Seasonal Occurrence of Key Arthropod Pests and Associated Natural Enemies in Alabama Satsuma Citrus

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ABSTRACT Six Alabama Satsuma mandarin orchards (four conventionally sprayed and two unsprayed) were surveyed during 2005 and 2006 to determine the population dynamics of arthropod pests and their natural enemies. Twenty-eight arthropod pest species were encountered; the major foliage pests were citrus whitefly, *Dialeurodes citri* (Ashmead); purple scale, *Lepidosaphes beckii* (Newman); Glover scale, *L. gloveri* (Packard); and citrus red mite, *Panonychus citri* (McGregor). Two distinct population peaks were recorded for citrus whitefly at most locations. The most important direct sources of citrus whitefly mortality were parasitism by *Encarsia lahorensis* (Howard) and infection by the pathogenic fungus, *Aschersonia aleyrodis* Webber. In general, all stages of both scale insects (purple scale and Glover scale) were present in the orchards year-round, indicative of overlapping generations; however, the highest densities were recorded during the early season. Citrus whitefly, purple scale, and Glover scale were more abundant on leaves collected from the interior of the tree canopy than in the exterior canopy. Citrus red mite densities were highest in the spring, with populations declining at the start of the summer, and were more abundant in the exterior canopy than in the interior canopy. The most important natural enemies of citrus red mite were predatory mites belonging to several families, of which *Typhlodromalus peregrinus* Muma (Phytoseiidae) was the predominant species. Major differences were recorded in the relative abundance of different arthropod pest species in the orchards: citrus whitefly, purple scale, and Glover scale predominated in the unsprayed orchards, whereas citrus red mite infestations were more severe in the sprayed orchards. The results are discussed in relation to the possible effect of orchard management practices on abundance of the major pests.

KEY WORDS Satsuma mandarin, *Dialeurodes citri*, *Lepidosaphes beckii*, *Panonychus citri*, beneficial arthropods

Satsuma mandarin, *Citrus unshiu* Marcovitch, has been grown for more than a century along the Gulf Coast in Alabama and neighboring states (English and Turnipseed 1940), but growth and expansion of the industry has been hampered by periodic freezes, which until recently, have been severely devastating to the crop (Winberg 1948, Campbell et al. 2004). Since the early 1990s, there has been an increase in the production of Satsuma mandarins in southern Alabama, particularly in the two coastal counties (Mobile and Baldwin) that surround Mobile Bay. Renewed interest in Satsuma production by coastal growers is fueled by recent availability of new cold-hardy rootstocks coupled with improved methods for tree protection from temperature variations that occur in the region (Campbell et al. 2004). Strong industry and state support are also promoting industry growth, with much effort being made to develop new markets (Campbell et al. 2004). About one third of the local Satsuma mandarin crop has been sold annually to the Alabama public school system since 2003.

As in other citrus-growing regions, one of the major factors limiting the expansion of the budding Alabama Satsuma citrus industry is pest damage and management. However, little is known about the identity and seasonal population dynamics of key arthropod pests of Satsuma citrus and their natural enemies in Alabama. The first published studies on life history and control of pests of Alabama Satsuma citrus was conducted in the early part of the last century (Dozier 1924, English and Turnipseed 1933, 1940), which resulted in the identification of the following arthropods as pests of the crop in Alabama: citrus whitefly, *Dialeurodes citri* (Ashmead) (Hemiptera: Aleyrodidae); purple scale, *Lepidosaphes beckii* (Newman)

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Table 1. Information about the citrus orchard sites in south Alabama

Orchard name	County	Approximate coordinates (latitude, longitude)	Approximate tree age (yr)	Pest management practices
Brantley	Baldwin	N 30°36.216′, W 87°53.014′	8–16	Conventionally sprayed
Buck	Mobile	N 30°26.225′, W 88°12.455′	4–8	Conventionally sprayed
Coker	Baldwin	N 30°33.598′, W 87°48.026′	6–13	Conventionally sprayed
Ladnier	Mobile	N 30°29.309′, W 88°22.542′	4–11	Minimally sprayed since 2002
McDaniel	Baldwin	N 30°32.044′, W 87°38.568′	24	Unsprayed since 1995
Revel	Mobile	N 30°30.337′, W 88°18.337′	10–20	Unsprayed since 2004/longer

(Hemiptera: Diaspididae); Glover scale, *L. gloveri* (Packard) (Hemiptera: Diaspididae); citrus red mite, *Panonychus citri* (McGregor) (Acari: Tetranychidae); and citrus rust mite, *Phyllocoptruta oleivora* (Ashmead) (Acari: Eriophyidae). After these early publications, commercial production of Satsuma mandarins in Alabama was largely abandoned because of severe freezes, although dooryard production continued sporadically. With the ongoing expansion of commercial Satsuma mandarin orchards in the state, it is imperative to develop ecologically based pest management practices that will optimize production while reducing pest management costs and impacts. A first step toward this goal is a systematic study of the population dynamics of key arthropod pests and associated natural enemies in local citrus orchards.

In 2004, we initiated a preliminary pest survey in a few local citrus orchards to determine arthropod activity and abundance. The survey identified several arthropod pests with the potential to cause economic loss to growers. These included fruit feeders such as citrus rust mite, *P. oleivora*, and leaffooted bugs, *Leptoglossus* spp. (Hemiptera: Coreidae), as well as foliage-feeders such as citrus red mite, *P. citri;* citrus whitefly, *D. citri;* citrus leafminer, *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae); purple scale, *L. beckii*); and Glover scale, *L. gloveri* (unpublished data). Based on these preliminary results, we conducted a follow-up extensive survey of six Alabama citrus orchards from June 2005 to December 2006 to quantify the population dynamics of citrus pests and their natural enemies. In this paper, we report the results of the pest survey and describe the population dynamics of the following key foliage pests and their natural enemies: citrus whitefly, purple scale, Glover scale, and citrus red mite.

Materials and Methods

Study Sites

Surveys were conducted during 2005 and 2006 in six citrus orchards located in Baldwin and Mobile counties (three orchards per county), the two main citrus-growing counties in south Alabama. The survey orchards were comprised primarily of Satsuma mandarin, with very limited occurrence of sweet orange (*Citrus sinensis* L. Osbeck), grapefruit (*C. 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'. Information about the location, size, and management practices for each orchard is presented in Table 1. Four of these orchards were commercial farms typically managed using conventional practices including routine applications of pesticides, whereas the remaining two orchards were unsprayed before and during the surveys.

General Survey for Citrus Pests and Natural Enemies

At each location, a group of six trees was selected at random, and the leaves were sampled repeatedly for pest and beneficial arthropods from June 2005 to December 2006. Sampling was conducted at approximately bi-weekly intervals from March to November (during high arthropod activity) and monthly from November to February. Three leaves were collected from the outer (exterior) and inner (interior) portions of the tree canopy at each of the four quadrant for a total of 24 leaves per tree per sampling date (i.e., 12 leaves each from the exterior and interior canopy). Samples consisted of a mixture of mature and young fully developed leaves (when available). After conducting on-site visual sampling of motile pest stages and natural enemies, the leaves were collected in properly labeled paper bags, held in a cooler, and transported to the laboratory, where they were stored in the refrigerator until examined. Each leaf (both the upper and lower surfaces) was later examined under a stereoscopic microscope counting the immatures (larvae/nymphs and pupae) and adults of the different pests. Because of their high abundance and potential economic impact in the surveyed orchards, particular attention was paid to the following pests and their key natural enemies: citrus whitefly, *D. citri*; purple scale, *L. beckii*; Glover scale, *L. gloveri*; and citrus red mite, *P. citri.*

The following data were recorded for citrus whitefly: number of life stages (i.e., nymphs, pupae, and adults), number of parasitized immatures (nymphs and pupae showing signs of parasitism such as darkening or presence of a visible parasitoid body), number of pupal cases with characteristic round parasitoid exit holes (another measure of parasitism), and number of immatures exhibiting signs of infection by the fungal pathogen, *Aschersonia aleyrodis* Webber. For scale insects, we recorded the following data: number of life stages of purple scale (i.e., crawlers, nymphs, and adults), number of parasitized purple scale, number of purple scale cases with parasitoid exit holes, number of life stages of Glover scale (i.e., crawlers,

Table 2. Arthropod pests encountered in six citrus orchard sites in south Alabama (2005–2006)

l	Common name	Scientific name	Pest status[a]	Distribution in Alabama[b]
Hemiptera	Citrus whitefly	*Dialeurodes citri*	Major	++++++
	Glover scale	*Lepidosaphes gloveri*	Major	++++++
	Purple scale	*Lepidosaphes beckii*	Major	++++++
	Leaffooted bug (western)	*Leptoglossus zonatus*	Minor-Major	++
	Leaffooted bug	*Leptoglossus phyllopus*	Minor	++
	Brown stink bug	*Euschistus servus*	Minor	+
	Green stink bug	*Acrosternum hilare (Nezara hilaris)*	Minor	+++
	Black citrus aphid	*Toxoptera aurantii*	Minor	++
	Green citrus aphid	*Aphis spiraecola*	Minor	+
	Cotton/melon aphid	*Aphis gossypii*	Minor	++++++
	Citrus mealybug	*Planoccocus citri*	Minor	++
	Citrus snow scale	*Unaspis citri*	Minor	+
	Cottony cushion scale	*Icerya purchasi*	Minor	++++++
	Caribbean black scale	*Saissetia neglecta*	Occasional	+
	Chaff scale	*Parlatoria pergandii*	Occasional	+
	Florida red scale	*Chrysomphalus aonidium*	Occasional	+
	Brown soft scale	*Coccus hesperidium*	Occasional	++++++
	Citron bug	*Leptoglossus gonagra*	Occasional	+++
Hymenoptera	Red imported fire ant	*Solenopsis invicta*	Minor	++++++
Lepidoptera	Citrus leafminer	*Phyllocnistis citrella*	Minor-Major	++++++
	Orangedog	*Papilio cresphontes*	Minor	++++++
Orthoptera	Eastern lubber grasshopper	*Romalea microptera*	Occasional	++
	American grasshopper	*Schistocera americana*	Occasional	+
Thysanoptera	Flower thrips	*Frankliniella bispinosa*	Minor	++++++
Acari	Citrus red mite	*Panonychus citri*	Major	++++++
	Citrus rust mite	*Phyllocoptruta oleivora*	Minor-Major	+++
	Broad mite	*Polyphagotarsonemus latus*	Occasional	++
	Six-spotted mite	*Eotetranychus sexmaculatus*	Occasional	+

[a] Pest status is based on population abundance and potential for economic damage.
[b] Distribution in Alabama is computed based on presence of a pest species in the surveyed orchards (+ indicates presence in only one of the surveyed orchards while ++++++ indicates presence in all six surveyed orchards).

nymphs, and adults), and number of Glover scale cases with parasitoid exit holes. Crawlers of purple scale are typically transparent white with fiery red eyes, whereas crawlers of Glover scale are translucent waxy white with the outer edge of the last joint yellowish. Eggs of citrus whitefly and scale insects were not recorded because these were impractical to accurately count. Data recorded for mites included numbers of eggs and motile stages of citrus red mite and number of predatory mites (citrus rust mite infestations were rarely observed on the foliage samples and hence will not be reported). Predatory mite (PM) data were initially recorded by family but were later pooled and summarized as total number of predatory mites. Additionally, we also recorded the incidence of less abundant pests and highly motile arthropods such as leaffooted bugs and ants.

Data for each species, location, and year were analyzed and presented separately. For each orchard and during each year, mean numbers of each arthropod species per 24 leaves were calculated for each sampling period (bi-weekly or monthly) using the six trees as replicates. For five of the locations, leaf samples obtained from the exterior and interior parts of the canopy were combined for analysis. However, exterior and interior leaf samples in one of the locations (Brantley) were processed separately. Data obtained at this location were normalized by using the square-root transformation ($\sqrt{x} + 0.5$) and analyzed by *t*-test (JMP Version 5.1 SAS Institute 1998) to determine any significant in the abundance of the different pests and their natural enemies in the exterior versus interior parts of the tree canopy ($P < 0.05$).

Results

Arthropod Pest Fauna of Alabama Satsuma Citrus Orchards

Twenty-eight species of insect and mite pests were encountered in the surveyed Satsuma citrus orchards during 2005–2006 (Table 2). These included 24 insect species from five orders: Hemiptera (18 species), Hymenoptera (1 species), Lepidoptera (2 species), Orthoptera (2 species), and Thysanoptera (1 species). In addition, four species of pest mites (Acari) were identified. The arthropod pest fauna was classified into four categories based on their occurrence, distribution, and abundance (population density) in the surveyed orchards.

The following species are considered "major pests" of citrus in Alabama because of their occurrence in all surveyed orchards (widely distributed) at high population densities: citrus whitefly, *D. citri;* purple scale, *L. beckii;* Glover scale, *L. gloveri;* and citrus red mite, *P. citri.* The second category includes pests that occurred in the majority of the surveyed orchards in moderate to high densities. These pests are classified in this paper as "minor-major" pests and included: citrus rust mite, *P. oleivora;* citrus leafminer, *P. citrella;* and western leaffooted bug, *L. zonatus* (Dallas). Although, the density of citrus rust mite was generally

low in this leaf-based survey, it is considered a minor-major pest based on the results of a separate survey of fruit samples that confirmed its occurrence in moderate to high densities in most of the orchards (unpublished data). Moderate to high infestations of citrus leafminer were observed in some orchards. Thus, intensive surveys including adult monitoring were conducted specifically for this pest and associated natural enemies during 2006–2007. The results will be summarized for publication at the completion of the 2007 season. "Minor pests," which occurred in at least one of the surveyed orchards in low to moderate population densities, constitute the third category. Twelve species are included in this minor pest category, which are also referred to as secondary pests, including leaffooted bug, *L. phyllopus* L.; citrus mealybug, *Planoccocus citri* (Risso) (Hemiptera: Pseudococcidae); black citrus aphid, *Toxoptera aurantii* (Boyer de Fonscolombe) (Hemiptera: Aphididae); flower thrips, *Frankliniella bispinosa* (Morgan) (Thysanoptera: Thripidae); green stink bug, *Acrosternum hilare* (Say) (Hemiptera: Pentatomidae); and red imported fire ant, *Solenopsis invicta* Buren (Hymenoptera: Formicidae). The fourth category referred to as "occasional pests" includes nine species that were encountered only sporadically in the surveyed orchards, such as broad mite, *Polyphagotarsonemus latus* (Banks) (Acari: Tarsonemidae); brown soft scale, *Coccus hesperidium* L. (Hemiptera: Coccidae); chaff scale, *Parlatoria pergandii* Comstock, (Hemiptera: Diaspididae); Florida red scale, *Chrysomphalus aonidium* (L.) (Hemiptera: Diaspididae); and orthopteran pests such as eastern lubber grasshopper, *Romalea microptera* (Beauvois) (Orthoptera: Acrididae) and American grasshopper, *Schistocera americana* (Drury) (Orthoptera: Acrididae).

We consider only the species in the first two categories (major and minor-major pests) as key pests of citrus in Alabama, because grower pest management decisions are likely to center on one or more of these pests. The 28 species can also be classified as direct (those that attack the fruit) or indirect (foliage feeders) pests. Leaffooted bugs, stink bugs, and citrus rust mite are direct pests of citrus in Alabama, although purple scale and citrus red mite damage can also occur on the fruit, in particular, when infestations are heavy. The remaining pests are primarily indirect pests of citrus.

Beneficial Species

Several species of natural enemies were observed in the surveyed orchards, many of which were found in association with some of the above pests. These included predators, parasitoids, and fungal pathogens. The most common predators observed were predatory spiders (Araneae); green lacewing, *Chrysoperla* spp. (Neuroptera: Chrysopidae); minute pirate bug, *Orius insidiosus* (Say) (Hemiptera: Anthocoridae); ladybeetles (Coleoptera: Coccinelidae); mirid bugs (Hemiptera: Miridae); and ants (Hymenoptera: Formicidae). All of these are generalist predators of several pests including citrus leafminer, citrus whitefy, scale insects, and mites. In addition, we recorded several species of predatory mites in the families Anystidae, Ascidae, Bdellidae, Cheyletidae, Cunaxidae, Erythraeidae, Eupalopsellidae, Phytoseiidae, and Stigmaeidae. The dominant predatory mite species was *Typhlodromalus peregrinus* (Muma) (Acari: Phytoseiidae). Many of these predatory mites may be important predators of citrus red mite and other pest mites. Mite species in the families Tydeidae and Tarsonemidae were also recorded, although further studies are necessary to confirm their feeding patterns and whether they are predatory. The six-spotted thrips, *Scolothrips sexmaculatus* (Pergande) (Thysanoptera: Thripidae), was occasionally observed attacking citrus red mite.

A few parasitoids were recorded in association with some key pests. These included *Encarsia lahorensis* (Howard) (Hymenoptera: Aphelinidae), the dominant parasitoid of citrus whitefly. An important parasitoid of purple scale, *Aphytis lepidosaphes* Compere (Hymenoptera: Aphelinidae), was also observed parasitizing nymphs of purple scale in some samples taken from the Revel and McDaniel sites. In addition, a predatory thrips, *Aleurodothrips fasciapennis* (Franklin) (Thysanoptera: Phlaeothripidae), was regularly observed attacking eggs, nymphs, and adults of purple scale during peak populations. Two parasitoids were reared from citrus leafminer: *Ageniaspis citricola* Logvinovskaya (Hymenoptera: Encyrtidae), an endoparasitoid, and *Cirrospilus ingenuus* Gahan (Hymenoptera: Eulophidae), an ecto-parasitoid. Widespread epizootic infection by the fungal pathogen, *A. aleyrodis*, was also recorded on citrus whitefly at most of the locations.

Seasonal Phenology of Major Pests and Associated Natural Enemies

The relative abundance of the major pests and predatory mites in the six surveyed orchards is shown in Table 3. The abundance of the various pests varied considerably by location and year. For brevity, seasonal phenology data for 2006 are presented for the top three locations for each pest (i.e., the three locations at which the highest population densities were recorded for each pest). Phenology data recorded in 2006 at the top three locations are presented in the charts (Figs. 1–3) because data were collected year-round. Although several types of data were collected, only data for the important parameters are summarized here. Similarly, parameters with insignificant numerical data are not presented. For citrus whitefly, counts of specific life stages were summed and presented as number of immatures (nymphs + pupae) and total number of life stages (nymphs, pupae, adults) per 24 leaves. For scale insects, counts of specific life stages were summed and presented as number of immatures (crawlers + nymphs) and total number of life stages (crawlers + nymphs + adults) per 24 leaves. Crawlers of both species of scale insects were

Table 3. Relative abundance of key arthropods in the six Alabama citrus orchards surveyed during 2005–2006

Year	Location	Seasonal mean ± SE no. per 24 leaves				
		CWF	PS	GS	CREM	PM
2005	Brantley	8.4 ± 2.1	8.4 ± 2.2	21.5 ± 6.3	284.0 ± 63.8	0.7 ± 0.2
	Buck	5.7 ± 2.8	0.3 ± 0.1	0.2 ± 0.1	29.2 ± 8.7	0.1 ± 0.1
	Coker	1.2 ± 0.4	0.1 ± 0.1	0.2 ± 0.1	90.8 ± 26.8	0.6 ± 0.2
	Ladnier	5.4 ± 1.1	12.1 ± 2.7	5.9 ± 4.6	77.2 ± 19.3	0.1 ± 0.1
	McDaniel	23.0 ± 7.1	37.7 ± 10.0	223.2 ± 37.7	40.4 ± 10.0	0.3 ± 0.1
	Revel	16.6 ± 3.0	977.9 ± 86.7	107.6 ± 19.5	16.0 ± 4.3	0.7 ± 0.2
2006	Brantley	**69.5 ± 7.6**	**10.2 ± 2.3**	**57.5 ± 10.4**	**38.9 ± 10.6**	**1.8 ± 0.3**
	Buck	12.7 ± 3.7	1.2 ± 0.2	0.4 ± 0.1	168.7 ± 36.4	0.5 ± 0.1
	Coker	5.9 ± 0.7	0.6 ± 0.2	0.9 ± 0.2	72.6 ± 15.1	0.3 ± 0.1
	Ladnier	18.7 ± 2.3	7.8 ± 2.0	3.7 ± 0.7	193.9 ± 44.1	0.5 ± 0.1
	McDaniel	**259.1 ± 23.1**	**56.1 ± 15.3**	**128.6 ± 27.9**	**6.2 ± 1.6**	**0.6 ± 0.1**
	Revel	**56.1 ± 8.0**	**409.5 ± 42.7**	**67.1 ± 9.6**	**5.3 ± 1.4**	**0.6 ± 0.1**

Means in bold indicate the top three locations with the highest abundance of each pest species in 2006.

CWF, nymphs + pupae + adults of citrus white fly, *Dialeurodes citri;* PS, crawlers + nymphs + adults of purple scale, *Lepidosaphes beckii;* GS, crawlers + nymphs + adults of Glover scale, *Lepidosaphes gloveri;* CREM, eggs + motile stages of citrus red mite, *Panonychus citri;* PM, motile stages of predatory mites (four families included: Anystidae, Bdellidae, Phytoseiidae, and Stigmaeidae).

very few in number and constituted <5% of the total life stages.

Citrus Whitefly. Infestation of citrus whitefly was confined almost entirely to the underside surface of leaves and varied considerably by year and orchard. Population densities of citrus whitefly ranged from a seasonal mean of 1.2 total life stages per 24 leaves per sampling date at Coker in 2005 to ≈260 total life stages per 24 leaves at McDaniel in 2006 (Table 3). The highest population densities were recorded at McDaniel, Brantley, and Revel in 2006, and data for these three locations were used to generate phenology charts for citrus whitefly (Fig. 1). Counts of live adults were very low in the orchards, even though there were high numbers of pupal cases with adult emergence holes.

At least two distinct population peaks were recorded at most locations, suggestive of a minimum of two generations per year (Fig. 1). Presence of citrus whitefly immatures was recorded as early as the first sampling date in 2006 (12 January), with the first peak occurring in April–May and the second peak in September–October (Fig. 1). Considerable reduction in the population density of citrus whitefly was recorded in June–July at most locations. Perhaps an exception to this was at Brantley, where a third peak was recorded in mid-June. At all locations, low to moderate densities of citrus whitefly were recorded at the termination of the survey in mid-November. The presence of immature citrus whitefly throughout the season at all locations indicates overlapping generations. Relatively moderate numbers of parasitized pupal cases were recorded especially during January through May. The key parasitoid identified was *E. lahorensis.* Incidence of infection of citrus whitefly by the fungal pathogen, *A. aleyrodis,* was also greater during January through May than later in the season (Fig. 1).

Comparison of the leaf samples collected at Brantley from the exterior and interior parts of the canopy showed significant differences in the numbers of citrus whitefly and associated natural enemies (Table 4). In both years, significantly greater numbers of citrus whitefly life stages, parasitized pupal cases, and *Aschersonia*-infected citrus whitefly were recorded on interior leaf samples compared with exterior leaf samples.

Scale Insects and Mealybugs. Several species of scale insects and mealybugs were observed in the surveyed orchards including Caribbean black scale, *Saissetia neglecta* De Lotto (Hemiptera: Coccidae); citrus snow scale, *Unaspis citri* (Comstock) (Hemiptera: Diaspididae); chaff scale, *P. pergandii;* Florida red scale, *C. aonidium;* brown soft scale, *C. hesperidium;* cottony cushion scale, *Icerya purchasi* Maskell (Hemiptera: Margarodidae); and citrus mealybug, *P. citri.* However, the two prevalent species were purple scale, *L. beckii,* and Glover scale, *L. gloveri.* Both species occurred in moderate to high densities in the majority of the orchards, with the highest infestations recorded at Revel, McDaniel, and Brantley (Table 3). Seasonal phenology data for both species in the above three locations in 2006 are shown in Fig. 2. In general, all stages of the two species were present in the orchards throughout the year, indicating overlapping generations at most locations. The highest population densities of both scale insects were recorded during January through May. Purple scale was the dominant scale pest in Revel with a peak density of ≈1,600 total life stages per 24 leaves in early April (Fig. 2A). A significant reduction in the population density of purple scale was recorded in the summer months with the lowest density of ≈ 55 total life stages per 24 leaves recorded in mid-July. In general, population density of purple scale increased again in the fall months (September–October), but this peak was lower than the spring peak. Incidence of parasitism, as measured by the number of scale cases with round exit holes, was also higher in the early months than later in the season. Glover scale was the prevalent scale species at McDaniel and Brantley with peak densities of ≈700 (6 April) and ≈250 (19 April) total life stages per 24 leaves, respectively (Figs. 2B and C). As recorded for purple scale, densities of Glover scale were drastically reduced in the summer months but increased again in the fall. Again, the fall peak was lower than the spring peak.

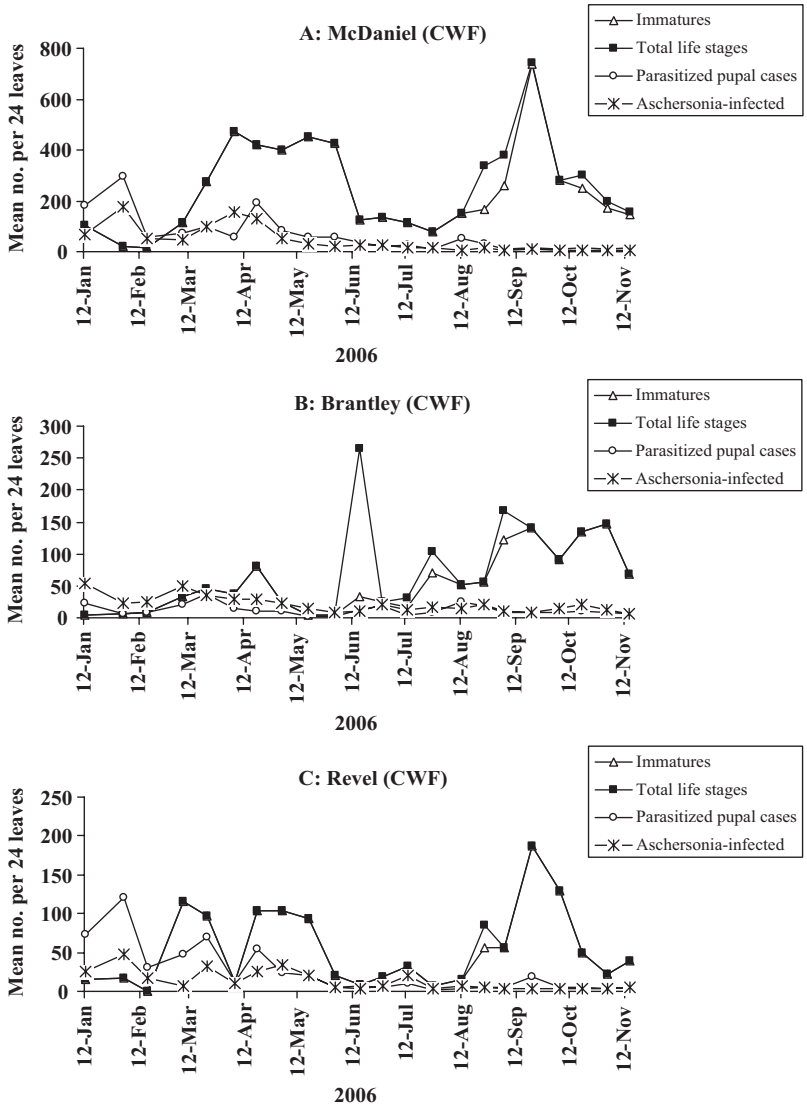

Fig. 1. Seasonal phenology of citrus whitefly (CWF), *D. citri*, and associated natural enemies in three south Alabama citrus orchards in 2006: McDaniel (A), Brantley (B), and Revel (C). Figure shows mean (±SE) number per 24 leaves per sampling date. Immatures, nymphs + pupae of citrus whitefly; total life stages, nymphs + pupae + adults of citrus whitefly; parasitized pupal cases, empty pupal cases of citrus whitefly with parasitoid exit holes; *Aschersonia*-infected citrus whitefly, citrus whitefly immatures exhibiting signs of infection by the fungal pathogen, *A. aleyrodis*.

Analysis of the leaf samples collected at Brantley from the exterior and interior parts of the tree canopy by *t*-test showed major significant differences in scale density. Significantly greater numbers of purple scale total life stages, parasitized pupal cases, and Glover scale total life stage were recorded in interior leaf samples compared with exterior leaf samples in both years of the survey (Table 5).

Citrus Red Mite. Citrus red mite is a major pest of Satsuma mandarin in Alabama occurring on both leaf surfaces in moderate to high densities at the majority of the orchards in both years (Table 3). In 2006, the greatest population densities were recorded in Ladnier, Buck, and Coker, with a seasonal mean number of citrus red mite total life stages (eggs + motiles) per 24 leaves of ≈194, 169, and 73, respectively (Fig. 3A–C).

In general, high densities of citrus red mite eggs and motile stages were recorded very early in the season, reaching a peak of ≈1,360 eggs per 24 leaves on 12 March in Ladnier (Fig. 3A). The peak density of citrus red mite motiles also occurred on this date at this location. Similar results were recorded at the other two locations (Fig. 3B and C). Significant reductions in population densities of citrus red mite eggs and motiles began in mid-April, with populations eventually crashing in July and remaining at near zero throughout the remainder of the year.

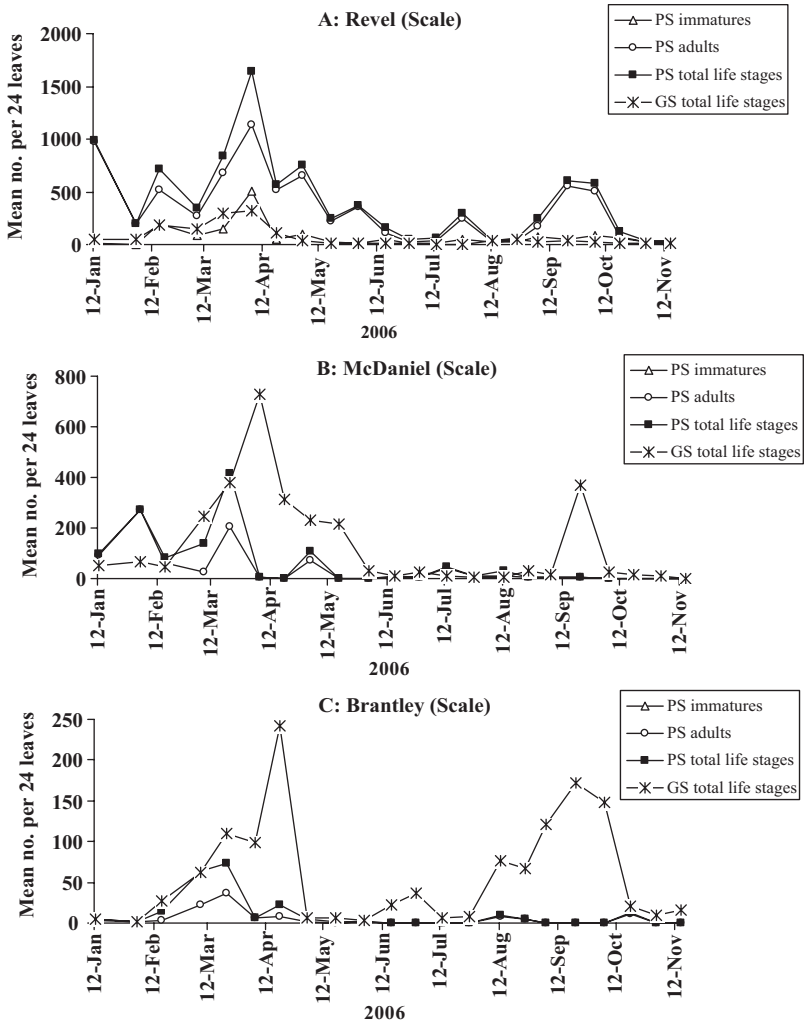

Fig. 2. Seasonal phenology of major scale insects and associated natural enemies in three south Alabama citrus orchards in 2006: Revel (A), McDaniel (B), and Brantley (C). Figure shows mean (±SE) number per 24 leaves per sampling date. PS immatures, crawlers + nymphs of purple scale, *L. beckii*; PS total life stages, crawlers + nymphs + adults of purple scale; GS total life stages, crawlers + nymphs + adults of Glover scale, *L. gloveri.*

Data collected from four key predatory mite families (Anystidae, Bdellidae, Phytoseiidae, and Stigmaeidae) were summed and summarized as total number of PMs; however, the family Phytoseiidae constituted the majority (>90%) of the PMs encountered. The population density of PMs varied by orchard and year but was comparatively low in all orchards. Seasonal mean numbers of PMs per 24 leaves ranged from ≈0.1 in Ladnier in 2005 to ≈1.8 in Brantley in 2006 (Table 3). The seasonal phenology of PMs generally followed the same pattern as that of citrus red mite at most locations, with activity being restricted to January through April. As with citrus red mite, densities of PMs were at near zero from summer through the remainder of the season (Fig. 3).

The relative abundance of citrus red mite and PMs on leaf samples collected at Brantley from the exterior and interior parts of the canopy is shown in Table 6. Significantly greater numbers of citrus red mite eggs and motiles were observed on leaf samples collected from the exterior canopy than from leaves collected from the interior canopy in 2005 (Table 6). However, there were no significant differences in the abundance of citrus red mite in exterior versus interior leaves during 2006. In contrast, PMs were significantly more abundant in interior leaf samples than in exterior leaf samples for both years (Table 6).

Orchard Comparison

Considerable variations were observed in population densities of key pests from orchard to orchard (Table 3). Because of the large variations recorded, we considered it unnecessary to compare data among the orchards statistically. However, the data clearly show some interesting trends. In both years, the highest population densities

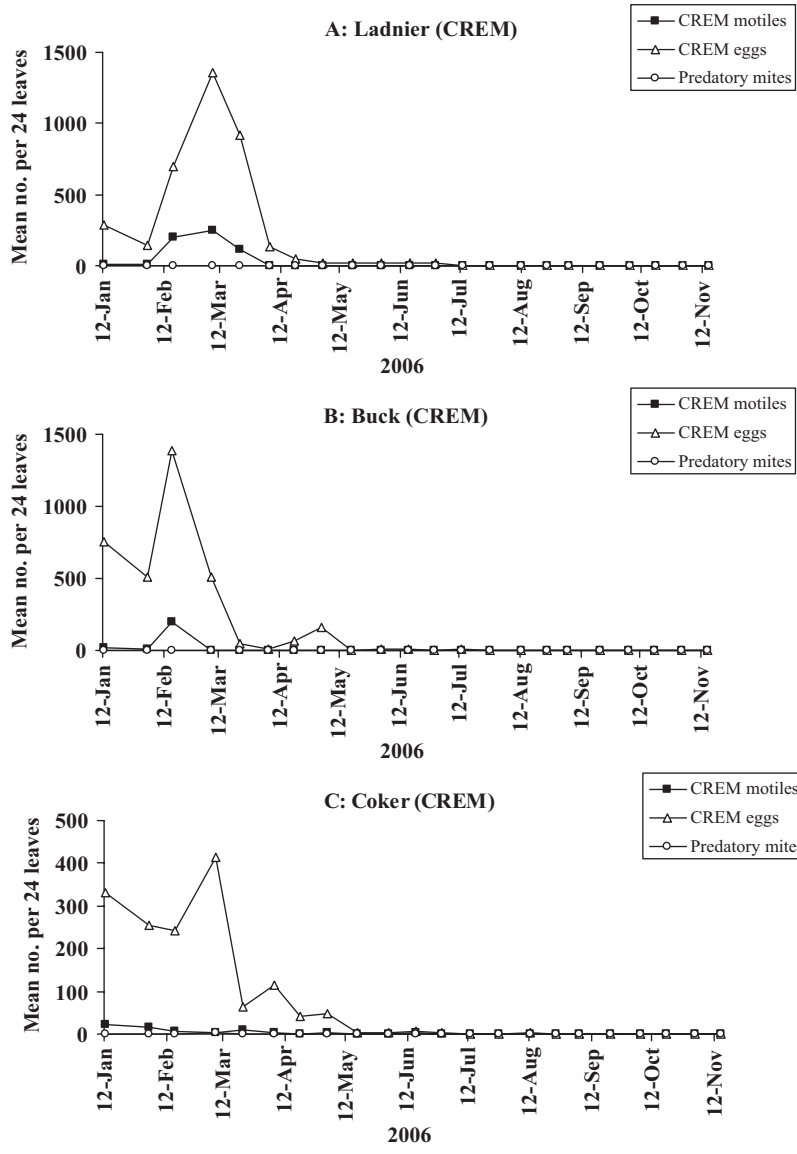

Fig. 3. Seasonal phenology of citrus red mite (CREM), *Panonychus citri* and associated predatory mites in three south Alabama citrus orchards in 2006: Ladnier (A), Buck (B), and Coker (C). Figure shows mean (±SE) number per 24 leaves per sampling date. CREM motiles, immatures + adults of citrus red mite; predatory mites, motile stages of predatory mites (four families included: Anystidae, Bdellidae, Phytoseiidae, and Stigmaeidae).

of citrus whitefly and scale insects were recorded in the two unsprayed orchards (McDaniel and Revel), whereas these two locations had the lowest population densities of citrus red mite, much less than the economic threshold of five motiles per leaf (Childers 1994, Childers et al. 2007). In general, population density of citrus red mite was ≈10- to 30-fold greater in the conventionally sprayed orchards (Buck, Coker, and Ladnier) than in the two unsprayed orchards (Table 3). In contrast, population densities of PMs were slightly numerically higher in the unsprayed orchards than in the conventional orchards. This difference, however, became more pronounced when the ratio of citrus red mite to PMs was calculated for the various locations. The citrus red mite:PM ratio in 2006 ranged from ≈9:1 to 10:1 in the unsprayed orchards and ≈22:1 to 388:1 in the conventionally managed orchards. A similar trend was also recorded in 2005.

Discussion

Arthropod Pest Fauna

The arthropod fauna of Satsuma mandarin in Alabama is similar to the citrus fauna in Florida, Louisiana, and Texas, although there are some notable differ-

Table 4. Relative abundance of citrus whitefly and associated natural enemies in leaf samples collected from different parts (exterior versus interior) of the tree canopy in Brantley orchard, South Alabama

Year	Tree canopy section	Seasonal mean ± SE no. per 12 leaves		
		CWF total life stages	Parasitized pupal cases	*Aschersonia*-infected CWF
2005	Exterior	3.1 ± 1.1b	2.8 ± 0.9b	13.5 ± 2.3b
	Interior	5.3 ± 1.2a	9.1 ± 1.5a	65.0 ± 7.0a
		$t = -1.95$	$t = -4.63$	$t = -7.51$
		df = 142	df = 142	df = 142
		$P = 0.05$	$P < 0.001$	$P < 0.001$
2006	Exterior	19.6 ± 4.4b	2.0 ± 0.2b	4.6 ± 0.5b
	Interior	49.8 ± 5.1a	10.3 ± 1.4a	16.1 ± 1.5a
		$t = -6.12$	$t = -8.41$	$t = -8.75$
		df = 262	df = 262	df = 262
		$P < 0.001$	$P < 0.001$	$P < 0.001$

Means in the same column for the same year followed by the same letter are not significantly different ($P > 0.05$; *t*-test).

CWF total life stages, nymphs + pupae + adults of citrus white fly, *Dialeurodes citri;* parasitized pupal cases, empty pupal cases of citrus whitefly with parasitoid exit holes; *Aschersonia*-infected CWF, citrus whitefly immatures exhibiting signs of infection by the fungal pathogen, *A. aleyrodis.*

Table 6. Relative abundance of citrus red mites (CREM) and associated predatory mites (PMs) in leaf samples collected from different parts (exterior versus interior) of the tree canopy in Brantley orchard, south Alabama

Year	Tree canopy section	Seasonal mean ± SE no. per 12 leaves		
		CREM motiles	CREM eggs	PMs
2005	Exterior	16.2 ± 6.0a	203.0 ± 52.3a	0.14 ± 0.06b
	Interior	2.8 ± 0.7b	62.1 ± 10.4b	0.63 ± 0.18a
		$t = 2.11$	$t = 2.01$	$t = -2.69$
		df = 142	df = 142	df = 142
		$P = 0.04$	$P = 0.05$	$P = 0.008$
2006	Exterior	1.4 ± 0.4	11.8 ± 3.2	0.33 ± 0.11b
	Interior	1.7 ± 0.4	24.1 ± 9.0	1.47 ± 0.28a
		$t = -0.07$	$t = -0.32$	$t = -4.77$
		df = 262	df = 262	df = 262
		$P = 0.94$	$P = 0.74$	$P < 0.001$

Means in the same column for the same year followed by the same letter are not significantly different ($P > 0.05$; *t*-test).

CREM motiles, immatures + adults of citrus red mite, *P. citri;* PMs, motile stages of predatory mites (four families included: Anystidae, Bdellidae, Phytoseiidae, and Stigmaeidae).

ences (Crane et al. 2001, Anciso et al. 2002, Shipp 2002, Aerts and Mossler 2006). The similarity in the arthropod fauna of Alabama citrus with the fauna in Florida and other Gulf Coast states is not surprising, given that Florida and Louisiana are the key sources for citrus plants grown in Alabama (unpublished data). However, most of the emerging and newly introduced pests of citrus in Florida were not recorded in this survey, including brown citrus aphid (*Toxoptera citricida* Kirkaldy), Asian citrus psyllid (*Diaphorina citri* Kuwayama), and citrus root weevil (*Diaprepes abbreviatus* L.) (Crane et al. 2001, Aerts and Mossler 2006). In addition, the Texas citrus mite (*Eutetranychus banksi* McGregor), which is the prevalent spider mite species in Florida (Childers 1994) and Texas (Anciso et al. 2002), was not detected during this survey. Some of the recorded pests seemed to occur at greater or lower densities in Alabama relative to neighboring citrus-producing states. For instance, the western leaffooted bug, *L. zonatus* is the major leaffooted bug species in Alabama, whereas *L. phyllopus* is the prevalent species in Florida orchards (Baranowski and Slater 1986). In addition, aphids that are important pests in Florida citrus (Crane et al. 2001, Aerts and Mossler 2006) are currently of minor importance in Alabama.

Table 5. Relative abundance of key scale insects in leaf samples collected from different parts (exterior versus interior) of the tree canopy in Brantley orchard, south Alabama

Year	Tree canopy section	Seasonal mean ± SE no. per 12 leaves		
		PS total life stages	Parasitized PS	GS total life stages
2005	Exterior	0.3 ± 0.3b	0.0 ± 0.0b	0.5 ± 0.9b
	Interior	8.0 ± 2.1a	0.6 ± 0.2a	21.0 ± 6.1a
		$t = -5.54$	$t = -3.03$	$t = -5.35$
		df = 142	df = 142	df = 142
		$P < 0.001$	$P = 0.003$	$P < 0.001$
2006	Exterior	0.4 ± 0.2b	0.2 ± 0.1b	1.4 ± 1.0b
	Interior	9.8 ± 2.3a	1.2 ± 0.4a	56.1 ± 10.2a
		$t = -4.81$	$t = -3.06$	$t = -8.98$
		df = 262	df = 262	df = 262
		$P < 0.001$	$P = 0.002$	$P < 0.001$

Means in the same column for the same year followed by the same letter are not significantly different ($P > 0.05$; *t*-test).

PS total live stages, crawlers + nymphs + adults of purple scale, *L. beckii;* parasitized PS, empty scale cases of purple scale with parasitoid exit holes; GS total life stages, crawlers + nymphs + adults of Glover scale, *L. gloveri.*

The results of this survey were used to classify arthropod pests of Satsuma citrus in Alabama into four categories: major, minor-major, minor, and occasional pests. The major pest species were identified as citrus whitefly, purple scale, Glover scale, and citrus red mite. These pests, together with the minor-major pests (leaffooted bugs, citrus rust mite, and citrus leafminer), constitute the key pests of Satsuma mandarin in Alabama and are likely to continue to be the focus of pest management practices initiated by growers. Many of these species also constitute key pests of citrus in other Gulf Coast states (Crane et al. 2001, Anciso et al. 2002, Shipp 2002, Aerts and Mossler 2006).

Seasonal Phenology of Key Pests and Associated Natural Enemies

Citrus Whitefly. The citrus whitefly (*D. citri*) is a polyphagous pest of citrus with widespread distribution throughout much of the world (Mound and Halsey 1978, Argov et al. 1999). Native to Southeast Asia, it was introduced into Florida from India sometime between 1850 and 1880 (Morrill and Back 1911). It was noted as a major pest of Satsuma mandarin in Alabama as far back as the early part of last century (English and Turnipseed 1940). The results of this study showed that citrus whitefly remains a major pest of the crop in Alabama, occurring in high densities in the surveyed orchards. This was also confirmed by the large amounts of honeydew and the associated infection by the sooty mold fungus (indirect measures of citrus

whitefly and scale infestations) observed on leaves collected from the orchards, in particular at the McDaniel, Brantley, and Revel locations.

Our data showed that citrus whitefly has at least two to three generations per year in Alabama and is in agreement with the two to three adult broods previously reported for this pest in Alabama by English and Turnipseed (1940). Citrus whitefly is known to have variable numbers of generations per year from region to region, ranging from two to three in relatively cold regions such as Europe (Viggiani and Mazzone 1978, Malausa and Franco 1986, Argov et al. 1999) to three to six in warmer regions such as China, Turkey, and Florida (Morrill and Back 1911, Zhang et al. 1991, Nguyen et al. 1993, Argov et al. 1999). Morrill and Back (1911) reported two to six generations for citrus whitefly in Florida noting, however, that the populations were mostly two-brooded. Similarly, two generations per year were reported for citrus whitefly in southern California (Bellows and Meisenbacher 2007), suggesting that number of generations per year could be as low as two, even in warmer locations. Even within the same country, number of generations could vary by population and location as reported in Israel by Argov et al. (1999). The greater abundance of citrus whitefly in interior leaf samples indicates that the interior of the tree canopy is the preferred site for oviposition and development of this pest, as reported also by Argov et al. (1999). Previous reports have indicated that female citrus whitefly prefer to oviposit on young, fully developed leaves, with spikes in population densities typically recorded during flushes (Uygun et al. 1990, Argov et al. 1999).

Several natural enemies were observed in association with citrus whitefly. These included generalist predators such as ladybeetles, mirid bugs, and green lacewings. Many of these have also been reported in association with citrus whitefly by other authors (Yigit et al. 2003). The key parasitoid identified on citrus whitefly in this study was *Encarsia lahorensis.* Formerly known as *Prospaltella lahorensis* Howard, this parasitoid was first introduced into Florida from Lahore, India, in 1911 (Woglum 1913). However, the first successful establishment of this parasitoid in the United States was recorded in California (Rose and DeBach 1981), and subsequent releases from California into Florida were necessary for the eventual establishment and success of the parasitoid in Florida (Sailer et al. 1984). The occurrence of *E. lahorensis* in Alabama is likely caused by movement of rootstock materials from Florida. We are not aware of any documented purposeful introduction of this parasitoid into Alabama citrus. However, a population of the parasitoid obtained from Florida was released against citrus whitefly populations on the ornamental plant, gardenia (*Gardenia jasminoides*), in central and north Alabama in 1979 (Hudson and Williams 1986). This introduction could also have contributed to the occurrence of the parasitoid in Alabama citrus. Although low levels of parasitized immature citrus whitefly were recorded in all orchards, the synchrony in the seasonal phenology of the parasitoid and its host suggests that *E. lahorensis* may be an important natural enemy of citrus whitefly in Alabama.

Perhaps the single most important direct source of citrus whitefly mortality recorded in this study was infections by the pathogenic fungus, *Aschersonia aleyrodis.* Epizootics for this pathogen, similar to those observed in this study, have also been reported in other humid subtropical and tropical locations (McCoy 1978, Meyerdirk et al. 1980, Morrill and Back 1911). The pathogen may have good potential as a microbial control agent against citrus whitefly in Alabama and other humid Gulf Coast states. In fact, a campaign was initiated in Florida in the early part of last century aimed at using this pathogen as a bioinsecticide against citrus whitefly (Berger 1907, McCoy 1978).

Scale Insects. The two most important scale pests of citrus in Alabama were identified as purple scale (*L. beckii*) and Glover scale (*L. gloveri*). Both species are important pests of citrus in most parts of the world attacking leaves, trunk, twigs, and fruit (Umeh et al. 1998). High infestations could result in tree death, whereas moderate infestations could weaken trees and make them more susceptible to freeze damage (English and Turnipseed 1940). In the United States, purple scale was found first in Florida (Essig 1926), and was first reported in south Alabama in 1914 (Dozier 1924).

Although all stages of both species could occur in the orchard throughout the year, the highest population densities were recorded during spring, similar to the report by English and Turnipseed (1940). Little published information is available on the seasonal phenology of both species on citrus worldwide. Our data show two population peaks, one in the spring and a smaller peak in the fall for both scale species on Alabama Satsuma citrus. However, the exact number of generations for both species may be more than two because of the observed overlapping of generations. It is also possible that these peaks do not completely represent the actual generations, because three or more generations per year have been reported for purple scale in Texas (Anciso et al. 2002). Glover scale is usually found in association with purple scale on citrus (English and Turnipseed 1940), as also indicated by our results showing similar phenology for both species in Alabama. Very low populations of both species were recorded in the summer and winter, suggesting that extremes of temperature may limit the development of these scale pests. English and Turnipseed (1940) observed that development of purple scale was retarded by cool weather and may be shut down by severe cold.

Similar to citrus whitefly, we recorded greater abundance of the two scale insects in interior leaf samples than in exterior leaves, indicating their preference for the interior of the tree canopy. Scale cases with the characteristic round parasitoid exit holes were recorded in considerable numbers in the early months than later in the season. The parasitic wasp, *A. lepidosaphes,* which was found to provide effective biological control of purple scale in Florida (Muma and

Clancy 1961), was also observed at some of our survey sites in very low numbers.

Citrus Red Mite. citrus red mite is an important pest of citrus in most parts of the world (Childers 1994, Gotoh and Kubota 1997, Jamieson et al. 2005). The nymphs and adults of citrus red mite and other spider mites feed primarily on both surfaces of 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 (Kranz et al. 1997). High infestations can also lead to fruit feeding and damage.

In this study, high densities of citrus red mite were generally recorded in all orchards well above the economic threshold of eight adult females per leaf (Childers et al. 2007). Citrus red mites were most abundant in the spring with the population declining at the beginning of the summer and eventually crashing in July, as previously reported by English and Turnipseed (1940). A similar trend was reported for citrus red mite in Florida, with the highest densities occurring between March and June (Childers et al. 2007). The development of spider mites is favored by dry weather and low relative humidities (Childers 1994, Childers et al. 2007). The hot and humid summer conditions typical of Alabama and other parts of the Deep South is the likely reason for the very low (near zero) densities of citrus red mite recorded in the summer and fall months. The data also suggest that citrus red mite can overwinter as eggs or motiles in southern Alabama. The remarkably high densities of citrus red mite eggs recorded at all locations at the beginning of the 2006 season could be attributed to high populations of overwintering eggs recorded in fall and winter of 2005. To determine whether temperature and rainfall could account for the recorded differences in the overwintering populations of citrus red mite in late 2005 versus late 2006, historic weather data for Fairhope (nearest weather station to the orchards) were analyzed, comparing climate data for fall and winter of both years. Temperature did not explain the recorded difference between both years. However, significant differences were recorded in the rainfall (precipitation) data: average total precipitation per month for the last 4 mo (September–December) was ≈6 and 10.7 cm for 2005 and 2006, respectively. Given that citrus red mite infestation is usually higher in dry weather and low relative humidities, it is possible that relatively drier fall/winter weather in 2005 may explain the high overwintering densities of citrus red mite eggs recorded late that season. In addition, the unusually stormy hurricane season recorded in the summer of 2005 (in particular, Hurricane Katrina, which occurred on 28–29 August 2005) could potentially have had an impact on the seasonal phenology of citrus red mite by shifting spider mite activity to the latter part of the season.

In contrast to citrus whitefly and scale insects, the 2005 data showed that citrus red mite was significantly more abundant in the exterior part of the tree canopy than in the interior canopy (although no significant differences were recorded in 2006), whereas PMs were more abundant in the interior canopy. Citrus whitefly and scale insects tend to prefer young, fully developed leaves (Uygun et al. 1990, Argov et al. 1999), whereas citrus red mite and other spider mites feed primarily on mature leaves (Childers 1994).

The most important direct sources of arthropod mortality to citrus red mite in this study were PMs. Although several families of PMs were observed (see Results), the predominant species was *T. peregrinus,* a phytoseiid. In Florida, spider mites are usually under effective biological control by predatory mites, of which *Galendromus helveolus* (Chant) and *T. peregrinus* are the predominant species (Childers et al. 2007). In Alabama orchards, however, the present density of PMs seems too low to provide effective suppression. Further studies are clearly needed to further characterize the predatory mite fauna and determine the reasons for the comparatively low densities of PMs in Alabama citrus orchards, with the ultimate goal of effective augmentation and conservation of PM populations in local citrus orchards. As a first step toward achieving this goal, we have since initiated a more focused and intensive survey of the predatory mite fauna in Alabama citrus orchards, the results of which will be presented elsewhere. The six-spotted thrips (*S. sexmaculatus*), which is primarily a predator of *Tetranychus urticae* Koch, was occasionally observed attacking citrus red mite at high pest population densities. However, the abundance and impact of this predatory thrips was so low that meaningful control of mite pests may not be achieved by the activities of this predatory mite.

Orchard Comparison

The variation recorded in the density of the key pests in different orchards is intriguing and could be related to differences in orchard management practices and local ecological conditions. Among the major pests, citrus whitefly and scale insects predominated in the two unsprayed orchards (McDaniel and Revel). In contrast, citrus red mite, which was the dominant pest species in the conventionally managed orchards (Brantley, Buck, Coker, and Ladnier), was rarely a problem in the two unsprayed orchards, with densities generally below the economic threshold. Citrus red mite is often considered a "pesticide-induced" pest, being that applications of broad-spectrum pesticides may disrupt the activity of predatory mites and other natural enemies of citrus red mite (Jamieson et al. 2005). This may explain, at least in part, the higher abundance of citrus red mite in the conventionally managed orchards. The ecology of the unsprayed orchards may also have contributed to the reduced abundance of citrus red mite. For instance, the two unsprayed orchards have grassy ground cover and surrounded by pine trees, habitats that potentially provide suitable microclimate and alternative food sources for PMs. The higher relative abundance of citrus whitefly and scale insects in both unsprayed

orchards may suggest that the level of control provided by natural enemies, in particular parasitoids, is minimal, and that conventional therapeutic practices are necessary for effective control of honeydew-producing hempiteran pests in Alabama citrus orchards. Alternatively, intraguild competition and other interactions among hemipteran insects and citrus mites potentially may explain the dominance of different pests at different locations, as recorded in this study.

Citrus production in Alabama and other parts of the Gulf Coast have some unique characteristics relative to other citrus growing regions. For instance, Satsumas are the major citrus grown in Alabama, Louisiana, and Mississippi (Shipp 2002, Fadamiro et al. 2007), and the blocks generally are quite small, whereas citrus blocks in Arizona, California, Florida, and Texas are mainly medium-large monocultures of oranges, grapefruit and other varieties (Childers 1994, Anciso et al. 2002, Aerts and Mossler 2006). Nevertheless, the results of this study are relevant to other citrus-producing states and regions of the world given the similarity in pest guild and management practices. For instance, many of the recorded key pests of Satsumas in Alabama including citrus whitefly (Mound and Halsey 1978, Argov et al. 1999), citrus red mite (Childers 1994, Gotoh and Kubota 1997, Jamieson et al. 2005), and scale insects (Essig 1926, Umeh et al. 1998, Anciso et al. 2002) are major citrus pests in many areas of the world. Also, conventional pest management practices such as application of sulfur (as a fungicide) has been attributed to high citrus red mite densities in many parts of the world (Childers 1994, Jamieson et al. 2005), and this may also explain the relatively higher densities of this pest observed in conventionally managed Alabama citrus orchards.

In conclusion, this study has characterized some aspects of the field ecology of key pests of Satsuma citrus foliage in Alabama, providing a foundation for the development of an integrated pest management program for the growing Satsuma citrus industry in the state. The survey has also identified recently introduced or emerging citrus pests in Alabama since the publication of the early studies in the mid-1900s (English and Turnipseed 1940), including leaffooted bugs, stink bugs, citrus leafminers, and red imported fire ants. Future studies will focus on the biology, ecology, and management of the identified key pests.

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