# Diversity and Seasonal Abundance of Predacious Mites in Alabama Satsuma Citrus

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**ABSTRACT** Nine Satsuma citrus orchards (seven conventionally sprayed and two unsprayed) in southern Alabama were sampled (mainly leaf samples) for predacious mites at eight different sampling dates from March 2005 to February 2006. At least 29 species of predacious mites from nine families (Anystidae, Ascidae, Bdellidae, Cheyletidae, Cunaxidae, Erythraeidae, Eupalopsellidae, Phytoseiidae, and Stigmaeidae) were identified. In addition, six primarily fungivorous species from three families (Parasitidae, Tydeidae, and Tarsonemidae) were recorded. Predacious mites in the families Phytoseiidae (18 species) and Stigmaeidae (one species) were the most abundant. The dominant species were *Typhlodromalus peregrinus* (Muma) and *Proprioseiopsis mexicanus* (Garman) (Phytoseiidae), and *Agistemus floridanus* Gonzalez (Stigmaeidae). Phytoseiid mites were most abundant in the spring with populations declining at the start of the summer and remaining at very low levels through the fall and winter. Analysis of fruit, leaf and orchard ground cover plant samples collected in fall (October) 2005 showed greater abundance of phytoseiid mites on ground cover plants than on citrus fruit and leaves, suggesting that ground cover plants may serve as overwintering reservoirs for predacious mites. In general, predacious mites were relatively more abundant in the conventionally sprayed orchards compared with the unsprayed orchards, as were the two key phytophagous species, *Panonychus citri* (McGregor) and *Phyllocoptruta oleivora* (Ashmead). The results are discussed in relation to the potential of the dominant predacious mite species as candidates for biological control of key phytophagous mites on Alabama Satsuma citrus.

**KEY WORDS** satsuma mandarin, predacious mites, Phytoseiidae, Stigmaeidae, *Typhlodromalus peregrinus*

Satsuma mandarin (*Citrus unshiu* Markovich) production is an emerging industry in southern Alabama and other parts of the Gulf Coast region of the United States (Campbell et al. 2004). A recent survey identified the key pests of Satsuma citrus in Alabama, which included two mite species: citrus red mite, *Panonychus citri* (McGregor) (Acari: Tetranychidae), and citrus rust mite, *Phyllocoptruta oleivora* (Ashmead) (Acari: Eriophyidae) (Fadamiro et al. 2008).

*P. citri* is a key pest of citrus in many parts of the world (Gotoh and Kubota 1997, Jamieson et al. 2005, Childers et al. 2007). The adults and immatures feed primarily on leaves producing tiny gray or silvery spots known as stippling damage. Damage to leaves inhibits photosynthesis, and severe infestations can result in premature leaf fall, shoot dieback, and decreased plant vigor (Krantz 1978). High infestations also can result in fruit feeding and damage. In Alabama, population densities of *P. citri* in early spring (February–March) are usually above the economic threshold of five motiles per leaf (Childers 1994, Childers et al. 2007) but typically start to decline at the beginning of the summer (Fadamiro et al. 2008).

*P. oleivora* is an important direct pest of citrus in the Gulf Coast (English and Turnipseed 1940, Hall et al. 1991, Fadamiro et al. 2007). Fruit feeding by *P. oleivora* can result in russeting of fruit and associated loss of fruit yield and quality (English and Turnipseed 1940, Allen 1979). Leaves of satsumas also can be injured and occur as russeted areas on the upper leaf surface, whereas the lower surface may have yellow, necrotic spots (English and Turnipseed 1940). In Alabama, activity of *P. oleivora* usually begins in June, with severe injury occurring in July through September (English and Turnipseed 1940, Fadamiro et al., 2007).

Traditionally, control of both citrus mite pests in the Gulf Coast has been accomplished through the use of conventional acaricides (Childers 1994). However, there are some reports of documented or suspected cases of resistance of some phytophagous mites to acaricides (Omoto et al. 1995, Bergh et al. 1999). Furthermore, indiscriminate use of broad-spectrum pesticides may induce or exacerbate populations of phytophagous mites by disrupting the

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activity of predatory mites and other natural enemies (Welty 1995, Antonelli et al. 1997, Jamieson et al. 2005). Many studies have reported on the biological control of phytophagous mites of citrus and other fruit crops with predacious mites, in particular those belonging to the families Phytoseiidae and Stigmaeidae (Hoyt 1969, Childers et al. 1975b, McMurtry 1983, Childers 1994, Wood et al. 1994, Jamieson et al. 2005). Childers (1994) discussed the potential use of predacious mites in the families Phytoseiidae, Stigmaeidae, and some species within the Tydeidae for effective suppression of phytophagous mites on citrus in Florida. However, little is known about the predacious mite guild in the Gulf Coast Satsuma agroecosystem, and the potential of predacious mites as biological control agents of pest mites on Satsumas has not been examined in Alabama.

The major objective of this study was to identify and determine the seasonal occurrence and potential impact of the predacious mites associated with phytophagous mites in Alabama satsuma orchards. This was conducted a follow-up study to a recently published one by the authors on the abundance and diversity of general arthropod pests and associated natural enemies on Alabama citrus (Fadamiro et al. 2008). Although, similar locations were used for both studies, the samplings were done at different times using different sampling procedures and techniques. Knowledge of the inventory and seasonal abundance of predacious mites in the Satsuma agroecosystem in Alabama is the first step toward development of effective biological control programs for managing *P. citri* and *P. oleivora* in the state.

## Materials and Methods

**Study Sites.** Nine citrus orchards located in Mobile and Baldwin counties, the two main citrus-growing counties in southern Alabama, were surveyed for predacious mites during 2005 and 2006. The survey orchards were comprised primarily of satsuma mandarin, with very limited occurrence of sweet orange (*Citrus sinensis* L. Osbeck), grapefruit (*Citrus paradisi* Macfad.), and kumquat (*Fortunella* spp.). The predominant cultivar of Satsuma mandarin was 'Owari', with a few trees each of 'Armstrong Early' and 'Brown's Select'. Seven of these orchards (Brantley, Buck, Coker, Ladnier, Sessions, Station, and Warden) were commercial farms whose pest management included use of acaracides, insecticides, fungicides, and horticultural oils. Although the selection and frequency of acaracide and other pesticide use varied among these sprayed orchards, all seven used ground driven, airblast sprayers. Two orchards (McDaniel and Revel) were unsprayed before and during the survey period.

**Predacious Mite Survey.** Each orchard was surveyed for predacious mites from March 2005 to February 2006. At each location, leaf and fruit samples were periodically collected and inspected for presence of predacious mites. Leaf samples were collected twice in March 2005, once in April and May 2005, twice in June 2005, once in the fall (October 2005), and once the following winter (February 2006) for a total of eight sampling dates. On each sampling date, 40 leaves (mature and fully developed) were collected each from four randomly selected trees. Leaf samples were taken each time from the four sides of the tree's canopy, as well as from the interior and exterior portions of the tree canopy.

In addition to leaf samples, fruit samples and ground cover plants (weeds) were collected from under the canopy of the selected trees during the October 2005 sampling date. This was done to compare abundance of predacious mites on leaves, fruit and ground cover plants during late season and to determine whether the understory weeds in the orchards could provide potential alternative food sources or overwintering plants for predacious mites in the fall/winter. For fruit samples, 10 fruit were randomly collected each from the four selected trees (from which leaf samples were collected) at each location. Ground cover plants (weeds) were randomly collected from beneath the canopy of the same selected four trees per location and sampled for mites.

Mites were dislodged from all samples using an alcohol wash technique (Childers and Nakahara 2006), wherein leaf, fruit, or weed samples were dipped into a bucket containing ≈250 ml of 80% ethanol and vigorously agitated. Most of the plant material was then removed from the solution and discarded. The alcohol wash was transferred into a labeled glass jar for further processing and examination in the laboratory. Mites in each processed sample (alcohol wash) were first sorted and counted by group (predacious or phytophagous) and identified using a stereomicroscope at 8–10× magnification. Mite specimens were then slide-mounted in Hoyer's medium (Krantz 1978), oven-dried, and then identified to family or genus using a phase-contrast microscope at 40× or 100× magnification and using available keys and reference specimens by Childers. Final species determinations of phytoseiids were made by H. A. Denmark of Gainesville, FL, and all other mite groups were identified by E. A. Veckermann of the Agricultural Research Center, Pretoria, South Africa. The phytophagous mites also were identified to species, but their abundance was not quantified because they were not the focus of the current study. The abundance of key phytophagous mite species in Alabama orchards have been quantified and reported in previous studies (Fadamiro et al. 2007, 2008). Voucher specimens are deposited in the Division of Plant Industry Museum, Gainesville, FL.

For each orchard, mean numbers of mites (immatures plus adults) per 40 leaves per sampling date were calculated for the most prevalent families and species of predacious mites by using the four trees as replicates. To compare abundance of key mite families and species among the nine orchards with different pest management practices, the seasonal mean numbers of predacious mites recorded per tree ($n = 4$) over the eight sampling dates (March 2005–February 2006) were calculated for the two most prevalent predacious

**Table 1. Mite species collected in nine citrus orchards in southern Alabama during 2005–2006**

| Family | Species | Feeding habit | Distribution[a] |
|---|---|---|---|
| Anystidae | *Anystis baccarum* (L.) | Predacious | +++++ |
| Ascidae | *Asca pineta* DeLeon | Predacious | + |
| | *Asca (Aceodromus) convolvuli* (Muma) | Predacious | + |
| | *Gamasellodes bicolor* Berlese | Predacious | + |
| | *Proctolaelaps* sp. | Predacious | + |
| Bdellidae | *Bdella longicornis* (L.) | Predacious | + |
| Cheyletidae | *Unknown species* | Predacious | + |
| Cunaxidae | *Neocunaxoides* sp. | Predacious | + |
| Erythraeidae | *Lasioerythraeus johnstoni* Welbourn & Young | Predacious | + |
| Eupalopsellidae | *Exothorhis caudata* Summers | Predacious | ++ |
| Phytoseiidae | *Amblyseius herbicolus* (Chant) | Predacious | ++ |
| | *Amblyseius channabasavanni* Gupta | Predacious | +++ |
| | *Euseius limonicus* Garman & McGregor | Predacious | ++ |
| | *Euseius hibisci* (Chant) | Predacious | ++++ |
| | *Neoseiulus californicus* (McGregor) | Predacious | ++ |
| | *Neoseiulus mumai* (Denmark) | Predacious | ++ |
| | *Neoseiulus dorsatus* (Muma) | Predacious | + |
| | *Neoseiulus setulus* (Fox) | Predacious | + |
| | *Proprioseiopsis citri* (Muma) | Predacious | + |
| | *Proprioseiopsis dorsatus* (Muma) | Predacious | +++ |
| | *Proprioseiopsis mexicanus* (Garman) | Predacious | ++++++++ |
| | *Proprioseiopsis rotundus* (Muma) | Predacious | ++ |
| | *Proprioseiopsis solens* (DeLeon) | Predacious | ++++ |
| | *Paraseiulus ellipticus* (Muma) | Predacious | + |
| | *Typhlodromalus peregrinus* (Muma) | Predacious | +++++++++ |
| | *Typhlodromips sp near simplicissimus* (DeLeon) | Predacious | + |
| | *Typhlodromips hellougreus* Denmark & Muma | Predacious | +++ |
| | *Typhlodromips mastus* Denmark & Muma | Predacious | + |
| Stigmaeidae | *Agistemus floridanus* Gonzalez | Predacious | +++++++ |
| Parasitidae | *Eugamasus* sp. | Fungivorous? | + |
| Tydeidae | *Afrotydeus munsteri* Meyer and Ryke | Fungivorous | + |
| | *Lorryia formosa* Cooreman | Fungivorous | ++++ |
| | *Parapronematus acaciae* Baker | Predacious? | + |
| | *Tydeus californicus* (Banks) | Fungivorous | ++++++ |
| | *Tydeus gloveri* (Ashmead) | Fungivorous | + |
| Tarsonemidae | Unknown species | Fungivorous? | +++++ |
| | *Polyphagotarsonemus latus* (Banks) | Phytophagous | ++ |
| Acaridae | *Thyrophagus entomophagous* (Laboulbne & Robin) | Phytophagous | + |
| Tetranychidae | *Panonychus citri* (McGregor) | Phytophagous | ++++++ |
| | *Eotetranychus sexmaculatus* (Riley) | Phytophagous | + |
| Eriophyidae | *Phyllocoptruta oleivora* (Ashmead) | Phytophagous | +++ |

[a] Distribution in Alabama is computed based on presence of predatory species in the surveyed orchards (number of +'s indicates the number of orchards in which the species was recorded).

mite families (Phytoseiidae and Stigmaeidae). Similar data were generated for two most abundant primarily fungivorous mite families (Tydeidae and Tarsonemidae) because some members of these families also may be predacious.

**Statistical Analysis.** Data were first normalized by using the square-root transformation ($\sqrt{x + 0.5}$) and analyzed with analysis of variance followed by the Tukey–Kramer honestly significant difference comparison test (JMP version 7, SAS Institute 2007) to determine significant differences ($P < 0.05$).

## Results

**Predacious Mite Fauna.** At least 41 species of mites (Acari) from 15 families were collected in this survey of Alabama Satsuma citrus orchards during 2005–2006 (Table 1). These included nine predacious mite families (29 species), three primarily/likely fungivorous mite families (seven fungivorous species plus one pest species), and three phytophagous (pest) mite families (four species). The two most abundant predacious mite families were Phytoseiidae and Stigmaeidae, whereas Tydeidae and Tarsonemidae were the most abundant primarily fungivorous families. Phytoseiid mites were collected in all, stigmaeid mites were found in seven, whereas the remaining predacious mite families were either found in very low numbers or absent in the majority of the surveyed orchards. Tydeid mites were collected in six, whereas tarsonemids were found in seven of the surveyed orchards (Table 1).

The relative abundance of the major families of predacious and primarily fungivorous mites in the nine surveyed orchards is shown in Table 2. Many of these predacious mites were recorded in association with key phytophagous species. The dominant predacious mite species was *Typhlodromalus peregrinus* (Muma) (Phytoseiidae). Other prevalent predacious mite species included *Proprioseiopsis mexicanus* (Garman) (Phytoseiidae) and *Agistemus floridanus* Gonzalez (Stigmaeidae). These three major predacious mite species were recorded at moderate densities in the majority of the surveyed orchards. Minor predacious mite species included *Anystis baccarum* L. (Anysti-

**Table 2. Relative abundance of two predacious mite families and two primarily fungivorous families collected on leaf samples in nine Alabama citrus orchards during 2005–2006**

| Pest management practice | Location | Seasonal mean (± SE) no. of mites per 40 leaves | | | |
|---|---|---|---|---|---|
| | | Phytoseiidae | Stigmaeidae | Tydeidae[a] | Tarsonemidae[a] |
| Conventionally sprayed | Brantley | 11.1 ± 3.9a | 1.1 ± 0.4ab | 147.5 ± 56.3a | 4.0 ± 3.4bc |
| | Buck | 0.1 ± 0.1c | 0 ± 0b | 0.07 ± 0.03b | 24.2 ± 17.3a |
| | Coker | 0.13 ± 0.1c | 2.3 ± 1.2a | 0.18 ± 0.14b | 0 ± 0b |
| | Ladnier | 4.9 ± 1.7b | 0.13 ± 0.1b | 0.06 ± 0.3b | 25.3 ± 13.5a |
| | Sessions | 3.6 ± 1.5bc | 0.38 ± 0.2ab | 0 ± 0b | 0 ± 0c |
| | Station | 0.5 ± 0.3bc | 0 ± 0b | 0.0 ± 0.0b | 14.5 ± 10b |
| | Warden | 0.2 ± 0.1c | 1.9 ± 0.7a | 0 ± 0b | 0.38 ± 0.30c |
| Unsprayed | McDaniel | 1.6 ± 0.6bc | 0.31 ± 0.2b | 0.28 ± 0.17b | 0.03 ± 0.02c |
| | Revel | 2.1 ± 0.1bc | 0.38 ± 0.2ab | 0.19 ± 0.11b | 0.09 ± 0.05c |
| | df = 8, 275 | $F = 9.17$ | $F = 3.76$ | $F = 13.70$ | $F = 2.64$ |
| | | $P < 0.0001$ | $P = 0.0003$ | $P = 0.0001$ | $P = 0.0084$ |

[a] Mites in these two families are primarily fungivorous but a few species may be predacious or phytophagous. Values are total number of motile stages (immatures plus adults) for each family. Means within the same column having no letters in common are significantly different among locations ($P < 0.05$).

dae), *Neocunaxoides* sp. (Cunaxidae), *Exothorhis caudata* Summers (Eupalopsellidae), and the phytoseiids *Amblyseius channabasavanni* (Gupta), *Euseius hibisci* (Chant), *Proprioseiopsis solens* (DeLeon), and *Typhlodromips hellougreus* Denmark. These species occurred in three to five of the surveyed orchards at low to moderate densities. The remaining predacious mite species which were detected only in a few (one or two) of the surveyed orchards at low densities were considered as occasional predacious mite species. The fungivorous mite species included four species in the family Tydeidae: *Afrotydeus munsteri* Meyer & Ryke, *Lorryia formosa* Cooreman, *Parapronematus acaciae* Baker, *Tydeus californicus* (Banks), and *Tydeus gloveri* (Ashmead); an unknown species in the family Tarsonemidae; and *Eugamasus* sp. (Parasitidae). Although these species may feed primarily on fungi or dead organic matter, some may be predacious on phytophagous mites (Jamieson et al. 2006). In addition, five phytophagous mite species were identified as *P. citri, Eotetranychus sexmaculatus* (Riley) (sixspotted mite) (Tetranychidae), *P. oleivora, Polyphagotarsonemus latus* Banks (broad mite) (Tarsonemidae), and *Thyrophagus entomophagous* (Laboulbène & Robin) (Acaridae). The most abundant phytophagous species was *P. citri.* The seasonal abundance of this species in Alabama Satsuma orchards has been described in a recent article (Fadamiro et al. 2008).

**Seasonal Abundance of Key Predacious Mites.** The seasonal abundance of the three most prevalent families and the three predominant species of predacious mites in the top three locations for each species (i.e., the three locations at which the highest population densities were recorded for each species) are shown in Figs. 1 and 2, respectively. Phytoseiid mites were generally more abundant in the spring than during the other times of the year (Fig. 1A). *T. peregrinus,* the species with the earliest seasonal activity was most abundant in February through May with its population declining in the summer (July–September) and slightly increasing again in the winter (October–January) (Fig. 2A). Populations of *P. mexicanus* were highest in April through June, declined to a very low level in July through August, increased slightly in September through October, and declined again to a very low level in November through March (Fig. 2B). Similarly, *A. floridanus* (Stigmaeidae) were moderately abundant in the spring (March–May) but these mites also were recorded in some locations at moderate to high densities in the summer (Coker) and at low to moderate densities in the winter (Brantley and Warden) (Fig. 1B). The seasonal abundance of *A. floridanus* generally followed this same pattern recorded for all stigmaeid mites (Fig. 2C). In contrast, tydeid mites were found in most orchards in low to moderate densities throughout the year, with the highest densities recorded in late spring through early summer (April–July) (Fig. 1C). Tarsonemid mites also were recorded throughout the year in the majority of the orchards, but seasonal abundance varied by location. The highest densities were recorded in the spring and fall in some locations and in the summer in other locations (Fig. 1D).

**Orchard Comparison.** In terms of abundance, the top three locations for phytoseiid mites were Brantley (11 mites per 40 leaves per sampling date), Ladnier (five mites per 40 leaves per sampling date), and Sessions (3.6 mites per 40 leaves per sampling date), which are all conventionally sprayed (Table 2). *A. floridanus* (Stigmaeidae) also were most abundant in the conventionally sprayed Coker, Brantley, and Warden orchards. Tydeid mites were collected in high numbers (≈148 mites per 40 leaves per sampling date) in the conventionally sprayed Brantley orchard, but their densities in the remaining orchards were very low (Table 2). In general, predacious mites were recorded at relatively lower densities in the two unsprayed orchards (McDaniel and Revel). Tarsonemid mites (including the phytophagous species *P. latus*) also were more abundant in the conventionally sprayed orchards (Table 2).

The three most abundant predacious mite species were *T. peregrinus, P. mexicanus,* and *A. floridanus.* They were found at low to moderate densities in the majority of the orchards (Table 3). The data suggest some differences in the relative abundance of the

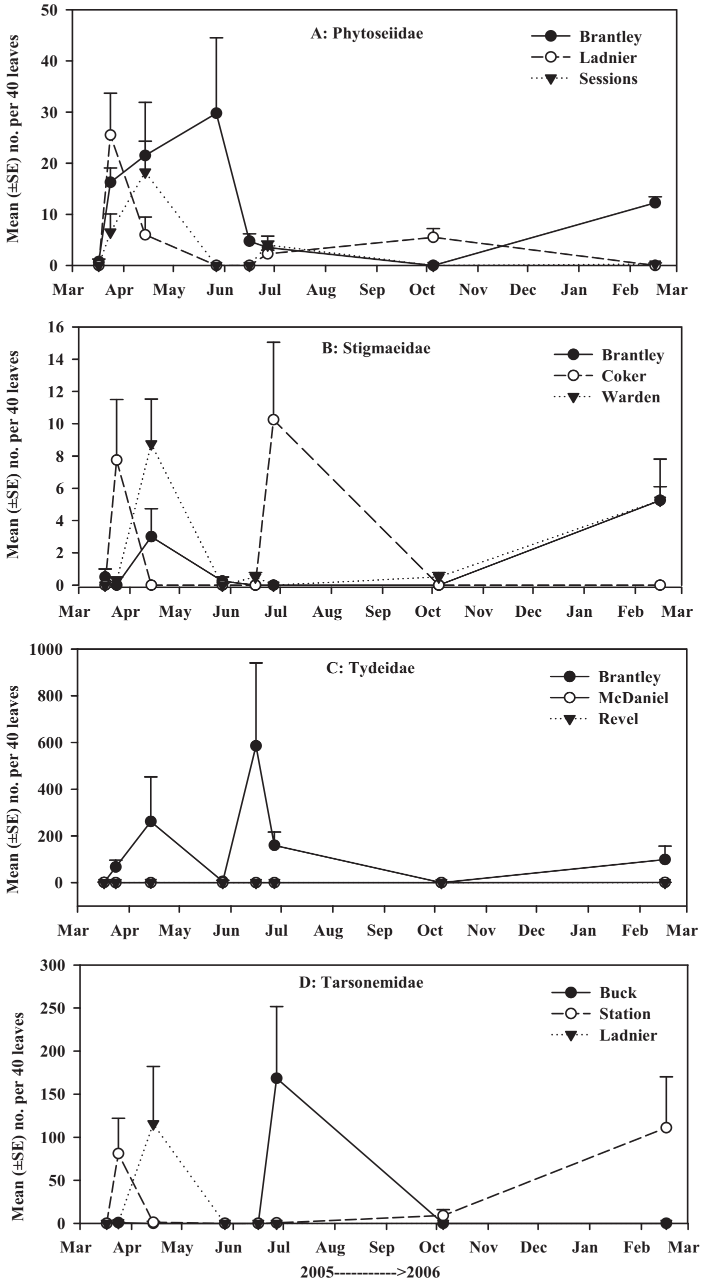


**Fig. 1.** Seasonal abundance of the two most abundant predacious mite families (Phytoseiidae and Stigmaeidae) and two primarily fungivorous families (Tydeidae and Tarsonemidae) in three Alabama citrus orchards during 2005–2006: Phytoseiidae (A), Stigmaeidae (B); Tydeidae (C), and Tarsonemidae (D). Figure shows mean ± SE number of mites (immatures plus adults) per 40 leaves per sampling date.

three species in the different locations. The phytoseiid *T. peregrinus* was collected in all locations and was the most abundant species in the majority of the orchards. The stigmaeid *A. floridanus* was collected in seven of the nine locations and was the most abundant predacious mite species collected in Coker and Warden orchards (Table 3). Comparing the locations, the highest population densities of the two phytoseiid species (*T. peregrinus* and *P. mexicanus*) were recorded in Brantley (conventionally sprayed) orchard with a seasonal mean number (mites per 40 leaves per sampling date) of ≈3.2 and 1.6 for *T. peregrinus* and *P. mexicanus*, respectively (Table 3).

To further determine association of key predacious mites with economically important phytophagous mites in Alabama citrus orchards, seasonal abundance

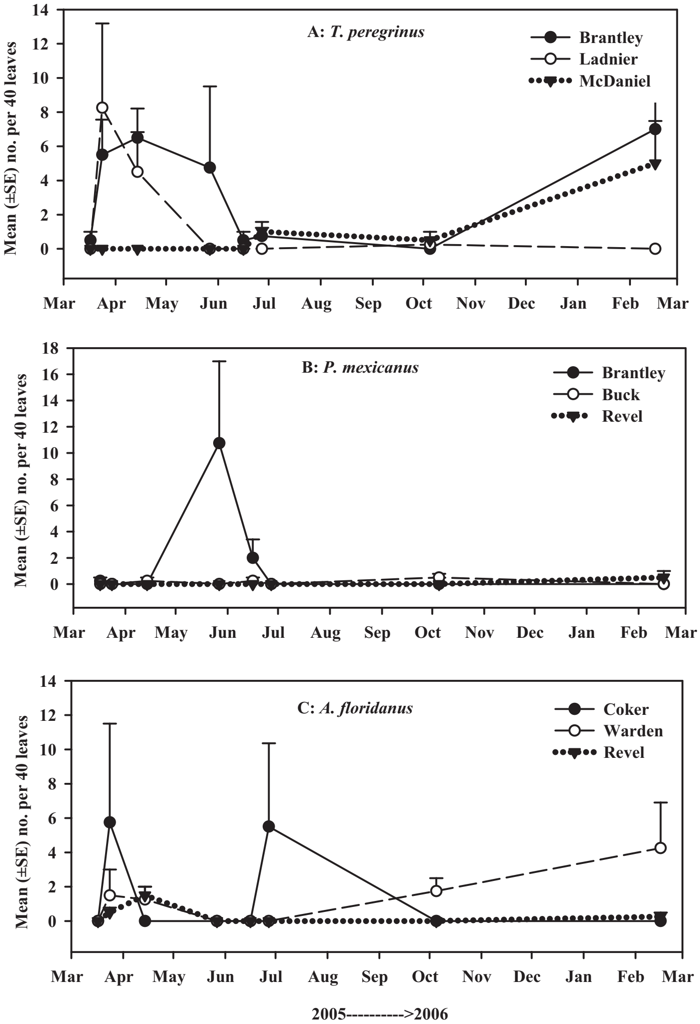


**Fig. 2.** Seasonal abundance of the three dominant predacious mite species in three Alabama citrus orchards in 2005–2006: *T. peregrinus* (A), *P. mexicanus* (B), and *A. floridanus* (C). Figure shows mean ± SE number of mites (immatures plus adults) per 40 leaves per sampling date.

data obtained for key predacious mites in some locations were associated with those recorded in previous studies at the same locations for the two most important pest mites, *P. citri* (Fig. 3, data presented in Fadamiro et al. 2008) and *P. oleivora* (Fig. 4, data not previously published). The data showed that *T. peregrinus*, *P. mexicanus*, and *P. citri* (eggs and motiles) were most abundant in the spring, but were rarely recorded in the summer (Fig. 3), suggesting an association. Similarly, the abundance of the stigmaeid *A. floridanus* and tydeid mites in the summer coincided with the increase of *P. oleivora* during this time of the year (Fig. 4).

**Comparative Abundance of Predacious Mites in Leaf, Fruit, and Weed Samples.** Analysis of the October 2005 samples showed significant differences in the abundance of phytoseiid mites in leaf, fruit, and ground cover plants (weed) samples. In general, phytoseiid mites were significantly more abundant on weed samples than on leaf or fruit samples in the majority of the locations (Table 4). Similar trends were recorded for the other important predacious mite families, but numbers were too low to detect any statistical differences. The ground cover plants identified and their approximate percentage composition in each orchard are shown in Table 4, the most common of which were chamberbitter (*Phyllanthus urinaria* L.), teaweed (*Sida spinosa* L.), bahiagrass (*Paspalum notatum* Flueggé), and broadleaf signalgrass (*Brachiaria platyphylla* [Munro ex C. Wright] Nash).

## Discussion

**Predacious Mite Fauna.** In total, 29 species of predacious mites from nine families were identified in this first inventory of predacious mites on Alabama Sat-

**Table 3. Relative abundance of major species of predacious mites collected on leaf samples in nine Alabama citrus orchards during 2005–2006**

| Pest management practice | Location | Seasonal mean (± SE) no. of mites per 40 leaves | | |
|---|---|---|---|---|
| | | *T. peregrinus* | *P. mexicanus* | *A. floridanus* |
| Conventionally sprayed | Brantley | 3.2 ± 0.8a | 1.6 ± 0.9a | 0.09 ± 0.1ab |
| | Buck | 0.07 ± 0.05b | 0.14 ± 0.06ab | 0 ± 0b |
| | Coker | 0.31 ± 0.15b | 0.06 ± 0.03b | 1.4 ± 0.9a |
| | Ladnier | 1.6 ± 0.8b | 0 ± 0b | 0.03 ± 0.1b |
| | Station | 0.06 ± 0.02b | 0 ± 0b | 0 ± 0b |
| | Sessions | 0.38 ± 0.2b | 0 ± 0b | 0.03 ± 0.02b |
| | Warden | 0 ± 0b | 0.04 ± 0.0b | 1.1 ± 0.4ab |
| Unsprayed | McDaniel | 0.81 ± 0.4b | 0 ± 0b | 0 ± 0b |
| | Revel | 0.34 ± 0.2b | 0.06 ± 0.03b | 0.3 ± 0.1ab |
| | df = 8, 275 | $F = 7.809$ | $F = 3.31$ | $F = 3.22$ |
| | | $P < 0.0001$ | $P = 0.0012$ | $P = 0.0016$ |

Values are total number of motile stages for each species. Means within the same column having no letters in common are significantly different among locations ($P < 0.05$).

suma citrus. In addition, six primarily fungivorous mite species from three families were identified. The three most prevalent predacious mite families were Phytoseiidae (18 species in seven genera) and Stigmaeidae (one species). Similar results have been reported on citrus in Florida (Muma 1965, Muma and Denmark 1970, Childers 1994, Childers et al. 2007), other citrus production regions (Tian 1995), as well as in noncitrus fruit production systems (Childers and Enns 1975b, Thistlewood 1991, Welty 1995, Hu et al. 1996, Roy et al. 1999, Collier et al. 2004, Croft and Luh 2004, Bostanian et al. 2006). The other predacious mite families (Anystidae, Ascidae, Bdellidae, Cheyletidae, and Erythraeidae) were collected only infrequently, as also has been reported in Florida (Muma and Denmark 1970).

In general, the abundance and diversity of predacious mites on Alabama Satsuma citrus pale in comparison with those previously recorded on Florida citrus, which included 35 species of phytoseiid mites in 18 genera (Muma and Denmark 1970), five species of stigmaeid mites (Muma and Selhime 1971, Muma 1975), and seven tydeid species in four genera (Muma 1975). Several factors may account for the relatively lower abundance and diversity of predacious mites on Alabama Satsuma citrus compared with Florida citrus.

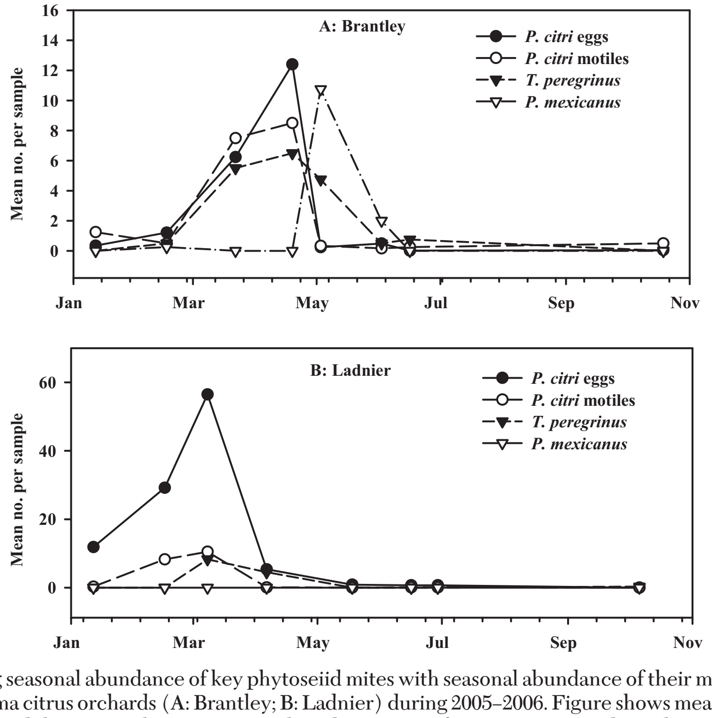


**Fig. 3.** Associating seasonal abundance of key phytoseiid mites with seasonal abundance of their main prey citrus red mite (*P. citri*) in two Alabama citrus orchards (A: Brantley; B: Ladnier) during 2005–2006. Figure shows mean number of phytoseiid mites (immatures plus adults) per 40 leaves per sampling date. Means for *P. citri* eggs and motiles are numbers per leaf per sampling date (note that data on seasonal abundance of *P. citri* were collected in 2006 and have been published in Fadamiro et al. 2008).

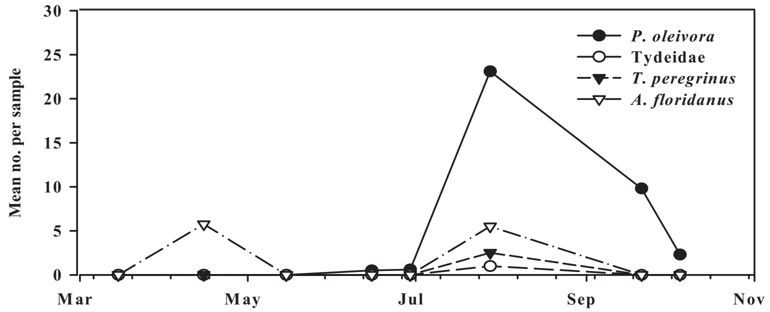


**Fig. 4.** Associating seasonal abundance of the stigmaeid *A. floridanus* and the Tydeidae (a primarily fungivorous family) with seasonal abundance of their probable prey *P. oleivora* in an Alabama citrus orchard (Coker) during 2005–2006. Figure shows mean number of *A. floridanus* or tydeid mites (immatures plus adults) per 40 leaves per sampling date. Means for *P. oleivora* are numbers per square centimeter of fruit per sampling date (note that data on seasonal abundance of *P. oleivora* were collected in a separate study in 2006 and have not been published previously).

First, Satsuma citrus is exotic to Alabama and the small localized plantings are like islands surrounded by oak trees or heavily sprayed field crops (e.g., cotton, *Gossypium hirsutum* L.) with little suitable pollen sources. Villanueva and Childers (2004) reported that the peak abundance of predacious mites in Florida citrus orchards coincided with the flowering period of *Citrus* species and many other plants, including *Pinus* sp. and *Quercus* sp., which are commonly found around citrus orchards and may serve as pollen sources for predacious mites. Second, many citrus orchards in Alabama use grasses heavily as ground cover vegetation and minimize broadleaf and other ground cover plants through their pre- and postemegence weed control practices, thereby limiting the availability of alternative food sources and overwintering plants for predacious mites. Third, pesticide use by Alabama citrus growers and spray drift from adjacent field crops may have created additional disruption of predacious mite populations. Studies have demonstrated that most conventional insecticides and acaricides are inherently toxic to predacious mites and may negatively impact their populations (Bostanian et al. 1985, Thistlewood 1991, Raudonis et al., 2004). Finally, the difference in the abundance of predatory mites on Alabama Satsuma compared with Florida citrus may be related to varietal differences or geographical factors.

Nevertheless, our findings on predacious mite diversity are comparable to those reported in many noncitrus fruit production systems in different parts of the world. For example, 34 species of predacious mites were collected in abandoned apple orchards in Quebec, Canada (Forest et al. 1982), whereas 16 species were reported in a survey of predacious mites in apple orchards in Ontario, Canada (Thistlewood 1991). Forty five species of predacious mites were recorded in Missouri apple (*Malus* spp.) orchards (Childers and Enns 1975b), whereas De Morais et al. (2007) reported 53 species of predacious mites from eight families in an organically managed tangerine (*Citrus* spp.) orchard in Brazil.

**Table 4. Relative abundance of predacious phytoseiid mites in fruit, leaves, and weed samples collected in nine Alabama citrus orchards during the October 2005 sampling date**

| Location | Mean (± SE) no. of phytoseiid mites per sample | | | Ground cover plants identified (approximate percentage of composition)[a] |
|---|---|---|---|---|
| | Leaves | Fruits | Weeds | |
| Brantley | 0 ± 0 | 0 ± 0 | 1.3 ± 0.9 | Chamberbitter (60–80), Florida pusley (*Richardia scabra* L., 0–40), teaweed (0–30) |
| Buck | 0 ± 0b | 0 ± 0b | 4.9 ± 1.7a | Bahiagrass (25–75), chamberbitter (20–50), broadleaf signalgrass (0–25), annual bluegrass (*Poa annua* var. annua L. Timm., 0–25), southern crabgrass (*Digitaria cilaris* [Retz.] Koeler, 0–25), teaweed (0–20), yellow nutsedge (*Cyperus esculentus* L., 0–10), wild geranium (*Geranium carolinianum* L., 0–10) |
| Coker | 0 ± 0 | 1 ± 0.4 | 9.4 ± 7.5 | Chamberbitter (60–100), southern crabgrass (25–80), smooth pigweed (*Amaranthus hybridus* L., 0–10) |
| Station | 0 ± 0 | 0.5 ± 0.4 | 1.3 ± 0.9 | Chamberbitter (100) |
| Ladnier | 5.5 ± 1.7 | 4.5 ± 1.6 | 7.5 ± 3.1 | Chamberbitter (0–60), bahiagrass (0–40), aligatorweed (*Alternanthera philoxeroides* [Mart.] Griseb., 0–40), southern crabgrass (0–10) |
| Warden | 0 ± 0 | 0.5 ± 0.4 | 32 ± 18.6 | Teaweed (0–100), chamberbitter (10–90), southern crabgrass (0–10) |
| McDaniel | 0 ± 0 | 0.8 ± 0.0.7 | 0.8 ± 0.7 | Chamberbitter (50–80), bahiagrass (10–50), teaweed (0–10) |
| Revel | 0 ± 0b | 0.5 ± 0.04b | 2.8 ± 1.3a | Ground cover data not available |

Values are means of four samples per orchard.

[a] Percentage of composition of ground cover plants shows composition range for the four replicated trees per orchard. Means within the same row (for each location) having no letters in common are significantly different among fruit, leaves, and weeds ($P < 0.05$).

The three dominant predacious mite species identified in the current study were *T. peregrinus* (Phytoseiidae), *P. mexicanus* (Phytoseiidae), and *A. floridanus* (Stigmaeidae). Similar to our results, *T. peregrinus* (Muma 1967, Peña 1992, Childers 1994, Villanueva and Childers 2004) and *A. floridanus* (Muma and Selhime 1971, Muma 1975) were among the most abundant predacious mite species on Florida citrus. Another stigmaeid species, *A. longisetus*, was the predominant predacious mite species recorded in the majority of the New Zealand citrus orchards sampled by Jamieson et al. (2005).

**Seasonal Abundance of Key Predacious Mites.** In general, the key predacious mite families and species were most abundant in the spring, whereas populations were very low in the summer and winter months. This pattern is generally similar to the seasonal abundance of key predacious mites on Florida citrus (Muma 1970, Muma and Selhime 1971). The seasonal abundance of predacious mites on Alabama citrus seems to be in synchrony with that of *P. citri*, which is the most abundant phytophagous mite species in Alabama citrus orchards. In Alabama, *P. citri* is usually most abundant in the spring with the population declining or crashing in the summer (English and Turnipseed 1940, Fadamiro et al. 2008). A similar trend has been reported for *P. citri* in Florida (Childers et al. 2007). The hot, humid conditions typically recorded in the summer months in Alabama are probably reasons for the recorded low population densities of *P. citri* (Fadamiro et al. 2008) and most predacious mites during summer. An exception may be the stigmaeid *A. floridanus*, which also was found in moderate numbers throughout summer at some locations. This species was also one of the few predacious species collected throughout the year (including summer) on Florida citrus (Muma and Selhime 1971), suggesting that *A. floridanus* may be able to tolerate the severe summer conditions typical of the Gulf Coast region. The relatively lower population densities of predacious mites recorded in the current study during the winter months is not surprising. The cold winter climate may not only directly impact the survival of overwintering predacious mites (Bostanian et al. 2006) but also may negatively affect availability of prey, alternative food sources and suitable microclimate (Childers and Enns 1975b). Nonetheless, our data in which we recorded low to moderate densities of the key predacious mite species (*T. peregrinus, P. mexicanus,* and *A. floridanus*) in the winter and through early spring at some locations suggest that all three species can overwinter in south Alabama, as also has been reported for their probable prey *P. citri* (Fadamiro et al. 2008).

The higher relative abundance of phytoseiids and other key predacious mite families on ground cover vegetation (weeds) than on citrus leaves and fruit collected in the fall 2005 sampling date suggests that the ground cover plants, including chamberbitter, teaweed, bahiagrass, and broadleaf signalgrass may serve as overwintering plant hosts for predacious mites. Ground cover vegetation, in particular broad leaf plants are important overwintering reservoirs and alternative food sources for predacious mites (Childers 1994, Childers et al. 2007). Some predacious mites also may overwinter in surface litter near the base of trees in the absence of suitable ground cover vegetation (Childers and Enns 1975b). However, our results which showed more predatory mites on weeds than on fruit and leaves in the fall should be interpreted with caution given that the samples were collected only on one sampling date (October 2005). Further studies are necessary to confirm these results.

**Orchard Comparison.** Our results showed that predacious mites were generally more abundant in the conventionally sprayed orchards than in the unsprayed orchards. This is contrary to the general notion that conventional pest management practices usually have a negative impact on predacious mite population. Negative effects of conventional pesticides on predacious mites have been noted in numerous studies (Croft and Nelson 1972, Childers and Enns 1975a, Bostanian et al. 1985, Hagley and Biggs 1989, Croft 1991, Hardman et al. 1991, Thistlewood 1991, Duso et al. 1992, Hu et al. 1996, Raudonis et al. 2004). In a survey of predacious mites in Ontario apple orchards, Thistlewood (1991) reported lower abundance of phytoseiid mites in commercial orchards where pyrethroids were used for leafminers than in orchards without pyrethroids. In addition, applications of some fungicides including benomyl and sulfur were shown to have a negative impact on predacious mite densities in Missouri apple orchards (Childers and Enns 1975a). The relatively higher abundance of predacious mites in the conventionally sprayed orchards in the current study may be due to the greater abundance of their probable main prey *P. citri* in these orchards (Fadamiro et al. 2008). Our data that showed a strong association in the abundance of predacious phytoseiid mites and *P. citri* further support this notion. In addition to increased prey availability, several explanations also may account for the higher abundance of predacious mites in the conventionally-sprayed orchards compared with the unsprayed orchards. Pyrethroid insecticides, which are known to be highly toxic to predacious mites (Croft 1991, Thistlewood 1991, Raudonis et al. 2004) were infrequently used in the conventionally sprayed orchards surveyed in this study. Furthermore, the two unsprayed orchards had relatively less diverse ground cover and flowering plants that may provide suitable microclimate, overwintering habitat, and alternative food sources for predacious mites.

That most of the predacious mites identified in this study are generalist predators that feed on a variety of food sources, including mites, insects, fungi, and dead organic matter, may further explain their higher abundance in some of the conventionally sprayed orchards (e.g., Brantley), which had a high abundance of honeydew and sooty mold. Similarly, the relatively higher abundance of tydeids in the conventionally sprayed Brantley orchard may be associated with higher abundance of whiteflies, scale insects, honeydew, and sooty mold at this location (unpublished data by HYF and YX). Tydeids are generally known to feed on fungi, dead organic matter, scale insects, and honeydew (Muma 1975, Childers 1994).

**Potential Biological Control Agents for Key Pest Mites on Alabama Citrus.** At least two of the dominant predacious mite species identified in this study, *T. peregrinus* and *A. floridanus* may play an important role in the regulation of phytophagous mites on Alabama citrus and both have been suggested as potential biological control candidates on Florida citrus (Muma 1967, Peña 1992, Childers 1994, Villanueva and Childers 2004).

*T. peregrinus* (Phytoseiidae). This species was reported as the dominant phytoseiid on Florida citrus (Muma 1967). *T. peregrinus* can be found on the underside of mature citrus leaves, inside tree canopy, under empty scale armor, clump of dead scale insects, whitefly exuvia, and sooty mold (Muma 1967, Childers 1994). Muma (1969) reported that *T. peregrinus* was able to reproduce and develop on *P. citri* but did perform better on eggs and crawlers of chaff scale, *Parlatoria pergandii* Comstock, and sixspotted mite, both of which are occasional pests in Alabama citrus orchards (Fadamiro et al. 2008). This phytoseiid also was reported to feed on *P. oleivora,* providing some degree of rust mite suppression on lime (*Citrus* spp.) fruit (Peña 1992). Thus, *T. peregrinus* seems to be a generalist species with the ability to reproduce and develop on the two key pest mites on Alabama citrus (*P. citri* and *P. oleivora*) and several other occasional pests. The observed association of *T. peregrinus* with the pest mites, in particular *P. citri,* and the recorded synchrony in its seasonal abundance and that of *P. citri* in southern Alabama further support the notion that this species may play a major role in the biological control of *P. citri* and other citrus mites in Alabama.

*A. floridanus* (Stigmaeidae). This species was identified as the dominant stigmaeid on Florida citrus (Muma and Selhime 1971, Muma 1975). A generalist predacious mite, *A. floridanus* has been reported to feed on a variety of prey, including eggs and immatures of *E. sexmaculatus,* all stages of *P. citri, T. gloveri, P. oleivora,* eggs and crawlers of purple scale, *Lepidosaphes beckii* (Newman) and Florida red scale, *Chrysomphalus aonidium* L., and eggs of a few whitefly species (Muma and Selhime 1971, Childers 1994, Goldarazena et al., 2004). Muma and Selhime (1971) reported that *A. floridanus* was able to complete its life cycle in <2 wk at summer temperatures on *P. oleivora,* indicating that the latter may be an optimal prey for the stigmaeid. *A. floridanus* and many other stigmaeids are known predators of spider mites and other arthropods. However, not much is known about their ability to regulate populations of these pests (Childers 1994). For example, the biological control potential of *A. floridanus* in Florida citrus orchards is still in doubt despite its demonstrated ability to feed and reproduce on important citrus pest mites and insects (Muma and Selhime 1971, Childers 1994). Some of the reasons that have been attributed to the reduced potential of *A. floridanus* as a biological control agent include its high susceptibility to conventional pesticides and sensitivity to extreme weather conditions (Muma and Selhime 1971). Nevertheless, the occurrence of *A. floridanus* throughout the year on Alabama citrus, as also was reported on Florida citrus (Muma and Selhime 1971), suggests that this species may be able to tolerate the hot, humid summer conditions usually recorded in Alabama and other parts of the Gulf Coast. Furthermore, the presence and moderate activity of this species in the summer months (June–September), which coincided with the activity and high abundance of *P. oleivora* (Fadamiro et al. 2007) suggest that *A. floridanus* may have potential in the regulation of this important economic pest in Alabama citrus orchards.

In addition to these two species, a few other identified species of predacious mites and some species in the family Tydeidae, including *T. californicus, T. gloveri* and *Lorryia* spp., also may contribute to natural biological control of pest mites on Alabama citrus. Both species are known to feed on fungi, dead organic matter, and honeydew but also may feed on mites and insects (Muma 1975). For example, *T. californicus* has been reported to feed on *Aceria sheldoni* (Ewing) (Baker and Wharton 1952). Other tydeid species also have been recorded feeding on phytophagous mites (Baker and Wharton 1952, Hessein and Perring 1986). However, the biology of Tydeidae and their biological control potential remain largely uninvestigated (Laing and Knop 1982, Childers 1994).

In summary, this study has identified several species of predacious mites from two families (Phytoseiidae and Stigmaediae) that may play a role in the regulation of populations of phytophagous mites of satsuma citrus in Alabama. The results which showed a strong association and synchrony between *T. peregrinus* and other phytoseiids and *P. citri* suggest that they may be important biological control agents for *P. citri* in Alabama. Similarly, the association recorded in the abundance of the stigmaeid *A. floridanus,* tydeid mites, and *P. oleivora* in the summer suggests that stigmaeid and tydeid mites may be important predators of *P. oleivora* in the state. Further studies are needed to evaluate the potential of these predacious mites, in particular *T. peregrinus* and *A. floridanus,* as biological control agents of *P. citri* and *P. oleivora,* the two economically important pest mites of Alabama citrus orchards (Fadamiro et al. 2007, 2008). An ongoing study also has identified two relatively specialized phytoseiid mites, *Neoseiulus californicus* (McGregor) and *Phytoseiulus persimilis* Athias-Henriot (which was not found in this survey), as promising candidates for biological control of phytophagous citrus mites in Alabama (Y.X. and H.Y.F., unpublished data). Integration of effective predacious mites with application of petroleum oils such as FC 435–66 petroleum oil that was found to be effective against *P. citri* and *P. oleivora* on Alabama satsumas with minimal adverse effects on trees (unpublished data), and selective acaricides (Fadamiro et al. 2005) may provide a long-term and economically sustainable strategy for managing phytophagous mites on Alabama citrus.

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