Spatial patterns of western flower thrips (Thysanoptera: Thripidae) in apple orchards and associated fruit damage

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ABSTRACT

Western flower thrips, *Frankliniella occidentalis* (Pergande), is an economic pest of apples in orchards of North America. Western flower thrips causes damage ("pansy spot") to apples by its egglaying activities during the bloom and immediate post-bloom periods. Difficulties in monitoring this pest and incomplete understanding of its biology during the bloom period have complicated control efforts in apple orchards. Densities of western flower thrips were monitored in seven (2003) or eight (2004) apple orchards at each of four bloom stages; in each orchard, thrips counts in blossom clusters were estimated at four to six distances into the orchard from an orchard edge that abutted native sagebrush-steppe habitat. We hypothesized that numbers of thrips in blossoms would decline with increasing distance along transects into orchards if the native habitat acted as a source of thrips. Thrips numbers in blossom clusters peaked at full bloom and petal fall. Densities showed a linear drop with increasing distance into the orchard, which we interpreted as evidence that the native habitat adjacent to each orchard did indeed act as a source of thrips moving into the orchards. Pansy spot incidence declined with increasing distance into the orchard. The major drop in damage occurred between the border row trees and samples taken at the adjacent distance (nine m away), suggesting that border rows adjacent to native habitats should be monitored with particular care. Regression analyses showed that damage and thrips density were positively correlated, albeit with substantial levels of unexplained variation in levels of damage.

Key Words: *Frankliniella occidentalis*, apple orchards, pansy spot, sampling, damage

INTRODUCTION

Western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), is a pest of stone and pome fruits throughout North America (Terry 1991, Beers *et al.* 1993, Pearsall and Myers 2000). In stone fruits, damage is caused by the feeding activities of the adult or immature thrips, whereas in apple orchards damage occurs as females deposit eggs into the developing fruit. The egglaying causes a whitish discoloration of the skin surrounding the oviposition scar, a condition known as pansy spot (Venables 1925, Childs 1927, Madsen and Jack 1966). Apple varieties in which damage is most noticeable are the lighter-skinned cultivars such as Granny Smith, McIntosh, or Rome Beauty (Madsen and Jack 1966, Terry 1991). It is not completely clear at what stage of blossom or fruit development that damage occurs, although several studies have suggested that most of the egglaying in tissues where damage is of concern (i.e., on the developing fruitlet) occurs at late full bloom through petal fall or just following petal fall (Venables 1925, Childs 1927, Madsen and Jack 1966, Terry 1991). Densities of adult thrips in blossoms appear to peak at full

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bloom and petal fall (Terry 1991; see also below).

The use of insecticides to control western flower thrips in apple orchards requires care to avoid harming pollinators and to minimize disruption of integrated mite control (Bush 2000, Smith *et al*. 2006). Thus, it would be beneficial to growers if chemical applications were made only if densities of thrips were high enough to warrant spraying, and if applications were made only in areas of the orchard actually requiring treatment. These needs have led to efforts to develop monitoring tools for western flower thrips in orchards (Terry and DeGrandi-Hoffman 1988, Bradley and Mayer 1994), as well as to studies that have defined the relationship between bloom phenology and timing of damage (Terry 1991). Objectives of the current study were to determine whether counts of western flower thrips in apple blossoms and damage to developing fruit were affected by distance into the orchard, particularly for orchards that abut native sagebrush-steppe rangeland. Studies done in nectarine orchards suggested that edges of orchards adjacent to native habitat experienced higher densities of western flower thrips than areas abutting other orchards (Pearsall and Myers 2000, 2001). The native habitat apparently was a source of thrips moving into the nectarine orchards. We tested whether thrips numbers and incidence of pansy spot within apple orchards declined with increasing distance into the orchards, and assessed whether bloom stage affected this relationship. We also analyzed the relationship between thrips densities and incidence of pansy spot in apple fruit, as the quantitative relationship between thrips counts and damage to apples has yet to be clearly established (Beers *et al.* 1993).

MATERIALS AND METHODS

Study sites and sampling methods. Studies were done in April-May, 2003 and 2004 at orchards located in northcentral and southcentral Washington State. Three (2003) or four (2004) orchards were monitored near Brewster (Douglas County) in northcentral Washington, and an additional four orchards (both years) were monitored in western Yakima (Yakima County) located in southcentral Washington State. In 2003, cultivars were Granny Smith (four orchards) and Red Delicious (three orchards); in 2004, cultivars were Granny Smith (two orchards), Fuji (one orchard), Cameo (two orchards), and Red Delicious (three orchards). All orchards had at least one edge adjacent to native sagebrush-steppe habitat. Insecticides were not applied during the studies.

Thrips densities and fruit damage were monitored along transects at four (2003) or six (2004) distances into each orchard, from an edge in each orchard that abutted native habitat. In 2003, the four distances were 0 (border row of trees), 30, 60, and 90 m into the orchard. The 2003 data suggested that the major drop in thrips numbers occurred between 0 and 30 m, so two additional distances (9 and 18 m) were added in the 2004 study. In all but two orchards, tree rows were parallel with the orchard border being monitored, thus transects in most orchards ran perpendicular to the tree rows.

Western flower thrips were sampled at each of four bloom stages: pink, open king bloom, full bloom (80% of flowers open), and petal fall (80% of flowers without petals). At each bloom stage and at each orchard, 25 flower clusters (each with five to six flowers) were clipped from 15-25 trees per distance; trees and flower clusters were chosen haphazardly. Height of samples was 1.5 to 2 m. The 25 clusters for each sample were placed in a self-sealing plastic bag, stored in an ice chest, and taken to the laboratory for examination. At the laboratory, thrips were extracted by immersing and agitating the blossoms in solutions of water and dishwashing soap. The tips of unopened flowers in pink and king bloom samples were cut away before immersion to allow the solution to freely circulate through the flower. Extracted thrips were stored in 70% ethanol until they were identified and counted beneath a dissecting microscope. For each sample of 25 clusters, we recorded numbers of adult female *F. occidentalis*.

Thrips damage was assessed in each orchard at all distances to determine if a correlation existed between damage and distance into the orchard. We limited fruit examination to the 2004 study. Developing apples varied from 1.9 to 3.2 cm in diameter at the time samples were taken, and pansy spot was readily visible on all cultivars (pansy spot disappears in red varieties as the fruit color intensifies later in the growing season). At each of the six distances in each orchard, 250 fruitlets were haphazardly selected from 15-25 trees (10-15 apples per tree) and examined for pansy spot. Height of samples was again 1.5 to 2 m. Two people did all of the fruit examination (each person sampling four orchards) to minimize variation among observers in assessing for the presence of pansy spot.

Data Analysis. Mean number of thrips per 25 blossom clusters was compared among distances and among bloom stages using a doubly repeated measures analysis of variance (due to repeated sampling in space [=distance] and time [=bloom stage] within each orchard). The data were transformed by ln(x+1) (Zar 1974) and analyzed using PROC GLM (SAS Institute 2002). Greenhouse-Geisser adjusted *P*-statistics are presented throughout. To assess the relationship between thrips density and distance into the orchard, we examined linear and quadratic effects using the Polynomial command in the Repeated statement of PROC GLM (SAS Institute 2002). The effect of distance on proportion of fruit showing pansy spot was assessed using repeated measures ANOVA including only distance as the repeated factor. Proportions were arcsine transformed before analysis (Zar 1974). Linear regression was used to test whether the percentage of fruit showing damage depended upon thrips densities in the bloom samples. Separate regressions were fitted for the four bloom stages, and for thrips counts summed over the four bloom stages.

RESULTS

We observed substantial variation among orchards in counts of thrips both years (Figs. 1-2). Thrips densities were significantly affected by bloom stage both years (Table 1). Densities were higher during the full bloom period (mean = 13.6 and 14.4 thrips per 25 clusters in 2003 and 2004, respectively; sample distances pooled) and petal fall period (14.4 and 16.3) than in the pink (1.3 and 2.4) and king bloom (4.6 and 7.0) stages. The interaction between distance and bloom stage was not significant either year (Table 1), so it is appropriate to examine the main effects of distance to determine whether thrips density changed with location in the orchard (Figs. 1E-2E). Distance effects were highly significant both years (Table 1). Thrips density declined as a linear function of distance from the native habitat both years (Table 1).

Mean percentage of fruit showing pansy spot declined with distance ($F = 3.8$; df = 5, 35; $P = 0.027$; Fig. 3). Linear and quadratic effects were examined, and suggested that damage declined as a quadratic function of distance into the orchard (linear: $F = 5.7$; df = 1, 7; $P = 0.048$; quadratic: $F = 6.0$; df = 1, 7; $P = 0.04$). A second analysis was done in which 5 profile contrasts were extracted to compare damage at consecutive distances (i.e., 0 vs 9 m, 9 vs 18 m, 18 vs 30 m, 30 vs 60 m, 60 vs 90 m). The analysis suggested that the primary decline in damage occurred between 0 and 9 m ($F = 14.8$; df = 1, 7; $P = 0.006$; the other 4 contrasts were non-significant).

Percentage damage increased with increasing thrips density, but with substantial scatter in the data (Fig. 4). Data for one of the eight orchards (labeled “Orchard 3” in Fig. 4) fell consistently out of the scatter shown in the other data. Regression models

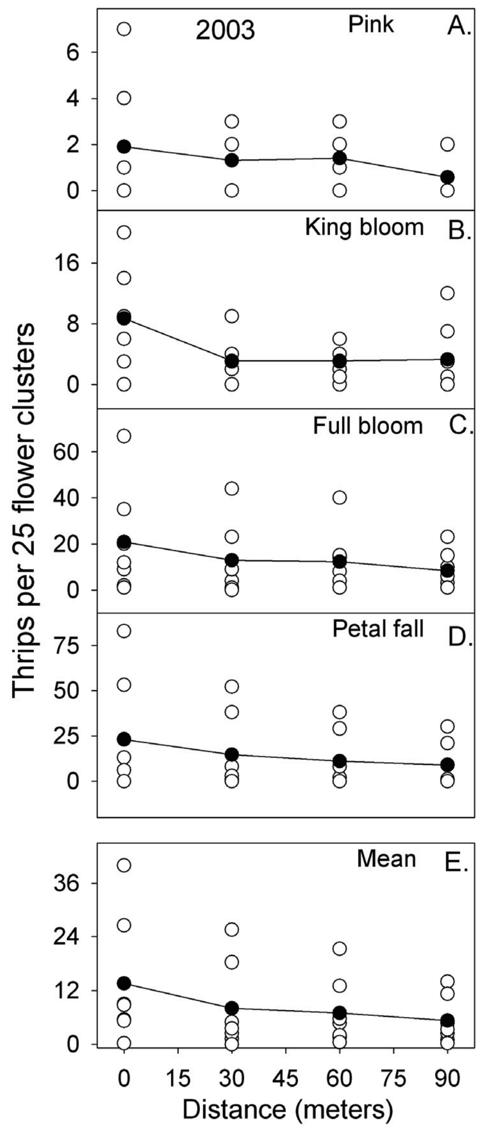

Figure 1. Number of adult female western flower thrips per 25 flower clusters in four bloom stages as a function of distance into the orchard (panels A-D); 2003 data. Panel E shows thrips counts averaged over bloom stage. Open circles show results for each orchard (N = 7 orchards; some data points overlap), while filled symbols depict numbers averaged over orchard. See Table 1 for ANOVA results.

were fitted both with and without the Orchard 3 data (Table 2). In all models, the intercept term differed significantly from zero, indicating that the models predicted some level of damage at a measured density of zero thrips (see also the scatter plots in Fig. 4). Slope coefficients were significantly different from zero in all models for which the Orchard 3 data had been excluded (Table 2); r^2 values were low in all models (≤0.26), reflecting the large scatter in the data. Regression models fitted to counts summed over bloom stage were significant (Fig. 5), albeit again with substantial scatter around the fitted lines.

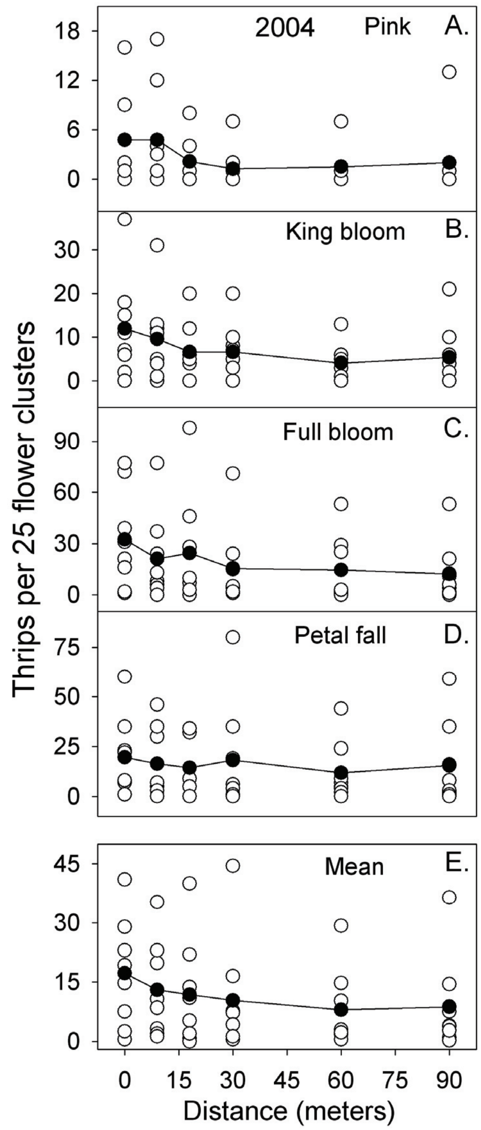

Figure 2. Number of adult female western flower thrips per 25 flower clusters in four bloom stages as a function of distance into the orchard (panels A-D); 2004 data. Panel E shows thrips counts averaged over bloom stage. Open circles show results for each orchard (N = 8 orchards; some data points overlap), while filled symbols depict numbers averaged over orchard. See Table 1 for ANOVA results.

DISCUSSION

Densities of western flower thrips in apple blossoms peaked between the full bloom and petal fall stages (Figs. 1-2), as shown also in other sampling studies done in apple orchards of western North America (Madsen and Jack 1966, Terry 1991). We observed a linear decline in thrips densities with increasing distance into orchards, from transects beginning at the edge of orchard that abutted native habitat. Other studies done in crop or commercial forest systems have shown that non-agricultural habitats adjacent to crops may be a source of pest thrips colonizing the crop, leading often to

Table 1.
Results from repeated measures ANOVA assessing effects of bloom stage and distance into the orchard on thrips densities in bloom clusters (Figs. 1-2). Greenhouse-Geisser adjusted *P*-statistics shown for main effects and interaction terms. Linear and quadratic contrasts are extracted for the distance effects.

	2003			2004		
	df	*F*	*P*	df	*F*	*P*
Bloom stage	3,18	5.3	0.042	3,21	9.3	0.003
Distance	3,18	8.2	0.009	5,35	5.7	0.007
Linear	1,6	15.4	0.008	1,7	10.0	0.02
Quadratic	1,6	0.7	0.45	1,7	3.9	0.09
Stage x distance	9,54	1.1	0.36	15,105	1.0	0.42

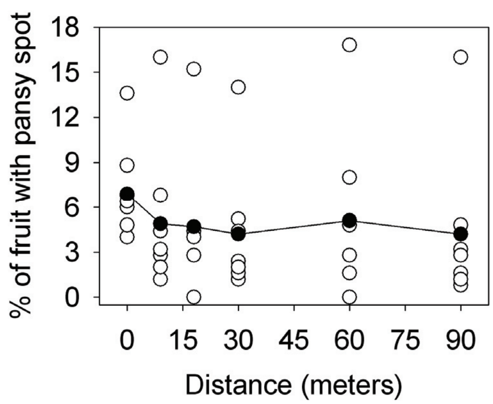

Figure 3. Percentage of fruit showing pansy spot as a function of distance into orchard. Open symbols show results for each orchard (N = 8 orchards; some data points overlap), while filled symbols show damage averaged over orchard. 250 fruit examined at each distance for each orchard.

high densities of thrips at field edges (Lewis 1973). Native habitat adjacent to nectarine orchards was a source of western flower thrips colonizing orchards in western Canada (Pearsall and Myers 2000, 2001). Orchards surrounded by other orchards tended to have lower densities of thrips than orchards adjacent to native habitat (Pearsall and Myers 2000). These studies failed to describe quantitatively how thrips densities or damage to fruit declined with increasing distance into orchards. In our study, patterns in damage paralleled patterns in densities of thrips. Incidence of pansy spot declined with increasing distance into orchards, with the major drop in damage levels occurring between 0 and 9 m into the orchard. The density and damage results suggest that apple growers may in some circumstances be able to limit spray applications to border rows.

A major impediment to developing control protocols for western flower thrips in apple orchards has been our lack of information regarding the quantitative relationship between adult thrips density and egg density in blossoms, or between density and actual damage (Terry 1991, Beers *et al.* 1993). We showed that percentage damage was positively correlated with thrips counts in blossoms (Figs. 4-5). However, there was substantial unexplained variation in the data, at all bloom stages (Figs. 4-5). Moreover, fruit damage often occurred even in the absence of thrips in samples (see scatter plots in Fig. 4 and regression models in

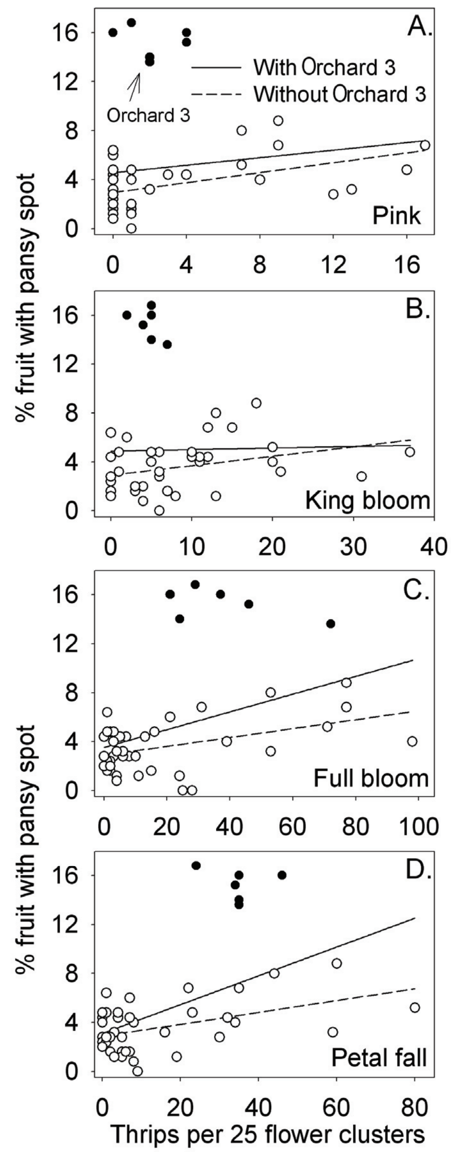

Figure 4. Scatter plot and linear regressions showing relationship between numbers of adult female western flower thrips in blossom clusters and percentage of 250 fruit showing pansy spot. Data from Orchard 3 are solid dots, other data are circles. Regressions fitted with (solid lines) and without (dashed lines) data for Orchard 3 (a Red Delicious orchard located in western Yakima). See Table 2 for regression statistics.

Table 2). We observed a damage level of 4.4% at one distance in an orchard for which no thrips were collected in any of the four sampling periods (Fig. 5). These results suggest one or more of the following: (a) our sample sizes were too small or taken too infrequently to adequately estimate thrips densities in the orchard; (b) limiting our samples to the four bloom stages between pink and petal fall means that we failed to sample during other stages of apple development in which the fruit is susceptible to thrips; (c) our method for extracting thrips from blossoms missed a significant number of thrips.

One Red Delicious orchard ("Orchard

Table 2.
Results from linear regressions relating percentage of fruit having pansy spot to thrips density. Separate models fitted with and without results for Orchard 3. Scatter plots and regression lines shown in Figures 4 and 5.

Bloom stage	Include Orchard 3	Intercept[1]	Slope	*P*	r^2
Pink (Fig. 4A)	Yes	4.56	0.154	0.30	0.02
	No	2.94	0.203	0.002	0.21
King bloom (Fig. 4B)	Yes	4.89	0.013	0.88	0.01
	No	2.91	0.078	0.03	0.11
Full bloom (Fig. 4C)	Yes	3.53	0.073	0.004	0.17
	No	2.89	0.036	0.003	0.20
Petal fall (Fig. 4D)	Yes	3.11	0.118	0.0002	0.26
	No	2.87	0.049	0.003	0.20
Cumulative (Fig. 5)	Yes	3.28	0.037	0.003	0.18
	No	2.72	0.019	0.001	0.23

[1] All intercept terms significantly ($P < 0.05$) different from zero.

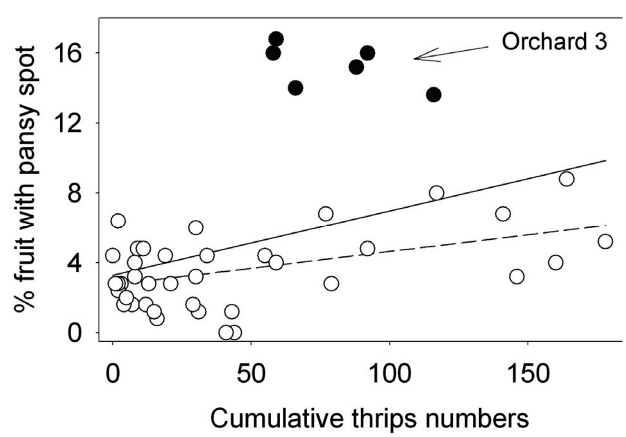

Figure 5. Scatter plot and linear regressions showing relationship between numbers of adult female western flower thrips in blossom clusters (summed over the four bloom stages) and percentage of 250 fruit showing pansy spot. Data from Orchard 3 are solid dots, other data are circles. Regressions fitted with (solid lines) and without (dashed lines) data for Orchard 3 (a Red Delicious orchard located in western Yakima). See Table 2 for regression statistics.

3" in Fig. 4) had damage estimates well above levels seen in the remaining seven orchards, for unknown reasons. This orchard had stands of feral alfalfa in the understory, and it is possible that the alfalfa acted as a source of western flower thrips moving into the trees whenever the understory was mowed. Venables (1925) stated that alfalfa cover crops in apples may affect incidence of pansy spot. Pearsall and Myers (2000) showed that alfalfa and other flowering plants in the understory of nectarine orchards supported potentially large numbers of western flower thrips. Bush (2000) cautioned against destroying flowering dandelions in orchard understory during the bloom period in apples, as thrips occupying dandelion flowers may then move into the trees and cause damage to developing fruit. It is possible that the alfalfa in Orchard 3 acted as an important source of western flower thrips moving onto developing fruit. In any case, data for Orchard 3 added substantially to the scatter of points surrounding the regression lines (Figs. 4-5, Table 2). These results again reinforce observations made elsewhere that the relationship between damage and thrips densities in apple blossoms can be difficult to predict (Terry 1991).

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