectively. One *T. jucundus* was collected from a commercial citrus block of 'Valencia' oranges in Lake Wales, Polk County, on 18 May 2012. This was the only phytoseiid collected from commercial citrus between 2009 and 2014. This phytoseiid was reported previously on *Acer rubrum* L. (Sapindaceae) in Maryland, USA (Denmark & Evans 2011).

Typhlodromalus peregrinus (Muma) (Mesostigmata: Phytoseiidae): Muma (1961, 1964b, 1975) reported that *T. peregrinus* was the most common phytoseiid species on Florida citrus. However, this was before *E. mesembrinus* was known to occur in Florida. *Euseius mesembrinus* was the most abundant phytoseiid collected from 7 citrus orchards using primarily horticultural mineral oil spray applications for pest control, followed by *T. peregrinus* (Childers & Denmark 2011).

Reported optimal foods of *T. peregrinus* included whiteflies, Aleurodidae, soft scale insects, Coccidae, and spider mites, Tetranychidae while species of Eriophyidae were listed as inadequate (Muma1971). Peña (1992) reported that *T. peregrinus* consumed eggs, immatures, and adults of broad mite, and preferred this species over the citrus rust mite when both species were together on the same plant. This phytoseiid fed on *P. oleivora* with no apparent effect in reducing their numbers. Fouly et al. (1995) found single diets of all stages of *T. urticae*, immature stages of *P. citri*, and the plant pollens *M. crocea*, *Q. virginiana*, and *Typha latifolia* L. (Poales) alone and combined with *T. urticae* were successful for completing the life cycle of *T. peregrinus*. *Tetranychus urticae* was the most favorable food source and *T. latifolia* the least. Three *T. peregrinus* gravid females were collected from Broward County on 'Tahiti' lime on 1 Jun 2011. One gravid female was collected from sweet orange on 11 Jun 2013 in Lee County. This phytoseiid was not found in numbers expected. One possible explanation for this was the lack of suitable pollen sources from nearby trees or mostly ground cover grasses in dooryard settings.

Typhlodromina arborea (Chant) (Mesostigmata: Phytoseiidae): This is a new species on Florida citrus. A total of 41 mites were collected from 8 citrus species in Dade, Broward, Palm Beach, and Martin counties (Tables 1–4). This species was previously collected from *Quercus* sp. in Plant City, Florida, USA, in 1985 (Denmark & Evans 2011).

Typhlodromina conspicua (Garman) (Mesostigmata: Phytoseiidae): Three mites were collected from an abandoned lemon block in St. Lucie County. This phytoseiid has been reported multiple times from citrus in Florida (Denmark & Evans 2011).

Typhlodromina johnsoni (Mahr): This is a new species on Florida citrus. A total of 60 mites were identified from dooryard citrus in 6 counties (Tables 1–4). This phytoseiid was collected on citrus in California, USA (Denmark & Evans 2011).

Typhlodromina subtropica Muma & Denmark (Mesostigmata: Phytoseiidae): A total of 21 mites were identified from dooryard citrus trees in 5 counties (Tables 1–4). This mite has been collected frequently on citrus in Florida (Denmark & Evans 2011).

Typhlodromina sp. (Mesostigmata: Phytoseiidae): Two gravid females were collected from a grapefruit tree in Sarasota on 17 Jun 2013 (Tables 1–4). One mite was collected from a Valencia orange tree in West Palm Beach, Florida, USA, on 21 Jun 2012.

Typhlodromips dentilis (De Leon) (Mesostigmata: Phytoseiidae): This phytoseiid has been collected on citrus in Florida several times (Denmark & Evans 2011). One female was collected from a lemon tree in Fort Pierce, St. Lucie County, Florida, USA, on 12 Jun 2012 in association with *P. oleivora* and *Aculops pelekassi*. Two female *T. dentilis* from a lemon tree in Lakeland, Polk County, Florida, USA, on 8 Jul 2012 were collected with the same 2 eriophyoid species as well as *Fungitarsonemus setillus* Sousa et al. (Acari: Tarsonemidae) and *Parapronematus acaciae* Baker (Acari: Tydeidae) (Childers & Ueckermann 2020).

Low numbers of several phytoseiid species reported in this paper may or may not be species of economic importance at the time samples were taken. However, the first reports of their presence on Florida citrus have been recorded. *Amblyseius largoensis* and several other species were reported first by Muma decades ago in low numbers with *A. largoensis* now among the most abundant on Florida dooryard citrus, whereas many others are no longer found (Table 4). The mite fauna on dooryard citrus between 2009 and 2014 was unexpectedly low both in terms of species diversity and frequencies of pest mite species. Many of the dooryard citrus trees sampled appeared to have been treated with 1 or more pesticides during 2009 to 2014. This was based on observed tree vigor and lack of mites. However, homeowners were not asked if their trees had been sprayed when samples were taken. There were 17 dooryard citrus trees that had no mites in the samples. An additional 83 trees were recorded with only eriophyoid mites. An additional 8 trees had only eriophyoid and tetranychid mites present followed by 43 trees that had only eriophyoid mites plus either 1 or more tarsonemid or tydeid species. A total of 166 dooryard citrus trees (30%) from the 854 trees sampled had no predaceous mites.

The mite fauna on pesticide-sprayed dooryard citrus trees would be expected to recover faster than in commercial settings due to fewer pesticide applications, as well as size of commercial blocks compared with 1 to 8 or more dooryard citrus trees surrounded by non-citrus plants in residential properties. However, this also would require availability of suitable plant pollen(s) or prey sources for the phytoseiids. *Euseius ovalis* was collected from John Williams Park and from the citrus varietal trees at the Division of Plant Industry Arboretum in Winter Haven, Florida. Both locations had been sprayed 1 or more times with pesticides.

Two species of phytoseiid mites, *Amblyseius largoensis* and *Euseius ovalis*, are recommended for evaluation in citrus under protective screen for suppression of pest mite species in the superfamilies Eriophyoidea, Tetranychoidea, and broad mite in the family Tarsonemidae. Both phytoseiids have been shown to be effective predators of these phytophagous mites as well as many insects. Their releases (singly or together) along with supplemental pollen applications can potentially provide suppression of these phytophagous mite and insect pests in citrus under protective screen. First, acute and residual toxicity of currently recommended insecticides and fungicides by 1 or more research centers of the University of Florida, Institute of Food and Agricultural Science, Gainesville, Florida, USA, must be assessed against the 2 phytoseiid species in laboratory studies. Second, where needed identify alternative pesticides as replacements that are less toxic to the 2 phytoseiid species while having comparable efficacy to the target arthropod(s) or disease pest(s). One example of a single early season fungicide substitution in apples resulted in no spider mite problems for the season in 2 orchards (Childers & Enns 1975). Follow-up studies should be conducted in citrus under protective screen units. Alternate row spraying of citrus in citrus under protective screen units with horticultural mineral oils at pre-determined rates could be used to reduce 1 or more susceptible arthropod pest populations to more manageable levels prior to introduction of predators. In some situations, timing of application of a needed pesticide can be followed with a delayed release of 1 or more phytoseiid species. Laboratory and follow-up pesticide evaluations within citrus under protective screen units would be needed.

Optimal release times of a selected predator(s) need to be determined prior to anticipated increases in pest mite or insect groups. Monitoring citrus under protective screen units for arthropod pest increases will dictate release date(s). Augmentative release of supplemental pollen would precede or follow initial phytoseiid releases with periodic pollen release times to be determined. Yue and Tsai (1996) identified the pollen of the Southern live oak, *Q. virginiana*, as being a suitable supplemental food source for *A. largoensis.* Identifying a suitable pollen source for *E. ovalis* remains to be determined although *Q. virginiana* or *T. latifolia* pollens are likely candidates.

Carrillo et al. (2010) noted that *A. largoensis* remained on coconut palms throughout the yr in Florida. This would be an added benefit if this phytoseiid and *E. ovalis* did the same on citrus grown in citrus under protective screen, thus reducing the number of subsequent predator releases that may be required. Growing citrus fruit for fresh market in citrus under protective screen has been shown to be profitable. The escalation of production costs to grow citrus in the field, shrinking available ha for agricultural use, rising land values, and seemingly endless construction of new housing developments and businesses in Florida all combined raise a question. Can citrus grown for processed or fresh fruit in citrus under protective screen be economically feasible given the above and the elimination of Asian citrus psyllid as an economic problem? Integration of biological control into citrus under protective screen may be one solution.

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