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Natural Enemies Associated with Avocado Thrips in Ventura County Avocado Groves: Results of a pilot study and year one of a three-year survey

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Abstract

Fourteen avocado groves were surveyed by leaf samples, beat samples and sticky cards to assess avocado thrips (AT) and natural enemies (NE) populations in avocado trees in 2003. In the groves, the presence of NE and AT between January and September was only slightly affected by a single abamectin treatment, with *Chrysopa* sp. being the only NE significantly impacted. In untreated groves, considerable differences between NE populations were found. *Leptothrips mali* were the most abundant predatory thrips in beat samples and arachnids the most abundant NE. On sticky cards, *Aeolothrips fasciatus* were most abundant, followed by the Coleoptera, while *Ceranisus menes* and *Franklinothrips orizabensis* were equally abundant in untreated groves. Distance from the coast did not affect *L. mali* or *Aeolothips,* but impacted *C. menes* (more abundant near the coast) and *F. orizabensis* (more abundant inland). The presence of groundcover (dead, dying, mowed and living) increased the number of parasitoids and spiders recorded in beat samples and increased the numbers *of Leptothrips mcconnelli* and predaceous Coleoptera. *F. orizabensis* and *C. menes* numbers on sticky cards declined when >70% of the orchard floor was covered. When only living ground cover is considered, parasitoids numbers in beat samples and *A. fasciatus* numbers on sticky cards increased with >70% living ground cover, while *C. menes* was more abundant where living ground cover did not exceed 70% and *F. orizabensis* were most abundant where 11-70% of the orchard floor was living ground cover. The presence of flowering plants on the orchard floor had no significant effect on NE observed in beat samples or on sticky cards. Trends indicated higher numbers of *L. mali* and *Orius* sp. in beat samples in orchards where between 1-10% flowering plants were present on the orchard floor, while lower numbers of *F. orizabensis* were found on sticky cards in these orchards. *C. menes* numbers were not impacted by the presence of flowers in the ground cover.

Most results of this survey are descriptive and need replication before conclusions or generalizations can be made. Data from future seasons will allow for temporal analyses which will be necessary to fully understand the NE complex in avocado orchards.

Introduction

Avocado thrips *(Scirtothrips perseae* Nakahara) has been a major pest in California avocado groves since it was first found in Ventura County in 1996 (Hoddle and Morse, 1997). Most growers are currently using chemical means to control their invertebrate pest problems and research into these areas is ongoing (Yee *et al.,* 2001ab; Oevering *et al.* 2002; Morse and Hoddle, 2003). Foreign exploration studies for natural enemies identified six genera of predatory thrips *(Aeolothrips, Aleurodothrips, Franklinothrips, Leptothrips, Scolothrips* and *Karnyothrips),* one parasitoid *(Ceranisus)* and one predatory mite *(Balaustium)* associated with avocado thrips in Mexico and Guatamala (Hoddle *et al.,* 2002). In Ventura county, *Franklinothrips orizabensis* (Johansen) and *Aeolothrips kuwanaii* (Moulton) were reported associated with higher numbers of avocado thrips in a three year study from 1998-2000 *(Yee et al.,* 2001 c). In the past four years, possible biological control measures against avocado thrips have been investigated, including releases of the generalist predator *F. orizabensis* (Oevering *et al.,* 2002, Hoddle *et al.,* submitted) and releases of *Chysoperla* sp. (Phillips and Faber, 1999). So far none of these studies have developed into a commercially available strategy, although some organic growers have adopted a practice of releasing generalist predators with varying results (Oevering, personal observations).

Since reliance on biological control remains the preferred method of pest control for most avocado growers, the focus for this study returned to natural enemies already present in the California groves. In Ventura County, during the *F. orizabensis* release studies a variety of generalist natural enemies were found on the sticky cards used to monitor *F. orizabensis* in the groves (Oevering, personal observation). To identify the spatial and temporal distribution of these generalists, a survey for natural enemies in chemically treated and untreated groves in Ventura County was initiated.

This survey is part of a larger 3-year project that investigates the possible effects of the presence of naturally occurring undergrowth on natural enemy abundance, where the undergrowth may supply carbohydrates in the form of flowering plants (nectar and pollen), shelter, and alternative food sources in the form of prey available on flowering plants. Ultimately, this project aims to identify how cultural techniques such as pruning, fertilization, the use of different cover crops or undergrowth mixtures can both improve natural enemy abundance and suppress populations of avocado thrips. In this paper we report on the results of the first year of the county-wide natural enemy survey.

Materials and Methods

Study sites and observation period

In a pilot study in 2002, avocado groves at three locations were observed. Two coastal groves, 2.5 miles and 4.1 miles from the coast, were observed 11 times between March and December, and 8 times between July and December, respectively. An intermediate grove (7.3 miles from the coast) was observed 12 times between April and December.

In 2003, 14 avocado groves were selected (including those from 2002), located between 1.6 and 24.4 miles from the coast. The groves were grouped into "coastal" (n=3, within 5 miles from the coast), "intermediate" (n=5, between 7 and 13 miles from the coast) and "inland" (n=6, between 16 and 25 miles from the coast). Between January and September 2003, each grove was observed 11 to 14 times, every two weeks between April and August (observations continued after August every 23 weeks but are not included in this preliminary report).

Trees at all study groves were at least 90% ‘Hass’ variety, 7-15 feet tall and ranged from 5 to 15 years of age.

Table 1 List of predator and parasitoid species observed for the natural enemies studies, including total numbers observed in beat samples and on sticky cards and a list of species abbreviations used

Arthropod species or family	Common name	# all beat samples	# all sticky cards	Name used in this publication
Predatory thrips (Thysanoptera: Aeolothripidae)				
Franklinothrips orizabensis	n.a. [x]	65	1498	F. orizabensis
Leptothrips mali	Black hunter	278	130	L. mali
Aeolothrips fasciatus	Banded thrips	14	3137	A. fasciatus
Scolothrips sexmaculatus	six spotted thrips	0	0	+
Leptothrips mcconnelli	n.a. [x]	26	313	L. mcconnelli
Predatory beetles (Coleoptera: Coccinellidae; Staphylinidae)*		238	2416	Coleoptera
Coccinellidae	Lady beetles*			
Stethorus picipes	Spider mite distroyer			
Staphylinidae	Other beetles*			
Lacewings (Neuroptera)*		185	296	Chrysopa
Chrysopa spp.	Green lacewings			
Hemerobius spp	Brown lacewings			
Coniopterygidae	Dusty wings			
Raphidiidae	Snake flies			
Bugs (Hemiptera: Anthocoridae)				
Orius spp, Anthocoris spp.	Minute pirate bugs*	58	426	Orius
Geocoris spp	Bigeyed bugs	7	0	+
Parasitoids (Hymenoptera: Eulophidae, Braconidae, Ichnomonidae)				
Ceranisus menes (Eulophidae)	n.a. [x]	41	1370	C. menes
	Other parasitoids [x]	208	xx	Parasitoids
Predatory flies (Diptera)				
Syrphidae	Syrphid flies	1	4	+
Predatory mites (Arachnidae: Acari)				
Anestidae sp.	Whirley gigs*	268	xx	Anestidae
Neoseilus (Amblyseus) sp. and/or Helveolus californicus	Predatory mites*	215	xx	++
Spiders (Arachnidae: Araneae)**		383	20	Araneae
Thomisidae	Crab spiders			
Salticidae	Jumping spiders			
Araneidae	Orchard spiders			

[x] n.a. when no common name is available
* not recorded on species level
** not recorded on family level
xx not observed on sticky cards
\+ + not used in analyses, numbers recorded too low
++ ++ not used in analyses, data recorded at one grove only

Sampling for arthropods

In the pilot study, 2 sites comprised of 5 observation trees each and which were at least 10 rows apart, were observed in each grove. At each site, one sticky card (6x6 inch) was hung underneath the canopy in each of 3 of the 5 observation trees. For each observation, the number of immature and adult avocado thrips (AT) and any natural enemies (ME; for a list of species observed and the abbreviated names used in paper, see Table 1) were counted on 10 flushing leaves. The sticky cards were changed with each observation and used cards were taken to the laboratory where the numbers of natural enemies per card were counted.

In the 2003 survey, the only changes in observation method were additional beat sample observations. For each quadrant in each of the 5 observation trees, a beat sample was obtained by hitting one branch three times on a blue tray (12x16 inches). Any natural enemies present on the tray were recorded.

Orchard ground cover

In 2003, the orchard floor was visually inspected and estimates for percentage ground cover were recorded. Three observations were taken: (1) percentage of "all ground cover" consisting of all organic material (living, dying, dead and mowed plants, dead leaves and branches), (2) percentage of "living ground cover" consisting of all green plants present including those flowering and (3) percentage of "flowering ground cover" consisting of flowering plants only.

The subsets of observation (2) and (3) were taken for assessment of the reported influence of alternative food and host sources on NE populations. The "all ground cover" observation was included to verify the overall effect of cover over a bare orchard floor. For each site, all plant species present were listed at least once during the observations. In the future more detailed speciation of weeds will be undertaken. No data on ground cover were collected in the pilot study.

Management information

Information on cultural, biological and/or chemical management activities were obtained from the growers. In the pilot study in 2002, no chemical control for avocado thrips was used in any of the 3 groves. In the 2003 survey, of the 14 groves observed, two coastal and three inland groves were treated once with the neurotoxic insecticide/miticide abamectin (Agri-Mek 0.15 EC, Syngenta Crop Protection, Greensboro, NC) and NR oil for avocado thrips control.

Data presentation and statistical analyses

For the 2002 pilot study, the observations lack sufficient replication to justify statistical analyses and the counts are presented as graphs for illustrative purposes. For the 2003 survey, statistical analyses were only performed on beat sample data and sticky trap data for those species for which more than 16 individual insects were recorded. The total numbers for each insect species recorded are listed in the tables for each analysis.

For lack of annual replication, temporal analyses of 2003 data have not yet been undertaken and are not presented in this paper.

Effect of chemical treatment

All 14 groves (5 treated and 9 untreated) were used to analyze the effect of chemical treatment using analyses of variance (ANOVA with Fisher's Least Significant Difference multiple range tests LSD<0.05, Statgraphics© plus 5.1, 2001) on the mean number of

AT and/or NE recorded per method on both sites within each grove. Statistical trends and significant differences are italicized in the tables. For leaf counts the mean number recorded on 100 leaves (10 leaves on each of 10 trees) was used for analyses and expressed in tables as mean per leaf for all observation dates pooled. Similarly, for beat samples the mean number of NE per 40 beats (4 beats for each of 10 trees) was used and expressed in tables as mean per grove (40 beats or 10 trees), and for sticky cards the mean number per 6 cards was used in analyses and expressed in tables as mean per grove.

Effect of distance from the coast

The effect of distance from the coast on numbers of AT and NE recorded was analyzed with ANOVA (LSD<0.05) using data collected at the 9 untreated groves only (to avoid any treatment effects of the abamectin applications). The total number of observations per distance group is listed in each table. The mean numbers recorded from leaf counts, beat sampling and sticky cards per observation were calculated for both sites in each of the 9 groves as described above for the analyses of treatment effect.

Effect of ground cover

The effect of percentage orchard floor ground cover on numbers of NE recorded was analyzed with ANOVA (with LSD<0.05) using untreated groves only. The mean numbers recorded per site were used for those dates when estimates for ground cover were available and beat samples and/or sticky card data were collected. Site data was preferred over grove data, because orchard floor ground coverage at the two sites within a grove was not always similar. The estimated percentages were grouped into three categories for the analyses. For percentage "all ground cover" and percentage "living ground cover" the three categories were 0-10%, 11-70% and 71-100%. For percentage "flowering ground cover"; 0% or no flowering cover, 1-10% flowering cover and 11-100% flowering cover were used as categories. For each of the three categories within each of the three observations recorded on ground cover (all ground cover; living ground cover and flowering ground cover) beat sample data were recorded per site as number of NE per 20 beats (4 beats for each of 5 trees) averaged for all observation dates pooled and sticky cards data were recorded as the number of NE per 3 cards averaged for all observation dates pooled.

Results and Discussion

2002 pilot study

At both the intermediate and one of the coastal groves (coastal 1), the sticky card data in the pilot study found the activity of *C. menes* out of the selection of NE observed, most closely in synchrony with the population dynamics of AT (Figure 1). Other NE species at these two locations were present in higher numbers only in the spring. At the second coastal grove (coastal 2), which was used in the past for release studies of *F. orizabensis* (see Oevering *et al.,* 2002 and Hoddle *et al.,* submitted), the numbers of *C.*

menes were extremely high (note Fig. 1 is scaled down and shows # per 6 cards/100 for *C. menes)* in summer, although no synchrony with AT was observed. *F. orizabensis* numbers increased only after *C. menes* numbers had dropped. This may be indicative of an intraguild relationship, where the generalist thrips parasitoid *C. menes* may have affected the population development and establishment of *F. orizabensis.* These observations, amongst other considerations, prompted the 2003 survey.

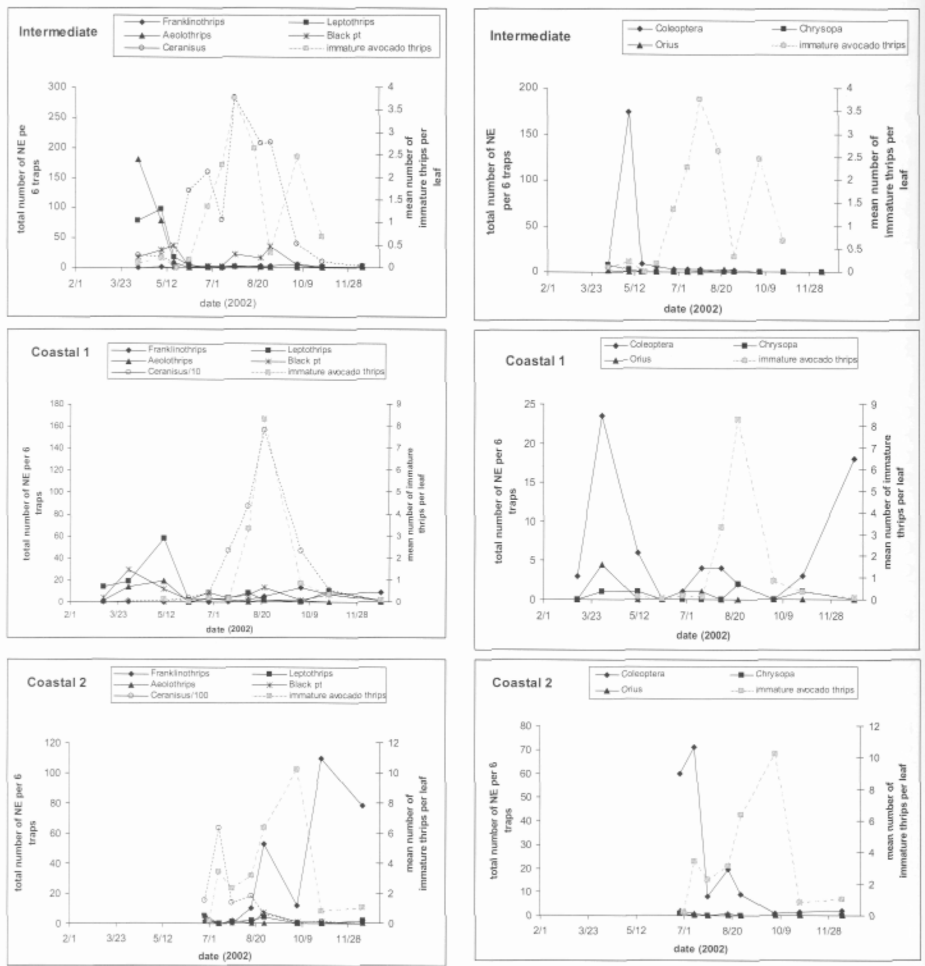

Figure 1 Mean number of immature thrips per leaf, and natural enemies per 6 cards as recorded in one grove at an intermediate distance from the coast and two coastal groves (see Table 1 for full names of natural enemies; to better fit the graphs, numbers of Ceranisus per 6 cards were divided by 10 and 100 for the coastal grove 1 and 2 respectively; coastal grove 2 has been used until 6/20/2002 for Franklinothrips release studies [see Oevering *et al*., 2002 and Hoddle *et al*., submitted]).

Effect of chemical treatments

The use of abamectin for AT control significantly reduced the number of Anestidae, and indicated a trend towards lower *L. mali* numbers in treated groves as recorded in beat samples (Table 2). In beat samples, *Chrysopa* sp. showed a trend towards higher numbers in treated groves and on sticky cards this effect was significant (Table 2). Although all other mean numbers of NE species were higher in untreated groves, none of these differences were statistically significant (Table 3).

Table 2. Mean number of natural enemies ± se recorded in beat samples at 5 groves with and 9 groves without chemical control actions expressed as mean number per grove per observation in 2003

Natural Enemy* species	ANOVA F	P	Mean number per grove (40 beats per date) ± se[+] Chemical control (5 groves)	No control (9 groves)	Total # recorded
F. orizabensis	0.17	0.6782	0.37 ± 0.143	0.44 ± 0.093	65
L. mali	*3.4*	*0.0617*	*0.89 ± 0.583x*	*2.17 ± 0.379 y*	*278*
A. fasciatus					14
L. mcconnelli	0.01	0.9329	0.17 ± 0.087	0.17 ± 0.057	26
Coleoptera	0.00	0.9706	1.52 ± 0.444	1.54 ± 0.29	238
Chrysopa	*3.11*	*0.0797*	*1.65 ± 0.31 y*	*1.0 ± 0.201x*	*185*
Orius	1.97	0.1624	0.17 ± 0.17	0.46 ± 0.111	58
C. menes	0.42	0.5169	0.33 ± 0.113	0.24 ± 0.073	41
Parasitoids	1.25	0.2644	1.74 ± 0.423	1.17 ± 0.275	208
Anestidae	*8.89*	*0.0033*	*0.37 ± 0.544a*	*2.30 ± 0.353b*	*268*
Aranae	0.64	0.4244	2.74 ± 0.399	2.36 ± 0.259	383

* see Table 1 for a list of abbreviations used
[+] no letters indicates mean values are not statistically different
different letters (a and b) on the same row indicate significant differences between groves with chemical control and no control (ANOVA *P*< 0.05 and LSD<0.05, with a<b),
different letters (x and y) on the same row indicate a trend difference between groves with chemical control and no control (ANOVA *P*<0.01, with x<y)

Table 3. Mean number of natural enemies ± se recorded on sticky cards at 5 groves with and 9 groves without chemical control actions expressed as mean number per grove per observation in 2003

Natural Enemy* species	ANOVA F	P	Mean number per grove (6 cards per date) ± se[+] Chemical control (5 groves)	No control (9 groves)	Total # recorded
F. orizabensis	0.10	0.7530	15.96 ± 5.513	13.82 ± 3.951	2498
L. mali	1.73	0.1917	0.91 ± 0.325	1.44 ± 0.237	130
A. fasciatus	2.42	0.123	19.73 ± 8.485	35.97 ± 6.088	3137
L. mcconnelli	1.25	0.2653	2.26 ± 0.859	3.44 ± 0.616	313
Coleoptera	1.02	0.3143	17.83 ± 6.843	26.35 ± 4.909	2416
Chrysopa	*4.45*	*0.0373*	*4.11 ± 0.724b*	*2.35 ± 0.519a*	*269*
Orius	2.63	0.108	1.79 ± 1.791	5.35 ± 1.285	426
C. menes	0.63	0.4290	9.94 ± 5.204	15.03 ± 3.734	1370
Aranae	1.54	0.2169	0.057 ± 0.135	0.26 ± 0.097	20

* see Table 1 for a list of abbreviations used
[+] no letters indicates mean values are not statistically different
different letters (a and b) on the same row indicate significant differences between groves with chemical control and no control (ANOVA *P*< 0.05 and LSD<0.05 with a<b)

Table 4. Mean number of immature and adult *Scirtothrips perseae* and natural enemies ± se recorded in leaf counts at 5 groves with and 9 groves without chemical control actions, expressed as mean number per leaf per observation in 2003

Arthropod species and life stage	ANOVA F	P	Mean number per grove (6 cards per date) ± se[+] Chemical control (5 groves)	No control (9 groves)	Total # recorded
Avocado thrips (*Scirtothrips perseae*)					
First instar	0.67	0.4144	1.50 ± 0.298	1.21± 0.188	19,960
Second instar	*2.77*	*0.0984*	*0.39 ± 0.073 y*	*0.25 ± 0.046 x*	*4,471*
Immature	1.03	0.3108	1.9 ± 0.359	1.46 ± 0.227	24,431
Adult	*2.92*	*0.0898*	*0.45 ± 0.071 y*	*0.31 ± 0.045 x*	*5,302*
*Natural enemies**	*28.78*	*<0.001*	*0.07 ± 0.001 b*	*0.023 ± 0.0043 a*	*542*

* all species listed in Table 1 combined
[+] no letters indicates mean values are not statistically different
different letters (a and b) on the same row indicate significant differences between groves with chemical control and no control (ANOVA *P*< 0.05 and LSD<0.05, with a<b),
different letters (x and y) on the same row indicate a trend difference between groves with chemical control and no control (ANOVA *P*<0.01, with x<y)

When considering AT observed per leaf, fewer specimens of all stages were found in untreated groves, although none of these differences were significant (Table 4). The number of all NE found in leaf counts was significantly higher in treated groves (Table

4).

Abamectin is a selective "soft" chemical that has a translaminar activity within the foliage and a short topical residual activity (Syngenta, 2001). One day after application it has minimal effects on parasitoids (Smith *et al.,* 1998; Brunner *et al.,* 2001), although the effect on predatory thrips may be more significant. *F. orizabensis,* and possibly other species, occasionally supplement their diet with plant liquids and those species may be affected by the translaminar presence of abamectin in the leaves (Hoddle, personal communication).

A treatment suppresses AT for 60 to 90 day periods (Oevering *et al.* 2002). Therefore, observations over an eight-month period (January-August) are unlikely to indicate a treatment effect that lasted 2-3 months, especially when AT populations before treatment often exceed those in untreated groves. When using data per observation pooled for the total observation period, these higher pre-treatment numbers may mask the treatment effect for a parameter that uses "mean number per observation date" obtained from pooled data. Abamectin is still under emergency Special Local Need (Section 18) registration for use in avocado groves and fits the needs for AT control perfectly. Since avocado fruit is only susceptible to AT scarring for a short period in their early development which takes place in early summer (Yee *et al.*, 2001 d) and since AT rarely cause economic damage to the leaves, proper timing of application will control the AT population during the susceptible period, while allowing AT, and subsequently NE, populations to be present at other times (Oevering *et al.,* 2002). High temperatures regulate AT populations in late summer, especially at inland locations (Hoddle, 2002).

Since NE associated with AT will vary with the availability of AT, the opportunistic *Chrysopa* sp. may not be solely related to AT populations, considering the observations of higher numbers in treated groves. However, small instar *Chrysopa* larvae have been observed feeding on thrips including avocado thrips, and the observed higher numbers in treated groves may indicate that the highly mobile *Chrysopa* adults are early arriving NE following treatment. Temporal analyses may elucidate this enigma, but for these analyses multiple year data are required and therefore not included in this paper.

Effect of distance from the coast

The spatial distribution of NE in Ventura County as observed using beat samples showed that at intermediate grove distance from the coast *F. orizabensis* was least abundant whilst all other species were equally abundant at all distances (Table 5). The total numbers recorded using beat samples indicated *L. mali* the most abundant predatory thrips species and the arachnids the most abundant NE (Table 5).

Using sticky cards, *F. orizabensis* were most often found in inland groves (Table 6). For *Chrysopa* the numbers recorded in inland groves were not different from coastal groves but higher than in intermediate groves. *Onus* sp. showed a trend similar to *Chrysopa* sp., while *C. menes* was more abundant on the coast than in inland groves. Of all the NE, the predatory thrips species *A. fasciatus* was most abundant on sticky cards, followed by *F. orizabensis* (Table 6).

The number of immature AT per leaf in coastal groves was significantly lower than in inland groves (Table 7). For adults a trend towards fewer numbers at intermediate groves was found. There were no differences in the total numbers of NE in leaf counts between coastal, intermediate and inland groves (Table 7).

Table 5. Mean number of natural enemies ± se recorded in beat samples in untreated groves at distances of 0-5, 5.1-15 and 15-24 miles from the coast expressed as mean number per grove per observation in 2003

Natural Enemy* species	ANOVA F	*P*	Mean number per grove (40 beats per date) ± se[+] 0-5 miles (n=11)	5.1-15 miles (n=59)	15.1-24 miles (n=39)	Total recorded
F. orizabensis	*4.88*	*0.0094*	*0.37 ± 0.289 ab*	*0.20 ± 0.125 a*	*0.82 ± 0.154 b*	*48*
L. mali	0.68	0.5091	1.27 ± 1.375	2.63 ± 0.594	1.74 ± 0.73	237
A. fasciatus						11
L. mcconnelli	1.15	0.3195	0.91 ± 0.181	0.10 ± 0.078	0.28 ± 0.091	18
Coleoptera	0.60	0.5517	2.73 ± 0.726	1.41 ± 0.314	1.54 ± 0.386	168
Chrysopa	1.3	0.2781	0.45 ± 0.463	0.93 ± 0.2	1.26 ± 0.246	109
Orius	0.74	0.48	0.09 ± 0.394	0.42 ± 0.17	0.62 ± 0.209	50
C. menes	2.04	0.1349	0.45 ± 0.225	0.32 ± 0.98	0.05 ± 0.12	26
Parasitoids	0.85	0.4306	1.82 ± 0.657	1.41 ± 0.28	0.82 ± 0.349	128
Anestidae	2.18	0.1182	2.73 ± 1.297	3.0 ± 0.56	1.15 ± 0.689	251
Aranae	1.44	0.2416	2.55 ± 0.639	2.63 ± 0.275	1.9 ± 0.339	257

* see Table 1 for a list of abbreviations used
[+] no letters indicates mean values are not statistically different
different letters (a and b) on the same row indicate significant differences between groves with chemical control and no control (ANOVA *P*< 0.05 and LSD<0.05, with a<b)

Table 6. Mean number of natural enemies ± se recorded on sticky cards in untreated groves at distances of 0-5, 5.1-15 and 15-24 miles from the coast expressed as mean number per grove per observation in 2003

Natural Enemy* species	ANOVA F	*P*	Mean number per grove (6 cards per date) ± se[+] 0-5 miles (n=7)	5.1-15 miles (n=36)	15.1-24 miles (n=25)	Total recorded
F. orizabensis	*11.28*	*0.0001*	*8.0 ± 7.586 a*	*4.46 ± 3.345 a*	*28.92 ± 4.015 b*	*1070*
L. mali	0.60	0.5544	0.57 ± 0.852	1.5 ± 0.375	1.6 ± 0.451	101
A. fasciatus	0.44	0.6481	32.15 ± 19.879	41.53 ±8.765	29.04 ± 10.519	2489
L. mcconnelli	1.42	0.2495	3.79 ± 1.786	4.24 ± 0.28	2.2 ± 0.936	296
Coleoptera	0.06	0.9455	2.71 ± 18.283	28.11 ± 8.062	24.82 ± 9.674	2023
Chrysopa	*8.22*	*0.0007*	*2.423 ± 1.086 ab*	*0.97 ± 0.479 a*	*4.0 ± 0.574 b*	*172*
Orius	*2.96*	*0.0586*	*1.21 ± 4.699 xy*	*2.83 ± 2.072 x*	*10.12 ± 2.486 y*	*371*
C. menes	*3.73*	*0.0292*	*35.5 ± 11.363 b*	*18.98 ± 5.011 ab*	*3.62 ± 6.013 a*	*1117*
Aranae	0.69	0.5039	0.0 ± 0.369	0.4 ± 0.162	0.16 ± 0.195	18

* see Table 1 for a list of abbreviations used
[+] no letters indicates mean values are not statistically different
different letters (a and b) on the same row indicate significant differences between groves with chemical control and no control (ANOVA *P*< 0.05 and LSD<0.05, with a<b),
different letters (x and y) on the same row indicate a trend difference between groves with chemical control and no control (ANOVA *P*<0.01, with x<y)

Table 7. Mean number of immature and adult *Scirtothrips perseae* and natural enemies ± se recorded in leaf counts in untreated groves at distances of 0-5, 5.1-15 and 15-24 miles from the coast expressed as mean number per grove per leaf per observation in 2003

Arthropod species and life stage	ANOVA F	*P*	Mean number per grove (6 cards per date) ± se[+] 0-5 miles (n=11)	5.1-15 miles (n=60)	15.1-24 miles (n=39)	Total recorded
Avocado thrips (*Scirtothrips perseae*)						
First instar	*4.61*	*0.0120*	*0.57 ± 0.553 a*	*0.87 ± 0.237 a*	*1.92 ± 0.294 b*	*13,400*
Second instar	*2.90*	*0.0596*	*0.09 ± 0.105 x*	*0.22 ± 0.045 xy*	*0.344 ± 0.056 y*	*2,700*
Immatures	*4.44*	*0.0141*	*0.66 ± 0.645 a*	*1.09 ± 0.276 a*	*2.26 ± 0.242 b*	*16,100*
Adults	*2.93*	*0.0577*	*0.29 ± 0.102 xy*	*0.24 ± 0.044 x*	*0.41 ± 0.054 y*	*3,300*
Natural enemies*	0.20	0.8203	0.017 ± 0.009	0.023 ± 0.004	0.023 ± 0.005	253

* all species listed in Table 1 combined
[+] no letters indicates mean values are not statistically different
different letters (a and b) on the same row indicate significant differences between groves with chemical control and no control (ANOVA *P*< 0.05 and LSD<0.05, with a<b),
different letters (x and y) on the same row indicate a trend difference between groves with chemical control and no control (ANOVA *P*<0.01, with x<y)

These data show that the method of observation is critical when assessing populations. Leaf observations sample only a small part of the tree. Beat samples sample NE present on a larger amount of foliage at the moment of sampling, but (as with leaf observations) the moment of observation may affect the NE diversity recorded, since some NE species are active at limited times during a 24hr period. Sticky cards on the other hand, record mostly flying NE over a longer period of time, which results in higher numbers. Although sticky cards were positioned underneath the tree canopy to limit the trapped species to those present within the tree, they only trap those insects that are dispersing through the canopy, which could lead to trapping an under representation of non-dispersing and/or aptere (wingless) species or life stages that are foraging or stationary.

In the 2003 survey, sticky cards provided more insightful data, because statistical differences were found that were not noticed using beat samples. However, some species would not have been recorded without beat sample data; *L. mali,* the most abundant species in beat samples, were present in very low numbers on sticky cards. The yellow color of the sticky cards was selected for easy of handing. White sticky cards have been reported more attractive to *F. orizabensis* (Hoddle *et al,* 2002), and although no data is available on attractiveness for *L. mali,* the color may have affected the number of *L. mali* on the yellow traps.

The effect of grove distance from the coast shows that there is a significant difference in AT and NE populations between coastal and inland groves, with the intermediate groves providing intermediate results. Coastal groves had fewer immature AT (Table 7) and higher *C. menes* numbers (Table 6) whilst higher immature and adult AT numbers at inland groves were accompanied by higher numbers of *F. orizabensis.* It is interesting that higher numbers of *C. menes* were trapped in the 2002 pilot study (Figure 1) than in the 2003 survey. The effect of *A. fasciatus* and *L. mali* presence in avocado groves needs further investigation, since these species topped the list of total numbers of predatory thrips observed by the two survey methods and neither is affected by the grove distance from the coast. The continuation of this study for a number of years will allow for further in-depth understanding of these insect population trends.

Effect of ground cover

Of all NE recorded in beat samples, the presence of groundcover affected only the number of parasitoids and spiders recorded. Significantly higher numbers were found when the orchard floor was more than 71% covered (Table 8).

On sticky cards, significantly higher numbers of *Leptothrips mcconnelli* (Crawford) were found in groves with more than 71 % cover and a similar trend was observed for predaceous Coleóptera (Table 9). *F. orizabensis* were found at highest numbers when undergrowth covered between 11 and 70% of the orchard floor, while *C. menes* was most abundant where no more than 10% of the orchard floor was covered (Table 9).

When only the living ground cover is considered, parasitoids were the only NE in beat samples that were significantly affected, with increased numbers when living ground cover exceeded 71 % (Table 10). On sticky cards, *A. fasciatus* were more abundant when living ground cover exceeded 71 % of the orchard floor, while *C. menes* was more abundant where living ground cover did not exceed 71 % (Table 11).

Table 8. Mean number of natural enemies ± se recorded in beat samples at untreated groves with 0-10, 11-70 and 71-100 % ground cover expressed as mean number per grove per observation in 2003

Natural Enemy* species	ANOVA F	ANOVA *P*	Mean number per grove (20 beats per date) ± se[+] 0-10% cover (n=45)	11-70% cover (n=37)	71-100% cover (n= 35)	Total recorded
F. orizabensis	1.99	0.1412	0.059 ± 0.085	0.29 ± 0.081	0.15 ± 0.067	21
L. mali	0.85	0.4285	1.21 ± 0.37	0.58 ± 0.348	1.03 ± 0.292	119
A. fasciatus						7
L. mcconnelli						15
Coleoptera	0.05	0.9513	0.65 ± 0.249	0.74 ± 0.236	0.74 ± 0.198	90
Chrysopa	1.42	0.2468	0.71 ± 0.147	0.53 ± 0.14	0.39 ± 0.117	65
Orius	1.32	0.2697	0.32 ± 0.171	0.026 ± 0.162	0.35 ± 0.135	31
C. menes	0.44	0.6438	0.18 ± 0.086	0.08 ± 0.08	0.17 ± 0.069	18
Parasitoids	*3.95*	*0.0218*	*0.35 ± 0.252 a*	*0.42 ± 0.238 a*	*1.13 ± 0.2 b*	*89*
Anestidae	0.56	0.5706	1.29 ± 0.383	0.76 ± 0.362	1.15 ± 0.303	135
Aranae	*3.29*	*0.0407*	*1.24 ± 0.2 b*	*0.61 ± 0.189 a*	*1.15 ± 0.159 b*	*127*

* see Table 1 for a list of abbreviations used
[+] *no letters indicates mean values are not statistically different*
different letters (x and y) on the same row indicate a trend difference between groves with chemical control and no control (ANOVA *P*<0.01, with x<y)
different letters (a and b) on the same row indicate significant differences between groves with chemical control and no control (ANOVA *P*< 0.05 and LSD<0.05, with a<b)

Table 9 Mean number of natural enemies ± se recorded on sticky cards at untreated groves with 0-10, 11-70 and 71-100% ground cover expressed as mean number per grove per observation in 2003

Natural Enemy* species	ANOVA F	ANOVA *P*	Mean number per grove (3 cards per date) ± se[+] 0-10% cover (n=45)	11-70% cover (n=37)	71-100% cover (n= 35)	Total recorded
F. orizabensis	*2.62*	*0.0766*	*3.76 ± 2.330 x*	*10.59 ± 2.176 y*	*5.44 ± 1.832 xy*	*840*
L. mali	0.24	0.7865	0.85 ± 0.231	0.69 ± 0.215	0.65 ± 0.181	92
A. fasciatus	0.57	0.5680	17.65 ± 4.862	12.59 ± 4.593	18.727 ± 3.823	2121
L. mcconnelli	*4.64*	*0.0114*	*1.24 ± 0.532 a*	*0.72 ± 0.497 a*	*2.62 ± 0.418 b*	*215*
Coleoptera	*2.55*	*0.0821*	*3.41 ± 5.246 x*	*14.33 ± 4.9 xy*	*18.36 ± 4.125 y*	*1685*
Chrysopa	1.61	0.2040	1.26 ± 0.363	1.513 ± 0.339	0.745 ± 0.286	143
Orius	0.65	0.5214	397 ± 1.366	2.1 ± 1.275	2.18 ± 1.073	337
C. menes	*4.70*	*0.0108*	*14.53 ± 2.812 b*	*3.28 ± 2.656 a*	*5.82 ± 2.211 a*	*942*
Aranae	1.68	0.0811	0.24 ± 0.123	0.24 ± 0.116	0.0 ± 0.097	17

* see Table 1 for a list of abbreviations used
[+] no letters indicates mean values are not statistically different
different letters (x and y) on the same row indicate a trend difference between groves with chemical control and no control (ANOVA *P*<0.01, with x<y)
different letters (a and b) on the same row indicate significant differences between groves with chemical control and no control (ANOVA *P*< 0.05 and LSD<0.05, with a<b)

Table 10. Mean number of natural enemies ± se recorded in beat samples at untreated groves with 0-10, 11-70 and 71-100% living ground cover expressed as mean number per grove per observation in 2003

Natural Enemy* species	ANOVA F	ANOVA *P*	Mean number per grove (3 cards per date) ± se[+] 0-10% alive (n=45)	11-70% alive (n=37)	71-100% alive (n= 35)	Total recorded
F. orizabensis	0.94	0.3928	0.1 ± 0.0713	0.25 ± 0.084	0.18 ± 0.081	21
L. mali	1.66	0.6890	0.96 ± 0.306	0.72 ± 0.360	1.15 ± 0.346	119
A. fasciatus						7
L. mcconnelli						15
Coleoptera	0.64	0.5308	0.72 ± 0.205	0.92 ± 0.242	0.54 ± 0.232	90
Chrysopa	0.41	0.6630	0.54 ± 0.123	0.58 ± 0.145	0.41 ± 0.139	64
Orius	1.56	0.2137	0.26 ± 0.142	0.028 ± 0.167	0.44 ± 0.16	31
C. menes	0.55	0.5802	0.14 ± 0.071	0.083 ± 0.084	0.21 ± 0.081	18
Parasitoids	*8.41*	*0.0004*	*0.34 ± 0.201 a*	*0.39 ± 0.237 a*	*1.48 ± 0.228 b*	*89*
Anestidae	0.11	0.8998	1.1 ± 0.318	0.94 ± 0.375	1.18 ± 0.36	135
Aranae	1.92	0.1516	1.18 ± 0.167	2.31 ± 0.727	1.10 ± 0.189	127

* see Table 1 for a list of abbreviations used
[+] no letters indicates mean values are not statistically different
different letters (a and b) on the same row indicate significant differences between groves with chemical control and no control (ANOVA *P*< 0.05 and LSD<0.05, with a<b)

Table 11. Mean number of natural enemies ± se recorded on sticky cards at untreated groves with 0-10, 11-70 and 71-100% living ground cover expressed as mean number per grove per observation in 2003

Natural Enemy* species	ANOVA F	P	Mean number per grove (20 beats per date) ± se⁺ 0-10% alive (n=45)	11-70% alive (n=37)	71-100% alive (n= 35)	Total recorded
F. orizabensis	2.19	0.1166	5.94 ± 1.934	16.35 ± 2.248	3.98 ± 2.163	839
L. mali	0.01	0.9899	0.74 ± 0.191	0.73 ± 0.222	0.7 ± 0.213	92
A. fasciatus	*2.58*	*0.0802*	*13.56 ± 3.962 x*	*11.78 ± 4.605 x*	*27.85 ± 4.429 y*	*2108*
L. mcconnelli	2.02	0.1366	1.66 ± 0.449	0.92 ± 0.522	2.38 ± 0.502	212
Coleoptera	1.55	0.2164	7.38 ± 4.377	18.59 ± 5.088	15.43 ± 4.893	1674
Chrysopa	1.81	0.1628	1.16 ± 0.301	1.57 ± 0.349	0.65 ± 0.336	142
Orius	0.46	0.6307	3.44 ± 1.132	1.81 ± 1.316	2.43 ± 1.266	336
C. menes	*4.57*	*0.0121*	*11.74 ± 2.328 b*	*8.22 ± 2.71 ab*	*1.25 ± 2.603 a*	*941*
Aranae	1.59	0.2085	0.27 ± 0.104	0.11 ± 0.11	0.0 ± 0.114	17

* see Table 1 for a list of abbreviations used
⁺ no letters indicates mean values are not statistically different
different letters (x and y) on the same row indicate a trend difference between groves with chemical control and no control (ANOVA $P<0.01$, with x<y)
different letters (a and b) on the same row indicate significant differences between groves with chemical control and no control (ANOVA $P< 0.05$ and LSD<0.05, with a<b)

The presence of flowers, expressed as a percentage of orchard floor cover, had no significant effect on NE observed with beat samples. Although not significant, for *L. mali* and *Onus* sp. a trend was observed where the most insects were found in orchards where between 1-10% flowering plants were present on the orchard floor, compared to the other two groups of 0 % and > 11 %.

The presence of flowers, as observed using sticky cards, affected only *F. orizabensis* for which a trend was found where the lowest numbers tended to be in groves with 1-10% flowering plants present and the highest numbers were found in groves without flowers, although levels were not different those in groves where flowers exceeded 11 % cover of the orchard floor (Table 13).

The increased abundance of parasitoids with undergrowth is likely indicative of aphid presence on plants in the ground cover, whether this undergrowth is living (Table 10) or mowed (Table 8). Although parasitoids other than *C. menes* were not identified, aphids were regularly seen on the undergrowth and it seems likely that the parasitoids are associated with the presence of aphids and the honeydew they produce. Additionally, the presence of carbohydrates and shelter may improve the habitat quality of orchards for parasitoids. A similar situation may be occurring with the Coleoptera (Table 9). The Coleoptera observed were for the most part Coccinellidae, which are opportunistic predators which often prefer aphids. In the coming seasons, the presence of herbivores on the undergrowth may need to be assessed to further develop this relationship.

Since a similar relationship between abundance of *L. mcconnelli* and ground cover was found, the prey species for this completely black colored predatory thrips needs to be identified. Foreign exploration studies found *L. mcconnelli* in avocado groves in Oaxaca, Mexico, but not at other locations in Mexico, Costa Rica or Guatamala (Hoddle *et al.,* 2002) and information on this species is scarce.

The increased presence of spiders in trees with presence of undergrowth may also relate to higher abundance of prey and the presence of ground cover may facilitate their migration through the orchard habitat (Table 8). It is very likely that the parasitoids, Coccinellidae, *L. mcconnelli* and spiders are not primarily associated with avocado thrips as they are not known as exclusive thrips predators, although they may accept avocado thrips as occasional prey. Their presence in the background NE population may add to the effect of more specialist species.

None of the identified predatory thrips species were significantly affected by the presence of flowers in the ground cover (Table 12 and 13), but the presence of some living ground cover seems favorable for *F. orizabensis* (Table 9). Larger orchard floor coverage with living plants increased *A. fasciatus* numbers (Table 11) and combined with the trends observed for *L. mali* (Table 11) these results determine an interesting dynamic where the different predatory thrips species are differentially abundant depending upon the environment. Their presence will also vary during the year, for which temporal analyses will be undertaken once additional seasons have been observed.

Table 12. Mean number of natural enemies ± se recorded in beat samples at untreated groves with 0, 1-10 and 11-100% flowering ground cover expressed as mean number per grove per observation in 2003

Natural Enemy* species	ANOVA F	ANOVA P	Mean number per grove (20 beats per date) ± se⁺ No flowers (n=45)	1-10% flowers (n=37)	>11% flowers (n= 35)	Total recorded
F. orizabensis	1.89	0.1551	0.09 ± 0.072	0.11 ± 0.079	0.29 ± 0.081	18
L. mali	*2.61*	*0.0782*	*0.91 ± 0.325 xy*	*1.59 ± 0.359 y*	*0.43 ± 0.369 x*	*115*
A. fasciatus						7
L. mcconnelli						15
Coleoptera	0.75	0.4726	0.91 ± 0.219	0.51 ± 0.242	0.69 ± 0.249	124
Chrysopa	0.03	0.9704	0.56 ± 0.133	0.51 ± 0.147	0.51 ± 0.151	62
Orius	*2.40*	*0.0949*	*0.16 ± 0.153 xy*	*0.57 ± 0.168 y*	*0.09 ± 0.173 x*	*31*
C. menes	1.40	0.2420	0.09 ± 0.077	0.27 ± 0.085	0.11 ± 0.087	18
Parasitoids	2.35	0.1003	0. 36± 0.229	0.89 ± 0.252	1.06 ± 0.259	86
Anestidae	0.20	0.8227	1.11 ± 0.344	0.95 ± 0.379	1.29 ± 0.39	130
Aranae	0.46	0.6296	1.07 ± 0.181	1.19 ± 0.199	0.91 ± 0.205	124

* see Table 1 for a list of abbreviations used

⁺ no letters indicates mean values are not statistically different
different letters (x and y) on the same row indicate a trend difference between groves with chemical control and no control (ANOVA *P*<0.01, with x<y)

Table 13. Mean number of natural enemies ± se recorded on sticky cards at untreated groves with 0, 1-10 and 11-100% flowering ground cover expressed as mean number per grove per observation in 2003

Natural Enemy* species	ANOVA F	ANOVA P	Mean number per grove (3 cards per date) ± se⁺ No flowers (n=45)	1-10% flowers (n=38)	>11% flowers (n= 37)	Total recorded
F. orizabensis	*2.57*	*0.0808*	*9.53 ± 2.046 y*	*2.71 ± 2.018 x*	*6.65 ± 2.257 xy*	*777*
L. mali	0.63	0.5337	0.87 ± 0.205	0.55 ± 0.222	0.84 ± 0.226	91
A. fasciatus	0.24	0.7886	18.4 ± 4.358	14.16 ± 4.725	17.59 ± 4.806	2013
L. mcconnelli	0.52	0.5987	1.42 ± 0.492	1.74 ± 0.533	2.16 ± 0.54	208
Coleoptera	0.23	0.7962	11.02 ± 4.744	12.18 ± 5.162	15.68 ± 5.232	1538
Chrysopa	0.72	0.4886	1.27 ± 0.327	1.29 ± 0.356	0.76 ± 0.361	134
Orius	0.12	0.8903	2.16 ± 1.197	3.0 ± 1.303	2.43 ± 1.32	301
C. menes	0.5	0.6102	8.27 ± 2.597	9.37 ± 2.826	5.49 ± 2.864	931
Aranae	1.44	0.2422	0.14 ± 0.113	0.29 ± 0.12	0.0 ± 0.121	17

* see Table 1 for a list of abbreviations used

⁺ no letters indicates mean values are not statistically different
different letters (x and y) on the same row indicate a trend difference between groves with chemical control and no control (ANOVA *P*<0.01, with x<y)

The abundance of *C. menes* in the tree canopy was significantly affected by the presence of more than 70% living ground cover in groves, where numbers on sticky cards were lower. The group of observations in groves with more than 70% living ground cover resulted in lower numbers of all NE, compared to the less than 70% cover, with exception of *A. fasciatus.* This indicates that the presence of herbivore prey and hosts on large (>70%) surface areas of living undergrowth may direct NE away from the trees, while smaller (<70%) surface areas of living plants may help to build up and sustain populations of NE in the trees. Future temporal analyses will further clarify this relationship. The presence of Western Flower Thrips *(Frankliniella occidentalis* Pergande) (Thysanoptera: Thripidae), which is common in almost all flowers in Southern California, is not the only host responsible for the presence of *C. menes* populations in the orchards, since percentage flowering plants in the undergrowth did not affect the *C. menes* numbers in the trees (Table 13).

Conclusions

Most results of the 2003 survey are descriptive and need replication before any conclusions or generalizations can to be made. The natural enemy complex present in Ventura County avocado orchards consists of a number of species that prey on avocado thrips. Following spiders and Anestidae in beat samples and with Coleoptera on sticky cards, the predatory thrips species are the most abundant predators in the NE complex. The dominant predatory thrips species varies with distance from the coast and presence and composition of ground cover of the orchard floor. *C. menes* is a generalist thrips parasitoid frequently encountered in the natural enemy complex. The abundance of *C. menes* decreases with distance from the coast, and is affected by the presence of living plants but not by the presence of flowering plants in the ground cover of the orchard floor. The population dynamics of avocado thrips, and predators and parasitoids in the NE complex, and relationships between these species are not analyzed in this study. Data from future seasons will allow for temporal analyses which will be necessary to fully understand the natural enemy complex in avocado orchards.

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