

Identification of slide-mounted specimens of female mites was accomplished with the aid of a taxonomic key (Key to the Phytoseiid Predatory Mites of California Crops, developed by J. McMurtry and E.E. Grafton-Cardwell, in progress) and a phase contrast microscope. Some mite collections (in grapes, walnuts, strawberries, citrus, caneberries and cherimoyas) were made repeatedly in the same sites through one or more seasons. Other collections were made on one or a few

dates during a season. Collectively, a total of 229 site-years were sampled.

Subtropical fruit: Dominated by *Euseius* species

Three subtropical fruit crops were studied: avocados, cherimoyas and citrus (table 1, fig. 2). Surveys demonstrated that subtropical crops had low predatory mite

TABLE 1. Species of phytoseiid predatory mites found in 12 permanent or semipermanent cropping systems in California

Host plant	Collection years	Counties	Site-years*	Seasonal samplert	No. of mites	<i>Phytoseiulus persimilis</i>	<i>Typhlodromina eharai</i>	<i>Galendromus occidentalis</i>	<i>Galendromus annectens</i>	<i>Neoseiulus californicus</i>	<i>Neoseiulus aurescens</i>	<i>Neoseiulus cucumeris</i>	<i>Neoseiulus brevispinus</i>	<i>Neoseiulus barkeri</i>
Citrus	2006–2018	Fresno, Tulare, Kern, Santa Barbara, Riverside, San Bernardino	21	No	994	0	0	0	0	0	0	0	0	0
Avocado	2000–2007	San Luis Obispo, Orange	11	Yes	1,892	0	1	3	37	4	0	0	0	0
Cherimoya	2006–2007	Santa Barbara, Ventura	3	Yes	104	0	0	2	0	0	0	0	0	0
Blackberry	2006–2007	San Luis Obispo	2	Yes	106	0	9	14	24	49	0	0	0	0
Raspberry	2006–2007	San Luis Obispo, Ventura	10	Yes	239	50	2	0	0	26	0	0	0	0
Strawberry	2006–2010	Santa Cruz, Santa Barbara, Ventura	18	Yes	1,570	271	0	0	0	612	403	204	19	5
Grape	2005–2010	Lake, Napa, Mendocino, Sonoma, Madera, San Joaquin, Kern, Ventura, San Luis Obispo, Monterey	78	Yes	5,604	13	5	415	0	87	12	1	0	1
Peach/ nectarine	2006–2007	Butte, Fresno, Kings, Tulare, Kern	19	No	576	0	0	35	0	1	0	0	0	0
Plum/ prune	2006–2007	Butte, Kern	4	No	67	0	0	3	0	0	0	0	0	0
Pear	1996–2008	Lake, Mendocino, Sacramento, Yolo	30	Yes	800	0	0	71	0	4	0	0	0	0
Almond	2006–2018	Kern, Butte	9	No	174	0	0	6	0	0	0	0	0	0
Walnut	2006–2013	Tehama, Butte, Yuba, Yolo, Sutter, Solano, San Joaquin, Kings, Tulare	24	Yes	2,533	0	0	362	0	5	0	0	0	2
				Total number	14,659	334	17	911	61	788	415	205	19	8

* Sites x years sampled.

† Yes = samples collected at intervals throughout the crop season. No = one or a few samples collected.

the southcoast area. The UC IPM guidelines for citrus (Dreidstadt 2012; Grafton-Cardwell et al. 2019)

recommend conservation of *Euseius* species to aid in control of pest mites and thrips.

A total of 1,892 phytoseiids representing nine species were collected from avocado in San Luis Obispo and Orange counties from 2000 to 2007, and 96.2% of these mites were in the genus *Euseius* (table 1, fig. 2). *E. hibisci* was the dominant species (95.8% of *Euseius* species) found on inland Southern California avocados, and *E. stipulatus* was the dominant species (96.0% of *Euseius* species) found on south coast avocados. Again, the abundance of *E. stipulatus* in the south coast area is a significant change from the 1960s through the 1980s, when *E. hibisci* dominated that region (Congdon and McMurtry 1985; McMurtry and Johnson 1965, 1966). The UC IPM guidelines for avocado (Dreidstadt 2008; Faber et al. 2018) list *Neoseiulus californicus*, *E. hibisci*, *Galendromus annectans*, *G. helveolus* and *Amblydromalus limonicus* as important predators of pest mites.

A total of 104 phytoseiids representing five species were identified from cherimoya in the south coast area (Santa Barbara and Ventura counties) during 2006 and 2007, and 93.3% of these mites were in the genus *Euseius* (table 1, fig. 2), including *E. stipulatus* (88.5%) and *E. quetzali* (4.5%). This is the first report of phytoseiids in cherimoyas (Murrietta 2015) and provides further evidence that *E. stipulatus* has established in south coast California subtropical crops.

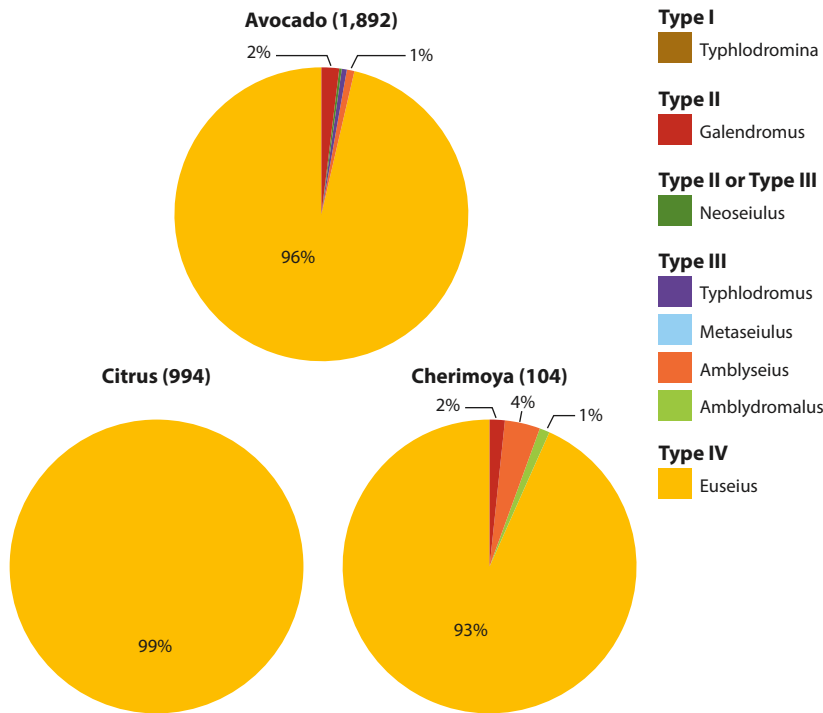


FIG. 2. Percentage of each phytoseiid predatory mite genus found in citrus, avocado and cherimoya (number of specimens).

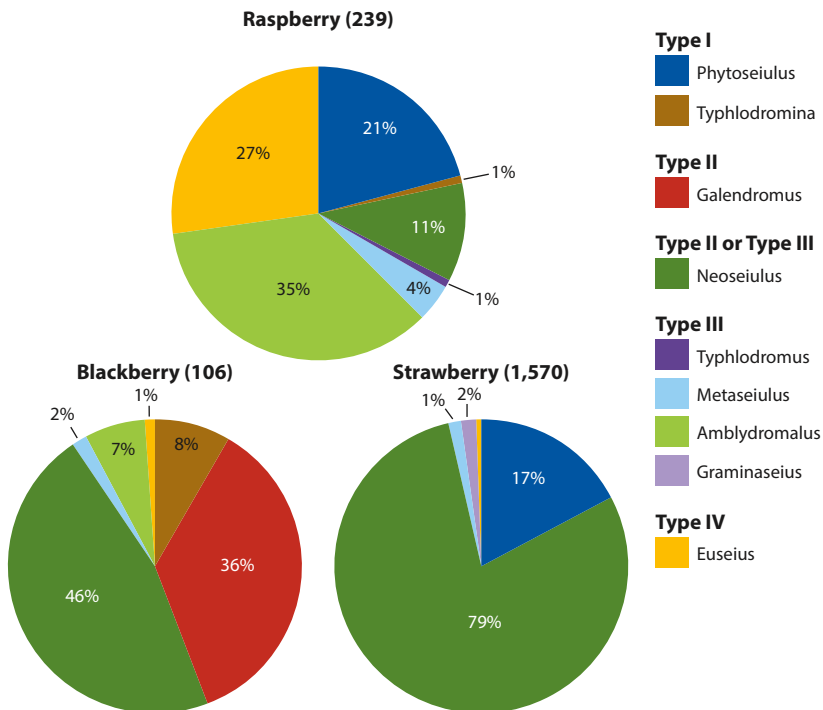


FIG. 3. Percentage of each phytoseiid predatory mite genus found in blackberry, raspberry and strawberry (number of specimens).

Berries: Specialized spider mite predators

In contrast to the subtropical crops that hosted primarily type IV phytoseiid species, blackberries, raspberries and strawberries supported a high percentage of type I and II specialized spider mite predators: *Phytoseiulus*, *Typhlodromina*, *Galendromus* and *Neoseiulus* species (fig. 3). Collections in our study were likely affected by augmentative releases of these phytoseiids by growers for tetranychid pest mites.

A total of 106 mites representing eight species were collected from blackberries in San Luis Obispo County, and 90% were identified as type I *Typhlodromina ehari* (8%) and type II species: *N. californicus* (46.2%) and *Galendromus* species (35.8%) (table 1, fig. 3). A previous study in blackberry by McMurtry and Show (2012) revealed lower diversity (only two species) compared to our untreated commercial site or the wild blackberries in their study, indicating pesticide effects on diversity.

A total of 239 mites represented by seven species were collected from raspberries in San Luis Obispo and Ventura counties, including type I *P. persimilis* (20.9%), type II *N. californicus* (10.9%), type III *Amblydromalus limonicus* (35.1%) and type IV *Euseius stipulatus* (27.2%) (table 1, fig. 3). Significant numbers of *E. stipulatus* found in south coast raspberries again demonstrate establishment of this species in this region. Raspberries had a greater number of type III and IV phytoseiids than blackberries; however, the

blackberry crop was represented by only one surveyed site. The UC IPM guidelines for caneberries discuss releases of *P. persimilis* for control of mites (Bolda et al. 2018b).

A total of 1,570 mites representing nine species were collected from strawberries in Santa Barbara, Ventura and Santa Cruz counties, including type I *P. persimilis* (17.3%) and type II and III *Neoseiulus* species (79.2%) (table 1, fig. 3). Because of early research demonstrating the efficacy of releases (Oatman et al. 1977), growers regularly use phytoseiid releases for tetranychid mite control in strawberries. The UC IPM guidelines for strawberry state that *P. persimilis* and *N. californicus* have established in south coast strawberries, and these were the two dominant species found in Santa Barbara and Ventura county surveys (Bolda et al. 2018a; Strand 2008). The Santa Cruz County survey revealed five species of *Neoseiulus*: *N. californicus* (35.6%), *N. aurescens* (41.1%), *N. cucumeris* (20.8%), *N. brevispinus* (1.9%) and *N. barkeri* (0.5%), suggesting greater species diversity of *Neoseiulus* in this county. Our study revealed *E. stipulatus* in south coast strawberries.

Grapes: Greatest phytoseiid diversity

Grapes (table 1, fig. 4) had the greatest diversity of phytoseiids (24 of 28 total species collected from all crops). However, the greater diversity found may be due to the higher number of ecological niches sampled. A total of 5,604 mites were collected from 10 counties, and species composition varied greatly by region. The dominant genera in north coast vineyards were type II *Galendromus* (72.5%) and type III *Amblyseius* (16.3%) species; in the Napa Valley, type III *Typhlodromus* (74.2%) and type IV *Euseius* (13.2%) species dominated; in the Central Valley, type II *Galendromus* (18.7%) and type IV *Euseius* (78.5%) were most common; and in south coast vineyards, type II *Galendromus* (13.2%), type III *Metaseiulus* (58.1%) and type IV *Euseius* (16.1%) species prevailed. The UC IPM guidelines for grape, updated based on the surveys described in this study, list *G. occidentalis*, *T. pyri*, *E. quetzali*, *E. tularensis*, *E. stipulatus*, *Neoseiulus fallacis*, *N. californicus* and *M. mcgregori* [*M. flumenis*] as beneficial species, with species dominance varying from region to region (Bettiga 2013; Haviland et al. 2019).

The differences in species composition could be explained by a number of factors, including variations in climate, prey species, neighboring crops and pesticide treatments (Hanna et al. 1997; Stavrinides and Mills 2009). Previous research (Flaherty and Huffaker 1970) in the Central Valley revealed a similarly high level of species diversity in grape and listed *E. hibisci* as the sole *Euseius* species collected. However, at that time, *E. tularensis*, *E. stipulatus* and *E. quetzali* had not yet been described (Congdon and McMurtry

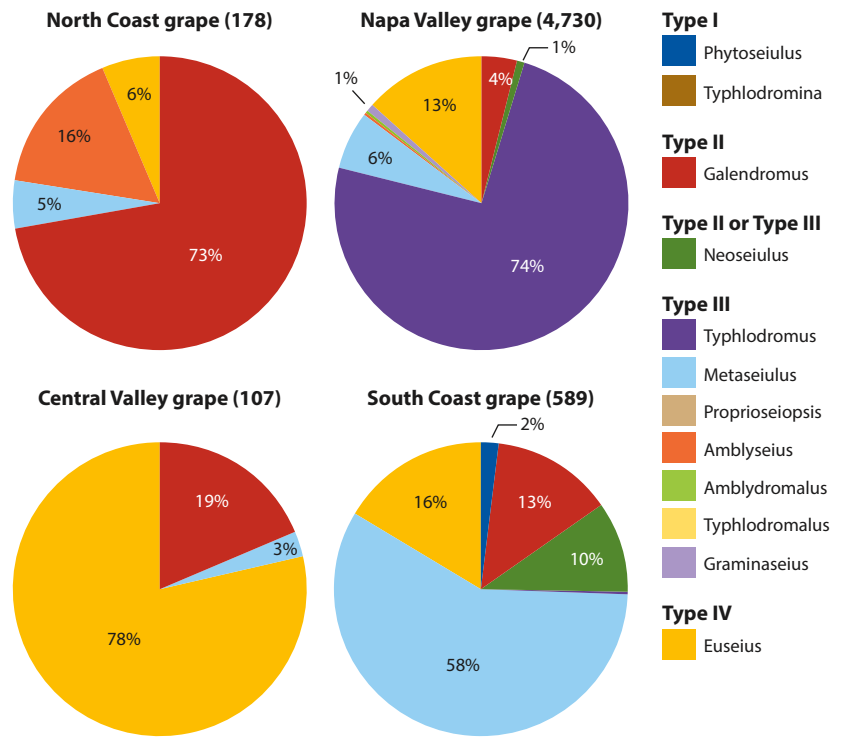


FIG. 4. Percentage of each phytoseiid predatory mite genus found in grape sampled from four regions (number of specimens).



Adult western predatory mite *Galendromus (Metaseiulus) occidentalis* attacking a twospotted spider mite egg. Inset: *Galendromus occidentalis* specimen as seen under a compound microscope.

1985). Our collections revealed all four species of *Euseius*, with *E. stipulatus* present in the south coast and Napa Valley regions, *E. hibisci* in the south coast, *E. tularensis* in the Central Valley and south coast and *E. quetzali* statewide.

Stone fruit and pears: Additional species found

A previous survey of peaches, nectarines and plums (Rice and Jones 1978) indicated that *Typhlodromus caudiglans*, *Metaseiulus citri*, *Galendromus occidentalis* and *Euseius hibisci* were the key phytoseiids in the Central Valley. Our study provided evidence of these but also additional species such as *Amblyseius similoides*, and the previously undescribed *E. tularensis* and *E. quetzali*.

A total of 576 mites representing eight species were collected from peaches and nectarines in Butte, Fresno, Kings, Tulare and Kern counties. The dominant species found were type II *G. occidentalis* (6.1%), type III *T. caudiglans* (29.2%) and *A. similoides* (12.8%) and type IV *Euseius* species (51.4%) (table 1, fig. 5). The UC IPM guidelines for peaches and nectarines list *G. occidentalis* as the key phytoseiid for control of key pest spider mites (Day et al. 2017a, 2017b; Strand 1999), yet this species accounted for only 6.1% of the specimens collected.

A total of 67 mites representing four species were collected from plum and prune orchards in Butte and Kern counties (table 1, fig. 5). The major species found were type II *G. occidentalis* (4.5%), type III *T. caudiglans* (23.9%) and type IV *E. tularensis* (71.6%). The UC IPM guidelines for plums and prunes suggest *T. caudiglans* and *Galendromus* species as effective control agents for key pest mites (Adaskaveg et al. 2017; Bentley et al. 2017).

A total of 800 mites representing nine species were collected from pear orchards in Lake, Mendocino, Sacramento and Yolo counties (table 1, fig. 5). The predominant species were type II *G. occidentalis* (8.9%), type III *T. caudiglans* (10.3%) and *M. citri* (6.5%) and type IV *E. quetzali* (72.5%). This is the first published survey of phytoseiids in pear. The UC IPM guidelines for pear list *G. occidentalis* for the control of key pest mites (Elkins et al. 2017; Ohlendorf 1999), yet this species represented < 9% of mites collected.

Nuts: Few phytoseiids in almonds

A total of 174 mites representing six species were collected from almond orchards in Kern and Butte counties (table 1, fig. 6). The predominant species were type III *Amblyseius similoides* (59.8%) and type IV *Euseius* species (29.9%). The UC IPM guidelines for almond list *Galendromus occidentalis* as the key predacious mite for tetranychid pest mite control (Flint 2002; Haviland et al. 2017). However, *G. occidentalis* represented a minor percentage (3.4%) of species collected. It should be noted that we searched almond sites for several years to obtain these collections and routinely found very few phytoseiids. The low populations of phytoseiids compared to decades ago may be explained by changes in chemical control programs that favor a second-level predator, the sixspotted thrips, *Scolothrips*

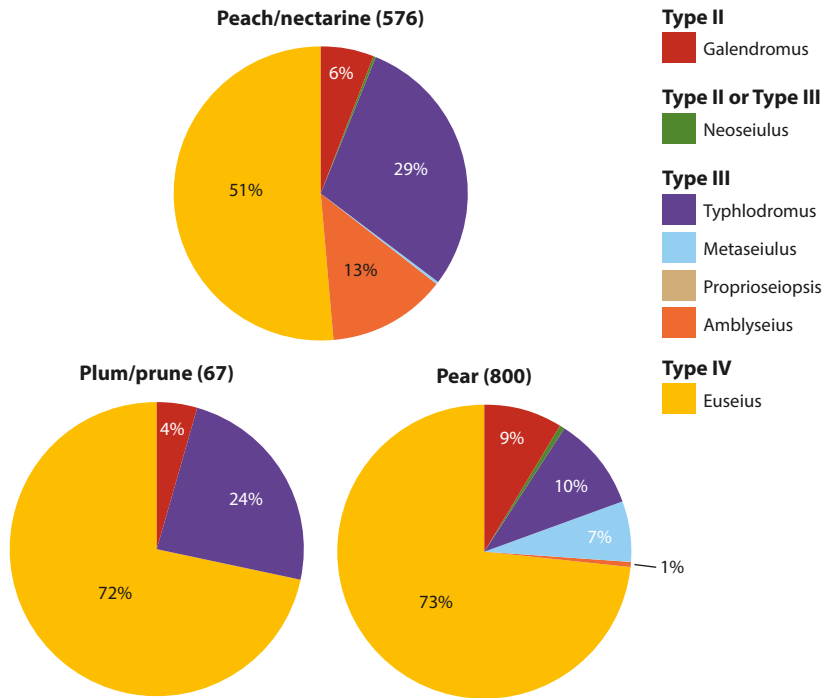


FIG. 5. Percentage of each phytoseiid predatory mite genus found in stone fruit and pear (number of specimens).

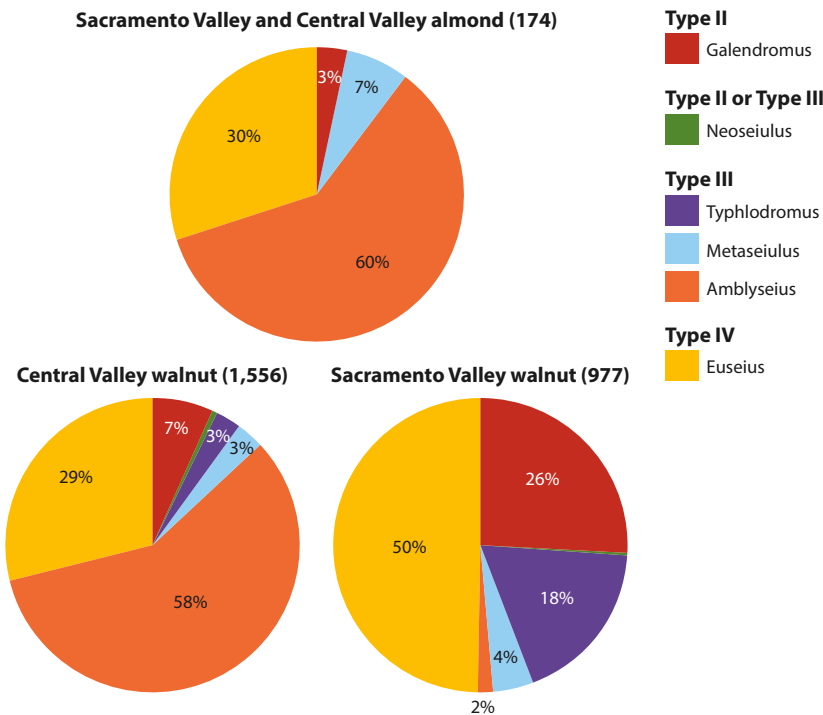


FIG. 6. Percentage of each phytoseiid predatory mite genus found in nut crops, with walnut sampled from two regions (number of specimens).

sexmaculatus, which feeds on both tetranychids and phytoseiids.

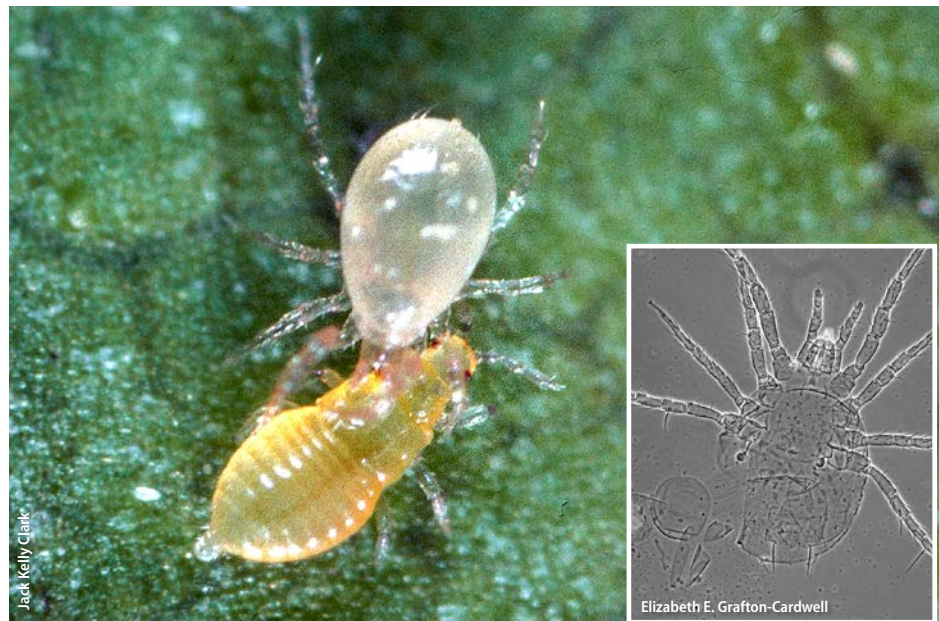
A total of 2,533 mites representing 11 species were collected from walnut orchards in Tehama, Butte, Yuba, Yolo, Sutter, Solano, San Joaquin, Kings and Tulare counties (table 1, fig. 6). When we examined the results by geographical region, the predominant genera in the Central Valley were very similar to almonds, with type III *Amblyseius* species (58.0%) and type IV *Euseius* species (28.7%) dominating. In contrast, walnuts grown in the Sacramento Valley had a much higher percentage of type II *G. occidentalis* (26.1%) and type III *Typhlodromus* species (18.1%), in addition to type IV *Euseius* species (49.5%) and very low numbers of type III *Amblyseius* (1.7%) species. The UC IPM guidelines for walnut indicate that *G. occidentalis* is the key predator of walnut pest mites (Grant et al. 2017; Strand 2003). However, it was found in much lower abundance in the Central Valley region than the Sacramento Valley.

Diversity levels, changes

The surveys in this study were undertaken to determine the level of diversity of phytoseiids in perennial crops in six regions of California and look for changes in species composition compared to earlier studies (Congdon and McMurtry 1985, 1986; Hoy et al. 1979; Kinn and Doult 1972; McMurtry and Flaherty 1977; McMurtry and Johnson 1965; McMurtry et al. 1971; McMurtry et al. 1979; McMurtry and Show 2012; Oatman 1971; Rice and Jones 1978; Rice et al. 1976). Similar to these other studies, our surveys found low phytoseiid diversity in subtropical crops, extremely high levels of diversity in grapes and moderate levels in tree fruits, nuts and berries. Berries hosted the greatest proportion of type I *Phytoseiulus persimilis* and type II *Neoseiulus californicus*, likely due to augmentative releases and/or establishment from prior releases of the commercially available predators.

The presence of *Euseius stipulatus* in citrus, avocados, cherimoyas, grapes, strawberries, blackberries, raspberries, almonds and walnuts is interesting because this species was introduced to citrus in Southern California in 1972 (McMurtry 1977) for the control of citrus red mite. It is now found as far north as the Sacramento Valley in walnut orchards and Napa Valley, and it appears to have displaced *E. hibisci* to a great extent in south coast subtropical crops.

The western predatory mite, *Galendromus occidentalis*, has long been recognized as an important biological control agent in California crops, as evidenced by its mention in many of the UC IPM guidelines. Our survey demonstrated that *G. occidentalis* was often a minor component of the phytoseiid complex, playing a major role only in grape, Sacramento Valley walnut and south coast blackberries. Previous authors noted that *G. occidentalis* populations decline when tetranychid prey are lacking and this



species is sensitive to insecticides (Hoy et al. 1979; Rice and Jones 1978).

The predatory mite complexes differed significantly between geographical regions for walnuts and grapes, and studies need to be undertaken to determine the underlying basis for these differences. In addition, studies are needed to evaluate the roles and effectiveness of the abundant type III and type IV phytoseiid species, such as *Typhlodromus*, *Amblyseius* and *Euseius* species, in the stone, pear and nut crops. Are these species regulators of key pests such as mites and thrips? Or are they feeding on pollen or nonpest mites such as tydeids, eriophyids and tarsonemids and insignificant for agricultural pest control? Most of our surveys were carried out without monitoring plant-feeding prey, but clearly there are host plant and prey influences. Additional work is needed to elucidate the impact of pest phenology, climate, crop variety, alternative prey and crop management activities on the abundance of phytoseiid species and their ability to regulate pest populations.

A significant impediment to evaluating the role of predatory mites in field situations is that they are difficult to identify to species using a hand lens because of their rapid movement, small size and similar appearance. Yet, there are large differences in their ability to regulate pest populations. As mentioned, a taxonomic key is being prepared for publication, but it requires slide-mounted specimens and a phase-contrast microscope. Consequently, phytoseiid identification may be limited for professionals who have no access to specialized equipment. Future work may take advantage of rapid advancements in and declining costs of field-useable molecular tools to quickly identify mites. If future research establishes the efficacy of the various phytoseiid species and a rapid identification method becomes available, then PCAs can make real-time decisions and avoid unnecessary pesticide applications. [CA](#)

Euseius tularensis predatory mite, top, feeding on a citrus thrips nymph, bottom. Inset: *Euseius tularensis* specimen as seen under a compound microscope.

E.E. Grafton-Cardwell and M. Hoddle are UC Cooperative Extension (UCCE) Specialists, J. McMurtry (deceased) was retired Professor of Entomology, and P. Gu and Y. Ouyang are Staff Research Associates, Department of Entomology, UC Riverside; W. Bentley is retired UCCE IPM Advisor, Kearney Agricultural Research and Extension Center; M. Bianchi is retired UCCE Farm Advisor, San Luis Obispo and Santa Barbara counties; F.E. Cave is retired Staff Research Associate and N. Mills is Professor, Department of Environmental Science, Policy and Management, UC Berkeley; R. Elkins is UCCE Farm Advisor, Lake and Mendocino counties; L. Godfrey (deceased) was UCCE Specialist, Department of Entomology, UC Davis; D. Haviland is UCCE Entomology Advisor and S. Rill is UCCE Staff Research Associate, Kern County; D. Headrick is Professor, Department of Horticulture and Crop Science, Cal Poly San Luis Obispo; M. Murrietta is UCCE

Farm Advisor Assistant, San Luis Obispo County; C. Pickel is retired UCCE IPM Advisor, Sutter and Yuba counties; M.C. Stavrínides is Assistant Professor, Department of Agricultural Sciences, Biotechnology and Food Sciences, Cyprus University of Technology; and L.G. Varela is UCCE IPM Advisor, North Coast.

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