Journal of Economic Entomology, XX(XX), 2020, 1–9
doi: 10.1093/jee/toaa283
Research

Sampling and Biostatistics

Evaluation of Sticky Traps for Monitoring *Scolothrips sexmaculatus* (Thysanoptera: Thripidae) and *Stethorus punctum* (Coleoptera: Coccinellidae) as Predators of Spider Mites in California Almonds

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Subject Editor: Dominic Reisig

Received 21 September 2020; Editorial decision 12 November 2020

Abstract

Changes in almond production practices have caused sixspotted thrips, *Scolothrips sexmaculatus* Pergande, and the coccinellid beetle, *Stethorus punctum* LeConte, to replace phytoseiid mites as the dominant predators of spider mites in California almonds. We conducted a series of field studies to evaluate nine commercially available adhesive traps for *S. sexmaculatus* and *S. punctum* and found that the yellow strip trap was the most effective, least expensive, and easy to use. At peak population levels, individual cards routinely caught >1,000 *S. sexmaculatus* and >100 *S. punctum* trap^{-1} week^{-1}. We documented that larger traps collected more *S. sexmaculatus*, and more *S. sexmaculatus* per square area, suggesting that the trap surface was attractive. We determined the number of traps needed to have 50, 70, and 90% confidence that the averages of trap captures were within 10, 30, and 50% of the population mean. Two yellow strip traps per orchard provided 90% confidence that trap captures were within 50% of the population mean if there were an average of 16.0 *S. sexmaculatus* trap^{-1} week^{-1} or 7.9 *S. punctum* trap^{-1} week^{-1}. Populations required to attain the same levels of confidence using four traps per orchard were 3.9 *S. sexmaculatus* and 2.9 *S. punctum* trap^{-1} week^{-1}. We conclude that use of the yellow strip trap to monitor for natural enemies, in combination with leaf samples for spider mites, has the potential to improve integrated pest management programs for spider mites, and assist future research to understand the biology and phenology of both predator species.

Keywords: sticky trap, monitoring, biological control, sixspotted thrips, spider mite destroyer

Natural enemies play a key role in spider mite management in California almonds (Strand 2002, Haviland et al. 2020). In the 1980s, the dominant predators were phytoseiids, such as Western predatory mite, *Galendromus occidentalis* Nesbitt, *Euseius hibisci* Chant, *Euseius tularensis* Congdon, and *Typhlodromus caudiglans* Schuster (McMurtry and Croft 1997, Hoy et al. 1979, Wilson et al. 1984, Strand 2002). Nearly absent from those publications are references to other predators of spider mites, such as sixspotted thrips, *Scolothrips sexmaculatus* Pergande, and spider mite destroyer beetles, *Stethorus* spp, Weise. Bailey (1939) observed that *S. sexmaculatus* was rarely found in large numbers, and that it was unlikely that spider mites were controlled or noticeably reduced by this predatory thrips.

During the 1990s and early 2000s, phytoseiids continued to be the dominant predator within almond orchards, with many producers making augmentative releases of *G. occidentalis* (Hoy et al. 1983, Headley et al. 1987). However, since the early 2000s, there has been a noticeable reduction in the prevalence of phytoseiids, even where they are being released (Grafton-Cardwell et al. 2020). From 2010 through 2018, this was confirmed in more than a dozen field trials in almond orchards where less than one phytoseiid was found per every 1,000 leaves, including orchards where broad-spectrum organophosphate and pyrethroid insecticides were not used (Grafton-Cardwell et al. 2020).

The disappearance of phytoseiids coincided with increased observations of other spider mite predators, particularly *Scolothrips sexmaculatus* and *Stethorus punctum* LeConte (Haviland, unpublished data). Current information on *S. sexmaculatus* is limited to laboratory studies showing that they feed on multiple species of spider mites, do not discriminate among life stages of prey, consume large numbers of prey, have thigmotactic immatures with a high searching capacity within webbing, and can be cannibalistic when prey are scarce, allowing them to survive when relatively few prey are present (Gilstrap and Oatman 1976, Gilstrap 1995). They have a high reproductive rate and can persist and increase in numbers at temperatures between 23.9 and 40.6°C (Gilstrap and Oatman 1976, Coville and Allen 1977) that are typical in the spring and summer where almonds are grown in California.

Laboratory data show that *Stethorus* sp. larvae and adults attack all stages of mites and under favorable conditions have the potential to consume prey faster than they can reproduce (Putman 1955, McMurtry 1970, Gordon and Chapin 1983, Roy 2003, Biddinger et al. 2009). Over a range of temperatures, ovipositing female *S. punctum* can consume an average of 40 spider mites per day while males can consume 20 spider mites per day, with both sexes tending to eat more mites under higher temperatures (Putman 1955). Reproductive females have the potential to consume an average of 75 mite eggs per day at 20°C (Roy 2003), while larvae can eat an average of 20.6 spider mites per day (Putman 1955). Additionally, there can be up to three generations per year (in Ontario, Canada); therefore, *S. punctum* can be present and preying on spider mites for a large portion of the growing season (Putman 1955).

We began efforts to evaluate the role of *S. sexmaculatus* and *S. punctum* as natural enemies of spider mites during the early 2010s, but had limited success due to a lack of an effective method for monitoring. Standard practice for research trials at the time was to collect leaves for mite and predator quantification in the laboratory under a stereomicroscope. However, we learned that adult *S. sexmaculatus* and *S. punctum* usually flew away before being counted, and thigmotactic immature stages of *S. sexmaculatus* routinely crawled off the leaves and disappeared into the corners of sample bags before they could be counted. This resulted in data showing close to zero *S. sexmaculatus* or *S. punctum* per leaf in 20-leaf laboratory samples from orchards where presence of each species could be observed while scanning large numbers of leaves in the field.

Sticky traps have been successfully used to monitor for various species of pestiferous thrips, such as *Frankliniella bispinosa* (Morgan) (Childers and Brecht 1996), *Frankliniella occidentalis* Pergande (Hoddle et al. 2002, Chen et al. 2004), *Scirtothrips perseae* Nakahara (Hoddle et al. 2002), *Scirtothrips citri* Moulton (Haviland et al. 2009), and *Scirtothrips dorsalis* Hood (Chu et al. 2006). Hoddle et al. (2002, 2004) showed that traps used for monitoring *Scirtothrips perseae* in avocados can also capture the predatory thrips *Franklinothrips orizabensis* Johansen (Thysanoptera: Acolothripididae). Sticky cards have previously been evaluated as a method for assessing populations of *Stethorus* sp (Haney et al. 1987, Felland et al. 1995, Roy et al. 2005).

In our study, we explored the use of commercially available sticky card traps as an improved method for monitoring *S. sexmaculatus* and *S. punctum*. This included comparisons of trap colors and sizes that led to the selection of a trap for commercial use by almond growers. The efficacy of the trap was compared to the industry standard practice of leaf sampling with an assessment made on the number of traps needed to attain various levels of confidence that average trap captures are reflective of the population mean.

Materials and Methods

Commercial Trap Evaluation—Original Sizes

Seven commercially available sticky cards were evaluated as traps for predators of spider mites in almonds (Table 1). Traps represented a range of sizes, colors, and adhesives that are used to monitor agricultural pests, such as thrips (Thysanoptera), whiteflies (Aleyrodidae), scales (Coccoidea), and leafminers (Agromizidae).

Traps were evaluated in four commercial almond orchards near McFarland, CA, USA in August 2016. Within each orchard, traps were randomly assigned to 1 of 28, 48 m × 13 m plots that were organized into a randomized complete block design (RCBD) with four blocks. Traps were hung within the inner tree canopy at a height of 2 m using a medium sized binder clip (Office Depot, USA) that was

Table 1. Commercially available sticky cards used as traps for spider mite predators in almonds

Trials[a]			Trap characteristics						
1	2	3	Name	Color	Dimensions (cm)	Adhesive surface[b] (cm²)	Ease of use[c]	Official trap name and manufacturer or supplier	Cost[d]
Y	Y	Y	Large Yellow Strip	Yellow	15.2 × 30.5	927	E	Olson sticky strips, yellow, 6 in × 12 in, Great Lakes IPM, Vestaburg, MI	$1.20
N	Y	Y	Small Yellow Strip	Yellow	7.6 × 12.7	193	E	Olson sticky strips, yellow, 3 in × 5 in, Great Lakes IPM, Vestaburg, MI	$0.35
N	Y	N	Blue Strip	Blue	7.6 × 12.7	193	E	Olson sticky strips, blue, 3 in × 5 in, Great Lakes IPM, Vestaburg, MI	$0.35
Y	Y	N	Large Yellow	Yellow	15.2 × 22.9	696	H	Yellow card - Folding, Alpha Scents, West Linn, OR	$2.21
Y	Y	N	Small Yellow	Yellow	10.2 × 15.2	310	E	Yellow card - Small 4 × 6 in, Alpha Scents, Inc. West Linn, OR	$1.00
Y	Y	N	Yellow Whitefly	Yellow	10.2 × 15.2	310	E	Sticky Aphid/Whitefly Trap, Yellow, Seabright Laboratories, Emeryville, CA	$0.85
Y	Y	N	Blue	Blue	10.2 × 15.2	310	E	Sticky Thrips/Leafminer Trap, Seabright Laboratories, Emeryville, CA	$0.95
Y	Y	N	Green	Green	7.6 × 12.7	193	H	Green sticky card, Alpha Scents, Inc., West Linn, OR	$1.31
Y	Y	N	White	White	8.9 × 15.2	271	E	Scale card, Alpha Scents, Inc., Linn, OR	$1.66

[a]Traps used (Y) or not used (N) to evaluate 1) traps in their original form, 2) traps after being cut to a standardized size, or 3) the same trap cut to different sizes.
[b]Includes adhesive surfaces on the front and back of all traps.
[c]Trap use was classified as easy (E) if the adhesive surface could be touched without causing your finger to get sticky, and hard (H) was assigned to cards where extra care was required to avoid getting sticky fingers.
[d]Price per trap for online purchase at www.greatlakesipm.com, www.alphascents.com, or www.seabrightlabs.com, as of 1 May 2020, not including tax or the cost of shipping. For traps with price ranges based on sales volume, trap prices were defined as the midpoint price of traps purchased individually or in large quantities.

attached to the tree limb using a short wire (unwound jumbo paper clip, Office Depot). After 1 wk, traps were removed and placed into clear sheet protectors (Office Depot) that had the bottom and opposite edges removed to allow for easy trap insertion. Traps were stored and evaluated using magnification to count the number of *S. sexmaculatus* and *S. punctum* on both sides of each trap. For traps with greater than 200 of a specific predator taxa, a random quadrants template was used to count a subsample of the trap surface and extrapolate total captures.

Commercial Trap Evaluation—Standardized Size

One challenge to evaluating capture rates on off-the-shelf commercially available sticky cards was that the surface area was not uniform. This had the potential to lead to confounding factors whereby it was not possible to determine if the number of trap captures were due to card characteristics such as color and adhesive surface, or due to size. For this reason, a second experiment was conducted to evaluate nine commercially available sticky cards, seven of which were the same cards used in the previous experiment, for their effectiveness as traps when cut to a standardized size of 12.7 cm × 7.6 cm (Table 1).

Traps were evaluated in two commercial almond orchards in Wasco and Lost Hills, CA, USA in late August and early September 2017. Trials within each orchard were organized as a RCBD with nine treatments and four replications using a plot size of eight trees by four trees (49 m × 27 m). Traps were hung within the tree canopy using binder and paper clips as previously described. After 7 d in Wasco and 14 d in Lost Hills the traps were recovered and evaluated as previously described.

Trap Size Evaluation

The effect of trap size on capture rates was evaluated using six sizes of yellow strip traps (Table 1). This included the large yellow strip trap at its original size of 15.2 cm × 30.5 cm, and the same trap cut down to 15.2 cm × 15.2 cm, 7.6 cm × 15.2 cm, 7.6 cm × 7.6 cm, and 3.8 cm × 7.6 cm. The small yellow strip trap was included at its original size of 7.6 cm × 12.7 cm. This resulted in surface areas, including both sides of the traps, of 927.2, 462.1, 231.0, 115.5, and 57.4 cm^2. Traps were evaluated in two commercial almond orchards in Lost Hills and Wasco, CA, USA. At each orchard, traps were organized in a RCBD with four blocks. Traps were hung in trees in August 2017 at the center of plots that were 23 m (Wasco) to 28 m (Lost Hills) long and 28 m wide. Traps were recovered after 7 d in Wasco and 14 d in Lost Hills and evaluated as previously described.

Comparisons of Leaf Sampling and Trapping

In order for traps to be an effective monitoring tool for predators of spider mites, captures need to be correlated to populations in the orchard. We evaluated these relationships for *S. sexmaculatus* and *S. punctum* by comparing captures on large yellow strip traps to the number recorded from leaves that were collected in the field and evaluated in the laboratory. Transects of large yellow strip traps were hung as previously described in three commercial almond orchards. This included four transects of 20 traps in Wasco, CA, USA from 19 April until 3 May 2016, one transect of 12 traps in Shafter, CA, USA from 12 July until 31 August 2017, and two transects of eight traps in Lost Hills, CA, USA from 12 July until 31 August 2017. Traps were spaced at a distance of 27 m and recovered weekly for evaluation as previously described. On the day they were recovered, 20 leaves were collected at random from within a 10 m radius of each trap, placed in a small paper bag, and returned to the laboratory. The total numbers of immature and adult *S. sexmaculatus* and *S. punctum* on each leaf were recorded and summed to determine the total number per 20 leaves at each trap location.

Number of Traps

The quantity of large yellow strip traps needed to have 50, 70, and 90% confidence that average trap captures were within ±50, ±30, and ±10% of the population mean were calculated. Each of the three confidence levels was chosen for different purposes. The 90% confidence level was selected for its acceptance within the scientific community as a value that is functionally equivalent to $\alpha = 0.1$. The value of 70% represented a level of confidence that might be associated with an optimum sampling size that balances accuracy with practicality. The 50% level of confidence is lower than traditionally reported in scientific literature. However, it would be adequate for pest control advisers that are determining if *S. sexmaculatus* density has changed since the previous sampling date, or are using trap captures to make treatment decisions for spider mites using thresholds based on natural enemy presence (Haviland et al. 2020). Calculations were made using data from the traps previously described for comparisons of leaf sampling and trapping.

Data Analysis

For all experiments, data were recorded as total number of *S. sexmaculatus* or *S. punctum* per trap. For two of the experiments (traps at original size and large yellow strip trap at different sizes), data were also converted to the number of captures per cm^2 of adhesive surface. For the first two experiments, captures per trap and per cm^2 were analyzed by analysis of variance as a RCBD repeated across locations with means separated by Fisher's protected least significant difference (LSD) ($P = 0.05$) after sqrt + 0.5 transformation of the means to homogenize variances (PROC GLM, SAS Institute Inc. 2015). For the third trial, regression analysis was used at each location to correlate adhesive trap area as the independent variable to the average capture rate for each size of trap as the dependent variable.

The effectiveness of sampling with traps compared to leaves was evaluated by correlating capture rates using regression analysis. Data points consisted of the mean *S. sexmaculatus* and *S. punctum* $trap^{-1}$ $week^{-1}$ as the independent variable, and per 20 leaves as the dependent variable from each transect each week.

Data from each transect each week for both predators were also used to calculate the number of traps or leaf samples needed to have 50, 70, or 90% confidence that the average capture rates were within margins of error of ±50, ±30, and ±10% of the overall mean. This was done using the formula $n = [(zc^*s)/E]^2$, where n equals the number of traps that are required at the standard deviation (s) so that average trap captures were within a desired margin of error (E) at a certain confidence interval (zc) (Karandinos 1976, Wilson and Room 1983).

Data for each of the nine models (three levels of confidence to be within three levels of deviation from the mean) were plotted as charts in MS Excel with the average weekly trap captures on the x-axis and number of traps required on the y-axis. Data were fitted to power regression curves ($n = \alpha x^{\beta}$) to describe the number of traps (n) required for any level of average captures (x). Subsequently, six values of x (1, 10, 50, 100, 500, and 1,000 $trap^{-1}$ $week^{-1}$ for *S. sexmaculatus* and 1, 5, 10, 25, 50, and 100 $trap^{-1}$ $week^{-1}$ for *S. punctum*) were inserted into the formula to determine the corresponding number of traps required. We also converted the regression curve formulas to $x = (n/\alpha)^{(1-\beta)}$ to determine the pest density required to attain values for each of the nine levels of confidence if two or four traps per orchard were used. A density of two traps corresponded to the number of stations per orchard that are typically monitored weekly for navel orangeworm, *Amyelois transitella* (Walker), and four represented the number of quadrants in an orchard typically monitored weekly for spider mites (Strand 2002, Haviland et al. 2020).

Results

Commercial Trap Evaluation—Original Sizes

Results from the off-the-shelf commercial trap evaluation are shown in Fig. 1. A total of 19,133 *S. sexmaculatus* and 1,764 *S. punctum* were counted. There were significant differences in the number of *S. sexmaculatus* per trap (Fig. 1a, $F = 145.64$; df = 6, 72; $P < 0.0001$) and *S. sexmaculatus* per cm^2 (Fig. 1b, $F = 54.12$; df = 6, 72; $P < 0.0001$). The yellow strip trap caught the greatest number of *S. sexmaculatus* (737 $trap^{-1}$) compared to <150 for all other traps (Fig. 1a). The yellow strip trap also caught the most *S. sexmaculatus* per cm^2 (0.80), which was statistically equivalent to the green trap (Fig. 1b). No particular color of trap appeared to be the best, with yellow traps representing some of the highest (yellow strip) and lowest (large yellow) capture rates.

There were significant differences in the number of *S. punctum* per trap (Fig. 1c, $F = 23.19$; df = 6, 72; $P < 0.0001$) and per cm^2 of adhesive surface (Fig. 1d, $F = 4.48$; df = 6, 72; $P = 0.0007$). The yellow strip trap caught the greatest number of *S. punctum* (54.6 per trap) compared to 15.2–17.3 for the small yellow, green, and yellow whitefly trap, with <6.3 for all other traps (Fig. 1c). The green trap caught the most *S. punctum* per cm^2 (8.1), which was statistically equivalent to the yellow strip, small yellow, and yellow whitefly traps (4.9–5.9) (Fig. 1d).

Commercial Trap Evaluation—Standardized Size

Trap captures from nine commercial sticky traps that were cut to the same size are shown in Fig. 2. A total of 8,474 *S. sexmaculatus* and 832 *S. punctum* were counted. There were significant differences in the number of *S. sexmaculatus* per trap at both locations (Fig. 2a and b, Wasco: $F = 15.84$; df = 8, 24; $P < 0.0001$; Lost Hills: $F = 9.34$; df = 8, 24; $P < 0.0001$). The highest captures in Wasco were on the large yellow strip and small yellow strip traps, which were statistically equivalent to the small yellow and green traps (Fig. 2a). At Lost Hills, the green, large yellow strip, small yellow, small yellow strip, and yellow whitefly traps all caught >27 *S. sexmaculatus* compared to <17 for the rest of the traps (Fig. 2b).

There were significant differences in *S. punctum* per trap at each location (Fig. 2c and d, Wasco: $F = 11.78$; df = 8, 24; $P < 0.0001$; Lost Hills: $F = 4.11$; df = 8, 24; $P = 0.0033$). The small yellow, yellow whitefly, large yellow strip, small yellow strip, and green traps all caught >23 *S. punctum* in Wasco compared to <14 for all other traps (Fig. 2c). In Lost Hills, where total captures were approximately 80% lower than Wasco, the green and small yellow traps caught 6.5 and 5.5 *S. punctum*, respectively, compared to <2 for all other traps (Fig. 2d).

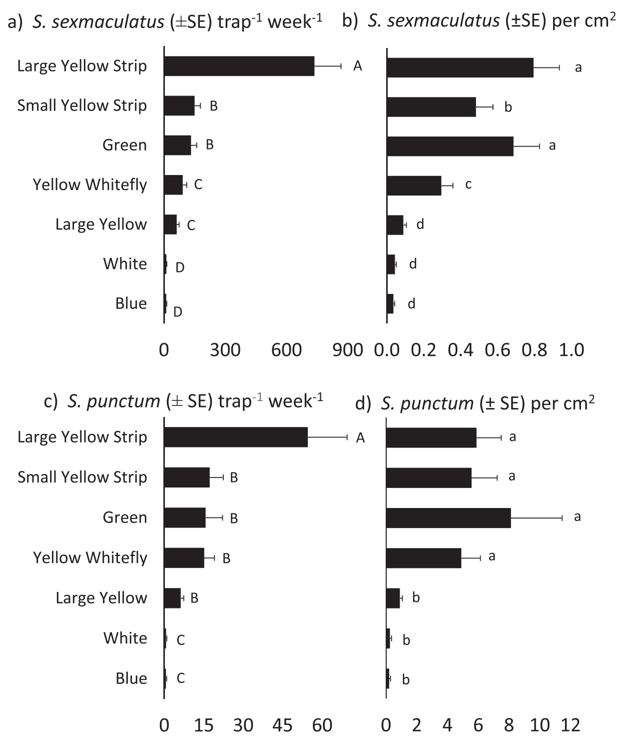

Fig. 1. Mean (±SE) captures on seven commercially available sticky traps reported as (a) adult *S. sexmaculatus* per trap, (b) adult *S. sexmaculatus* per square area of sticky surface, (c) adult *S. punctum* per trap, and (d) adult *S. punctum* per square area of sticky surface. Means followed by the same letter are not significantly different after analysis of variance with means separated by Fisher's Protected LSD ($P = 0.05$) after sqrt transformation of the data. Untransformed captures are reported.

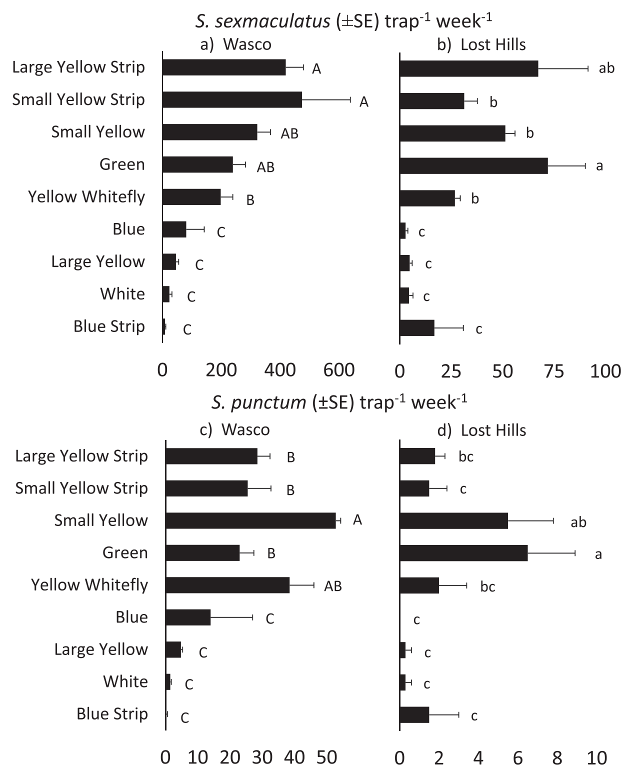

Fig. 2. Mean (±SE) captures of (a) *S. sexmaculatus* and (b) *S. punctum* on nine commercially available sticky traps that were cut to a uniform size of 12.7 × 7.6 cm and hung in almond orchards located in Wasco and Lost Hills, CA. Means followed by the same letter are not significantly different after analysis of variance with means separated by Fisher's Protected LSD ($P = 0.05$) after sqrt transformation of the data. Untransformed captures are reported.

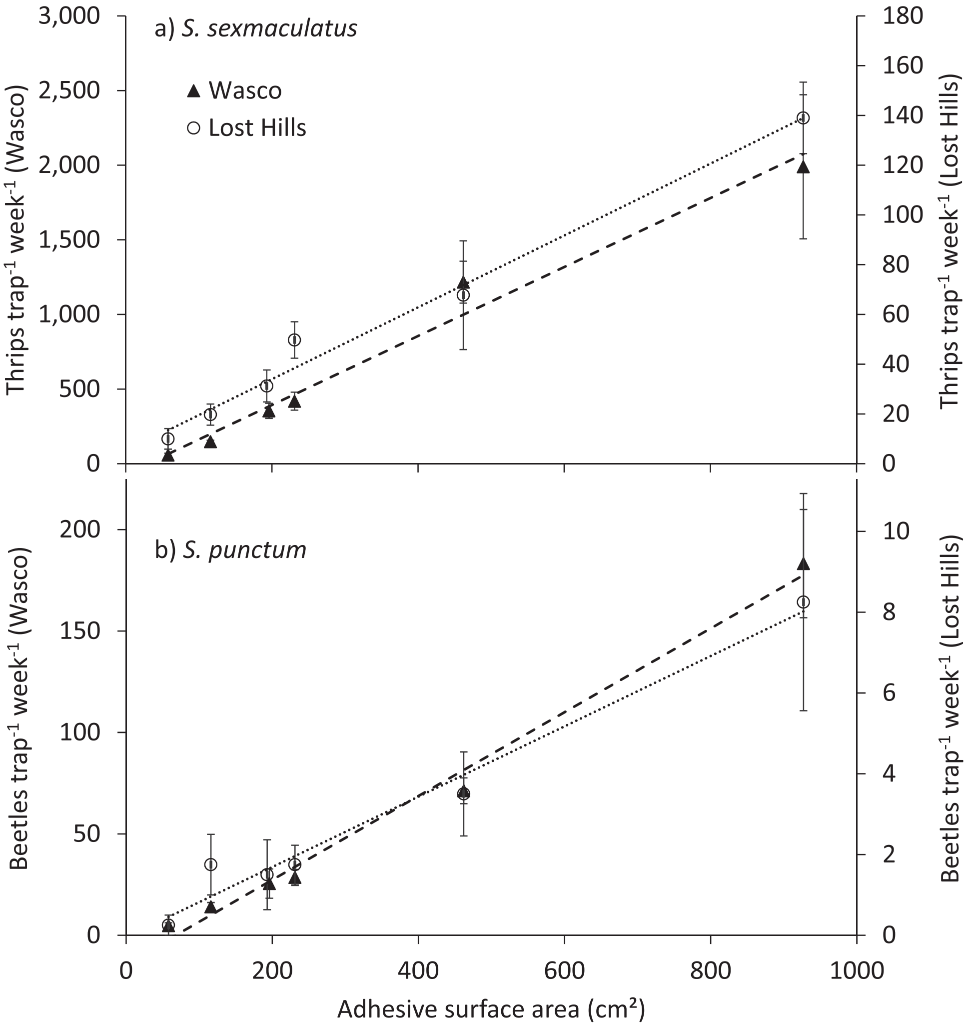

Fig. 3. Regression between adhesive surface area and trap captures of (a) *S. sexmaculatus* and (b) *S. punctum* in almond orchards in Wasco and Lost Hills, CA.

Trap Size

There was a positive linear relationship between trap size and captures of *S. sexmaculatus* (Fig. 3a) in Wasco (slope = 2.31; y-int = −67.87; R^2 = 0.98; F = 193.1; df = 1, 4; P = 0.0002) and Lost Hills (slope = 0.14; y-int = 5.08; R^2 = 0.98; F = 262.5; df = 1, 4; P < 0.0001). Likewise, positive linear relationships were seen between trap size and captures of *S. punctum* (Fig. 3b) at both locations (Wasco: slope = 0.2066; y-int = −13.99; R^2 = 0.99; F = 378.9; df = 1, 4; P < 0.0001); Lost Hills: slope = 0.0087; y-int = −0.050; R^2 = 0.98; F = 155.1; df = 1, 4; P = 0.0002).

Larger traps at Wasco had >2-fold increases in capture rates per cm² than smaller traps for *S. sexmaculatus* (Fig. 4a, F = 4.54; df = 5, 18; P = 0.0075) and for *S. punctum* (Fig. 4b, F = 2.90; df = 5, 18; P = 0.0432). Therefore, larger traps not only caught more *S. sexmaculatus* and *S. punctum*, but also caught more per square area of adhesive surface. There were no significant differences in trap captures per cm² at Lost Hills (P > 0.52), where capture rates were more than 10-fold lower than in Wasco.

Sticky Card Traps Versus Leaf Samples

There was a positive linear relationship between the average number of *S. sexmaculatus* on traps and collected from leaves (Fig. 5, n = 32, slope = 0.0067; y-int forced to zero; R^2 = 0.8818; F = 301.4; df = 30; P < 0.0001). Data suggest that the yellow strip trap was a more effective sampling tool, especially when capture levels were low. Out of the 32 data points, captures ranged between 0.1 and 28.5 *S. sexmaculatus* trap^{-1} a total of 16 times (Fig. 5). Of these, *S. sexmaculatus* were not detected in leaf samples 93.8% of the time. According to the regression line (Fig. 5), when *S. sexmaculatus* density in the orchard resulted in a minimum detection threshold of 1 *S. sexmaculatus* per 20 leaves, corresponding yellow strip traps collected 149.3 *S. sexmaculatus* trap^{-1} week^{-1}.

Relationships between the average number of *S. punctum* per trap and per 20 leaves could not be determined due to the relative ineffectiveness of leaf sampling. Out of 32 potential data points, *S. punctum* were captured on cards 22 times with mean, minimum, and maximum values of 23.9, 0.1, and 137.9 trap^{-1} week^{-1}, respectively. In only 2 of the 30 transects were *S. punctum* found in leaf samples. In transects with the highest *S. punctum* density on cards (36.9, 41.5, 70.1, 82.3, and 137.9 trap^{-1} week^{-1}), the average number of *S. punctum* per 20 leaves were 0, 0, 0, 0.25, and 0, respectively.

Number of Traps

The number of traps needed to monitor for *S. sexmaculatus* depended on the three predefined levels of confidence that the average captures fell within three margins of error of the population mean (Table 2). For a desired margin of error of 50%, three traps were sufficient to provide 50, 70, and 90% confidence in the average, as long

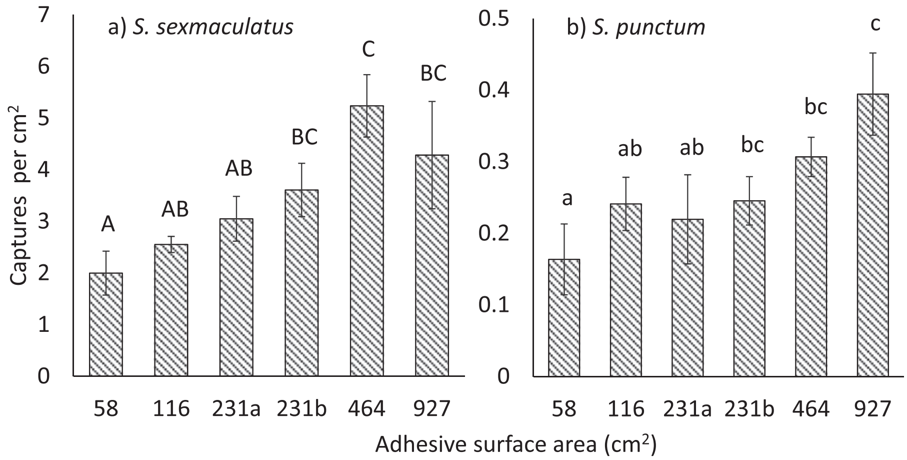

Fig. 4. Relationship between trap size and captures of (a) *S. sexmaculatus* and (b) *S. punctum* per cm^2 of adhesive surface area in Wasco, CA. Means followed by the same letter are not significantly different after analysis of variance with means separated by Fisher's Protected LSD ($P = 0.05$) after sqrt transformation of the data. Untransformed catches are reported.

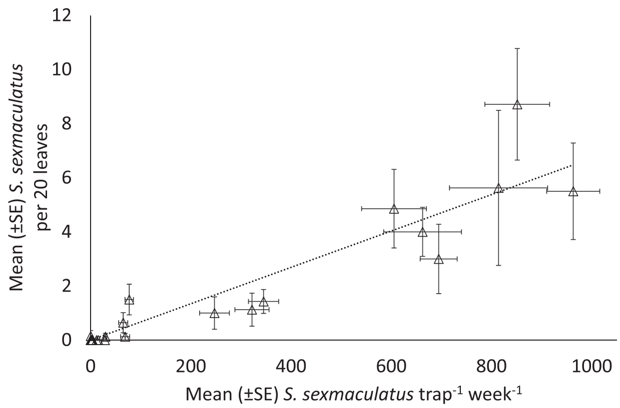

Fig. 5. Correlation between the number of *S. sexmaculatus* captured per large yellow strip trap and the number of *S. sexmaculatus* per 20-leaf sample ($y = 0.00674x$, $R^2 = 0.8818$).

as the population means were at least 1, 10, and 50 *S. sexmaculatus* trap^{-1} week^{-1}, respectively. For a desired margin of error of 30%, you could have 50, 70, and 90% confidence in the data if using six traps, as long as the population averaged at least 10, 50, and 100 *S. sexmaculatus* trap^{-1}, respectively. In order to obtain a desired margin of error of 10% with confidence interval levels of 50, 70, and 90%, a minimum of 20 traps were required if *S. sexmaculatus* captures were less than 50, 500, or 1,000, respectively. The number of traps needed to have confidence in *S. punctum* captures at six population means ranging from 1 to 100 trap^{-1} are also shown in Table 2.

For commercial use by pest control advisers working in almonds, we made an assumption that placing two to four traps per orchard would be practical, based on the number of sampling locations typically used for pheromone traps for navel orangeworm or leaf sampling for spider mites (Haviland et al. 2020). Data showed that for a desired margin of error of 50%, up to 90% confidence could be attained if the population means for *S. sexmaculatus* were at least 16.0 *S. sexmaculatus* trap^{-1} week^{-1} if two traps were used, and 3.9 *S. sexmaculatus* trap^{-1} week^{-1} if four traps were used (Table 3). The same margin of error and levels of confidence could be attained for *S. punctum* if there were at least 7.9 and 2.9 *S. punctum* trap^{-1} week^{-1} using two or four traps, respectively. Population means required to attain margins of error of 30% and 10% are also shown. The population means required to attain the same margin of error and levels of confidence using four traps instead of two were approximately fourfold and threefold lower for *S. sexmaculatus* and *S. punctum*, respectively.

Discussion

Effective integrated pest management for spider mites requires knowledge about the species presence and population levels of spider mite natural enemies. This has become particularly true in the modern era as broad-spectrum insecticides for navel orangeworm and other almond pests are being replaced by more selective alternatives with decreased impacts on natural enemies (CDPR 2019). The current industry practice is to monitor for natural enemies while doing presence–absence sampling for spider mites, with a focus on searches for phytoseiids (Wilson et al. 1984, Haviland et al. 2020). However, changes in almond production practices, including changes in pesticide use patterns, have led to a decrease in the prevalence of predatory mites in favor of predatory insects, especially *S. sexmaculatus* and *S. punctum*. We postulate that in the past, broad-spectrum insecticides depressed populations of insect predators, whereas now, insecticide programs with negligible impacts on *S. sexmaculatus* and *S. punctum* favor these higher-level predators that feed on both phytophagous and acarophagous species of mites.

The focus of our research was to develop monitoring tools that could be used for insect predators of spider mites, particularly *S. sexmaculatus* and *S. punctum*. Evaluations of nine off-the-shelf commercial sticky cards as predator traps identified significant differences in the ability to attract and capture both species. These studies led to our selection of the yellow strip trap as the most effective monitoring tool based on trap captures of both species, cost, and ease of use. We showed that the yellow strip trap is attractive to *S. sexmaculatus*, and not just a 'blunder' trap that insects accidentally land on, by documenting that larger traps not only caught more *S. sexmaculatus* (Fig. 3), but also more *S. sexmaculatus* per square area of adhesive surface (Fig. 4). Our choice of the yellow strip trap for *S. punctum* was consistent with work by Felland et al. (1995) showing that *Stethorus* sp. beetles prefer yellow compared to white traps.

Historically, leaf sampling has been the standard method for sampling spider mites, and by default for spider mite natural

Table 2. The number of traps required to have 50, 70, and 90% confidence that average large yellow strip trap captures of *S. sexmaculatus* and *S. punctum* fall within ±50%, ±30%, and ±10% of the population mean

Margin of error (%)	CI (%)	α	β	Traps needed at six population means[a]					
S. sexmaculatus				1	10	50	100	500	1,000
50	50	2.7	−0.436	2.7	1.0	0.5	0.4	0.2	0.1
	70	6.3	−0.436	6.3	2.3	1.1	0.8	0.4	0.3
	90	15.8	−0.436	15.8	5.8	2.9	2.1	1.1	0.8
30	50	7.4	−0.436	7.4	2.7	1.3	1.0	0.5	0.4
	70	17.5	−0.436	17.5	6.4	3.2	2.3	1.2	0.9
	90	43.9	−0.436	43.9	16.1	8.0	5.9	2.9	2.2
10	50	66.4	−0.436	66.4	24.3	12.1	8.9	4.4	3.3
	70	156.9	−0.436	156.9	57.5	28.5	21.1	10.4	7.7
	90	395.5	−0.436	395.5	144.9	71.8	53.1	26.3	19.5
S. punctum				1	5	10	25	50	100
50	50	2.7	−0.591	2.7	1.3	1.0	0.7	0.5	0.4
	70	6.3	−0.591	6.3	3.1	2.3	1.6	1.2	0.9
	90	16.0	−0.591	16.0	7.9	5.9	3.9	2.9	2.1
30	50	7.4	−0.591	7.4	3.7	2.7	1.8	1.4	1.0
	70	17.6	−0.591	17.6	8.7	6.4	4.3	3.2	2.4
	90	44.4	−0.591	44.4	22.0	16.3	10.9	8.1	6.0
10	50	67.0	−0.591	67.0	33.2	24.6	16.5	12.2	9.0
	70	158.4	−0.591	158.4	78.5	58.0	38.9	28.8	21.3
	90	399.2	−0.591	399.2	197.9	146.3	98.1	72.5	53.6

Calculations are based on the formula ($n = \alpha x^{\beta}$) where n equals the number of traps, x equals the population mean, and α and β were determined through power regression of 32 sets of field data at each of the nine levels of confidence (*S. sexmaculatus*: $R^2 = 0.8279$. *S. punctum*: $R^2 = 0.8129$).

[a]Six population means were selected arbitrarily to represent a typical range of capture rates found in studies over the past 2 yr. Means are reported as average *S. sexmaculatus* or *S. punctum* trap^{-1} week^{-1}.

Table 3. Mean population levels of *S. sexmaculatus* and *S. punctum* required to have 50, 70, and 90% confidence that trap averages are within 50, 30, and 10% of the population mean if using two or four traps per orchard

		Two traps per orchard		Four traps per orchard	
Desired margin of error (%)	CI (%)	*S. sexmaculatus*	*S. punctum*	*S. sexmaculatus*	*S. punctum*
50	50	2.7	1.3	0.7	0.5
	70	6.3	3.1	1.6	1.2
	90	16.0	7.9	3.9	2.9
30	50	7.4	3.7	1.8	1.4
	70	17.6	8.7	4.3	3.2
	90	44.4	22.0	10.9	8.1
10	50	67.0	33.2	16.5	12.2
	70	158.4	78.5	38.9	28.8
	90	399.2	197.9	98.1	72.5

Values are reported as average *S. sexmaculatus* or *S. punctum* trap^{-1} week^{-1}.

enemies. Leaf samples are currently used in California almonds to monitor for predators of *Tetranychus* spp. mites, including *S. sexmaculatus* (Haviland et al. 2020), similar to the way *S. longicornis* Priesner and *S. takahashi* Priesner may be monitored in strawberries in Spain, beans in Turkey, and pears in Japan (Garcia-Mari and Gonzalez-Zamora 1999, Takahashi et al. 2001, Polat and Kasap 2011). In our studies, adhesive traps proved to be a much more effective method for monitoring *S. sexmaculatus* and *S. punctum*. Correlations showed that when *S. sexmaculatus* were at a density of 1 per 20 leaves, traps caught an average of 149 trap^{-1} week^{-1}; *S. sexmaculatus* were only found on leaves 6.2% of the time that they were caught in traps. For *S. punctum*, correlations between trap captures and leaf sampling could not be done because leaf samples never exceeded 1 *S. punctum* per 160 leaves, even when traps averaged more than 100 *S. punctum* trap^{-1} week^{-1}.

The effectiveness of yellow strip traps to simultaneously monitor for *S. sexmaculatus* and *S. punctum*, coupled with the ineffectiveness of leaf samples to adequately be used to assess predator populations, suggests that the use of sticky traps can help improve integrated pest management programs for spider mites. This is a shift from previous industry practice where leaf samples could be used effectively to monitor for both spider mites and the phytoseiids that used to be their predominant predator (Haviland et al. 2020).

We present guidelines on the number of traps needed to obtain nine combinations of confidence intervals and margins of error at six *S. sexmaculatus* densities. This includes values that represent high scientific rigor (90% confidence that averages are within 10% of the mean), and values that are be better described as approximations (50% confidence that averages are within 50% of the mean). This latter model has the most applicability to pest managers using sequential sampling programs for spider mites that only require knowledge of the presence or absence of predators (not absolute values), and whether or not their density has changed since the previous sampling date (Wilson et al. 1984, Zalom et al. 1984, Haviland et al. 2020). Decisions regarding which of the nine models to use, and mean *S. sexmaculatus* density at which to calculate trap needs (Table 2) will depend on the purpose for monitoring and densities at which *S. sexmaculatus* are relevant. Currently, no literature is available on the field biology of *S. sexmaculatus*, its seasonal phenology in any cropping system, or on the level of captures on sticky traps that correlate to suppression of spider mite density that can be used to determine the most appropriate model. Similarly, literature on two other *Scolothrips* spp., *S. longicornis* and *S. takahashi*, report that these species are important in the regulation of spider mites, but none defines those relationships quantitatively (Garcia-Mari and Gonzalez-Zamora 1999, Takahashi et al. 2001, Polat and Kasap 2011).

Until new information is published on densities of *S. sexmaculatus* that are functionally relevant to biological control, we advise pest control advisers to hang two to four large yellow strip traps at locations in the almond orchard already being used for monitoring other pests, such as the same location of pheromone traps for navel orangeworm, or at locations where leaf sampling is conducted for spider mites (Haviland et al. 2020). Data showed that pest control advisers can have 70% confidence that trap captures are within 50% of the mean if there are at least 6.3 *S. sexmaculatus* or 3.1 *S. punctum* trap^{-1} week^{-1} using two traps, or 1.6 *S. sexmaculatus* or 3.1 *S. punctum* if four traps are used (Table 3). This level of confidence and accuracy should be adequate to document the presence or absence of both predators, and to monitor weekly trends in predator density.

After being placed in the orchard, we recommend leaving traps for 1 wk. This is the sampling interval typically used to collect leaf samples for spider mites and evaluate pheromone traps for navel orangeworm (Haviland et al. 2020). Cards can be evaluated in the field with the naked eye or a hand lens to determine the presence of either predator, or returned to the laboratory to quantify predators with more accuracy under higher magnification. Over time, trap data can allow a pest control adviser to monitor trends in predator density, thus improving the advisers' ability to make treatment decisions based on biological control, in addition to the current industry standard method of basing treatment decisions on presence–absence sampling for mites on leaves (Wilson et al. 1984, Zalom et al. 1984, Haviland et al. 2020).

The development of an easy to use, effective adhesive trap also has the potential to advance our scientific understanding of *S. sexmaculatus* and *S. punctum* in the field. Traps are already being used in field studies to validate biological parameters that were established in laboratories for *S. sexmaculatus* and *S. punctum*, and to improve our understanding of the phenology of both natural enemies (Haviland, unpublished data). This includes how they overwinter, when they first appear in the spring, how they move among crops, temperatures at which they are active, and how they respond to changes in spider mite density. Ultimately, traps could be used to study the impacts of predator–prey ratios on spider mite density that lead to improved treatment thresholds for spider mites that rely on quantifiable natural enemy populations.

Acknowledgments

We thank Gary Osteen and Misty Rex for assistance with site selection and coordination with commercial almond production operations. We thank California almond growers for funding through the Almond Board of California.

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