Spatial and Temporal Patterns of Dispersal of Western Flower Thrips (Thysanoptera: Thripidae) in Nectarine Orchards in British Columbia

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ABSTRACT Thrips were sampled from six nectarine orchards in the Dry Central Interior, British Columbia, Canada, between April and June 1993 using yellow sticky cards on posts spaced around the perimeter of each orchard. Although 12 identified species of thrips were captured, >90% of individuals were the western flower thrips, *Frankliniella occidentalis* (Pergande). The flight patterns and abundances of western flower thrips were compared between orchards located in two differently oriented valleys (N-S and E-W) and between orchards located close to or far from areas of wild land. Results indicate that densities of western flower thrips entering orchards, and their direction of movement, were related more to the external vegetation than either location within the two different valleys or general wind flow patterns. Western flower thrips tended to move into orchards close to ground level in early spring (late April and early May) but flew higher as ground cover grew taller and temperatures increased. Densities of western flower thrips at ground level were highest in an orchard with the densest dandelion ground cover. We conclude that the location of nectarine orchards in relation to wild areas is a major determinate of western flower thrips densities.

KEY WORDS *Frankliniella occidentalis*, nectarine, flight patterns, dispersal, circular statistics, western flower thrips

WESTERN FLOWER THRIPS, *Frankliniella occidentalis* (Pergande), are serious pests in nectarine, *Prunus persica* (L.) Batsch, orchards in the Dry Central Interior of British Columbia, Canada. Adult female thrips lay their eggs in the developing nectarine buds early in spring: these develop and hatch into larvae approximately at the time of petal fall. Larval feeding on the developing fruitlets causes minute scars which result in large patches of superficial russetting on the mature fruit (Pearsall 2000).

Comprehension of the movement patterns of western flower thrips into, out of, and within a particular crop is necessary to provide information for possible management strategies. It has been suggested that strong regional, temporal, and varietal differences in the damage to fruit exist in the interior of British Columbia. Western flower thrips overwinter in areas of wild land surrounding orchards as well as within orchards (Pearsall and Myers 2000); thus, we believed that orchards bordering wildlands would possess the highest densities and diversity of thrips. Western flower thrips are minute insects and both sexes are capable of flight. However, we were primarily interested in the movement patterns of the adult females, as damage levels are a direct consequence of oviposition by the female.

For studies of flight activity, orchard pests are commonly captured using sticky cards, light traps, and pheromone baited traps (Prokopy and Owens 1978, 1983). In the case of western flower thrips, colored sticky traps and water pan traps have been the preferred choices. Results of studies on the most effective color of sticky traps (e.g., Lewis 1959; Kirk 1984a, 1984b; Brodsgaard 1989; Gillespie and Vernon 1990; Teulon and Penman 1992; Vernon and Gillespie 1995) suggest that blue, yellow, and non-UV-reflecting white traps may be the most effective colors. We decided to use yellow sticky cards because the thrips are highly contrasted and therefore most easily counted against a yellow background. Yellow cards were also the most readily available commercially.

Specifically, we wanted to determine if and when western flower thrips move into orchards in the early spring, and the direction from which they fly into orchards. In addition to direction of flight, we also wanted to examine how the height of movement by thrips changes over the season as nectarine buds develop and the climate and vegetation within and around orchards change. Comprehension of the height and direction from which thrips fly could prove useful for the use of trap crops, or the construction of barriers at the orchard edge.

Finally, we wanted to examine flight of thrips in patches of wild land (predominantly sagebrush, *Artemisia tridentata* Nutt.) bordering two of the orchards. We wanted to determine when flight activity was taking place in these areas, whether it was synchronous among the two areas, and whether the peaks of

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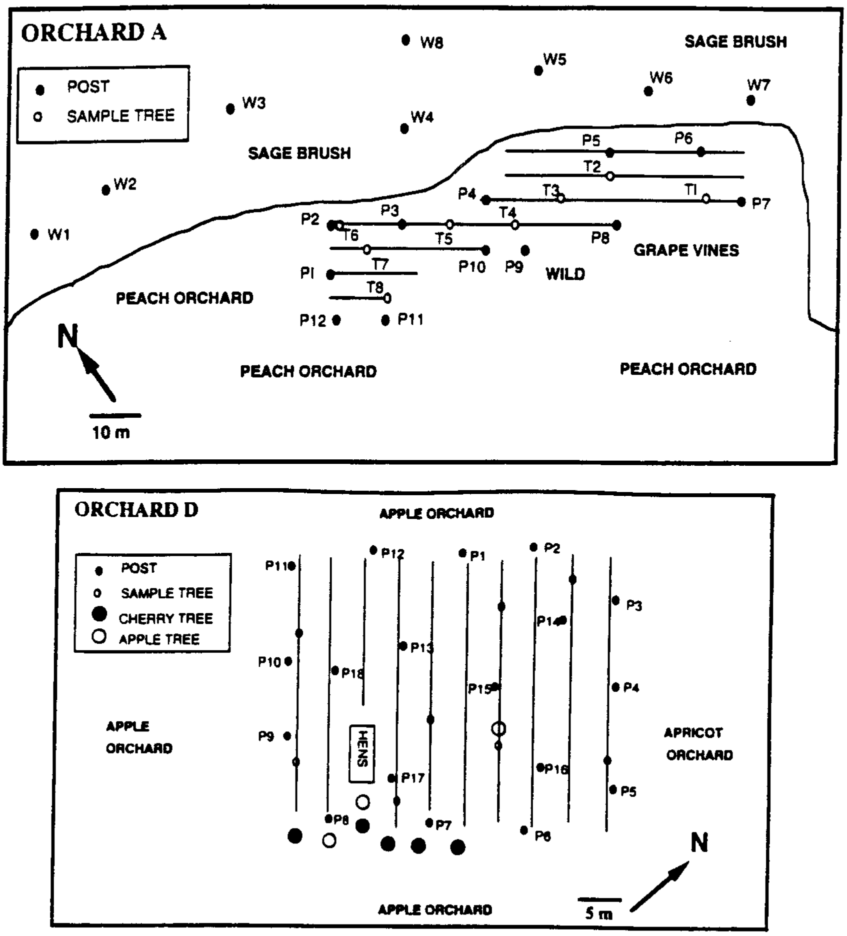


Fig. 1. Orchards A and D showing the orchard size, location of peripheral posts, interior posts (for orchard D) and wild land posts (for wild land adjacent to orchard A) as well as orchard orientation and surrounding vegetation.

thrips movement were coincident with those in the orchards.

Materials and Methods

Study Sites. The dispersal studies were carried out between April and June 1993 in six nectarine orchards in British Columbia: four in Cawston (A, B, C, D) in the southern Similkameen Valley, which runs approximately northwest to southeast, and two located further north (E, F) close to Summerland adjacent to the Okanagan Lake in the Okanagan Valley, which runs northeast to southwest. Both northern orchards were highly exposed and were adjacent to patches of wild land. In the southern region, orchards A and B were both located on the hillside and also were flanked on one side by large areas of wild land. Orchards C and D were both in the valley bottom. Only orchard D did not lie adjacent to any areas of wild land, but was surrounded by other orchards.

Sticky Traps. To monitor dispersal, thrips were sampled using yellow sticky cards (7.5 cm by 13 cm) (Phero Tech, 7572 Progress Way, Ladner, British Columbia) placed on posts 2 m high and spaced at 30° intervals around the perimeter of each orchard. Typical arrangement of these posts are shown for two orchards (Fig. 1). On each 'peripheral' post, cards were paired so that three to four faced in toward the orchard ('in' cards), and the other three to four faced outwards ('out' cards). The out cards were expected to catch thrips flying into orchards from surrounding areas. These cards were put out in early April while the buds were still dormant (5 and 13 April for the southern and northern orchards, respectively), and were collected every 3–4 days (or as necessary based on numbers of thrips) until 31 May/1 June. Densities of thrips and direction of their movement into and out of the orchards were monitored in relation to surrounding vegetation, temperature, and the stage of development of the nectarine buds. Vertical variation in movement of thrips was assessed using cards placed at heights of 0.25 (ground), 1 m (low), 1.5 m (medium), and 2 m (high) and correlated with tree height and the type of ground cover in each orchard. Sticky cards were also collected from a fifth height (2.5 m - labeled 'Top' for two collections dates [8 and 15 May]) in orchard C only. The ground level cards were put into all orchards except F, on 1 May, when dandelions (*Taraxum officinale* Weber) were in full bloom. Only medium and low level cards were placed onto posts after 23–25 May because of very high densities of thrips.

Sticky cards were also placed among weeds in areas of uncultivated land around orchards A (Fig. 1) and B. Eight posts (1 m high) were put out with two sticky cards (one facing toward the orchard ['in'], the other facing wildland ['out'] attached at the average level of the surrounding wild vegetation. These were sampled at the same time as the sticky cards surrounding the orchards.

Sticky cards also were used within five of the orchards (B–F) to trap thrips flying inside the orchard (for example, Fig. 1). Four to six posts were set up within each orchard (depending on orchard size) and two cards were attached at the height of tree mid-canopy and sampled between 18 April–1 June, and for all orchards except F, at ground level after 4 May. The posts were placed randomly between trees, and the cards were removed at the same time as the cards on the outside posts. For 'interior' posts, cards were not associated with an 'out' or 'in' direction.

Nectarine Development. The development of buds on each of eight randomly chosen sample trees within each orchard was scored into the following categories: silver tip (silver dormant buds), swelling bud (white and swollen buds), petal show (petal is first visible), full pink (popcorn stage), bloom, and petal fall, so that flight of thrips into orchards could be related to tree development (Pearsall 1998).

Insect Identification. Sticky cards were soaked in varsol overnight or until the Stickum glue had dissolved. Thrips floating in varsol were removed using a camel's-hair brush, placed into vials of ethanol, and later mounted in a drop of Hoyer's solution on glass slides. After at least 2 wk of curing slides were sent to Sueo Nakahara (USDA Beltsville, MD) for identification. For some rare species it was not possible to successfully mount any individuals.

Weather Records. Temperature and wind direction data recorded in Keremeos were provided by Environment Canada and were used for orchards in the Similkameen; weather records collected at the Summerland Agriculture and Agri-Food Canada Research Center, 5 km from the study orchards in the Okanagan were used to represent the weather conditions in those orchards. Measurements of wind speed were made directly within orchards using a hand held anenometer.

Data Analysis. Abundance of western flower thrips in flight within orchards was described using the mean number of thrips per sticky card expressed on a per day basis, so that catches after differing periods of time could be compared. To determine whether among-valley differences exist, these adjusted numbers of thrips caught on each date were compared between northern and southern orchards using analysis of variance (ANOVA) ($P < 0.05$ significance level) (Wilkinson 1990). In the case of the southern orchards, comparisons were also made among orchards using ANOVA. Where data did not meet the assumptions of ANOVA, and where numbers could not be adequately transformed, a nonparametric Kruskal–Wallis test was used. The Tukey honestly significant difference test was used for all posthoc comparisons of ANOVA results. A Mann–Whitney U test was used for posthoc comparisons of Kruskal–Wallis results with a Bonferroni adjustment to control the experiment wise probability of a type I error to 5%.

Mean direction of western flower thrips movement into and out of orchards was assessed for each date using circular statistics (Rayleigh test: $P < 0.05$ significance level). The mean angle of flight of thrips into orchards was determined as α for each date for each orchard, and the Rayleigh test was used to determine whether the direction of flight departed significantly from random (Batschelet 1981). Height (ground, low, medium, and high) and orientation (in, out) of western flower thrips movement into and out of orchards was analyzed by two-way ANOVA for each date using unadjusted data ($P < 0.05$ significance level).

Results

Species. More than 90% of the captured species of thrips flying into orchards during the period of nectarine flower development were *F. occidentalis* (Pergande) (pale and dark forms). The next most commonly captured species were a newly described species *Thrips fallaciosus* Nakahara, and *Haplothrips kurdjumovi* Karny and *Thrips treherni* Priesner, which each accounted for between 0.1 and 2–3% of the thrips caught. The species *Aeolothrips fasciatus* (L.), various *Aeolothrips* spp., and *Neohydatothrips* sp. each accounted for between 0.1 and 1–2% of thrips captures. Other less commonly captured species (0.1–0.6% of total catches) were as follows: *F. minuta* (Moulton), *T. tabaci* Lindeman, *T. vulgatissimus* Haliday, *H. verbasci* (Osborn), and *H. halophilus* Hood. Percentages given are based on total catches over the whole sampling period of 21,271, 17,612, 11,866, 5,040, 2,767, and 5,216 thrips in orchards A-F, respectively. Of these species caught, only the *Haplothrips* spp. and the *Aeolothrips* spp. are predacious. The other species are phytophagous and are in the family Thripidae. The *Haplothrips* spp. belong in the family Phlaeothripidae. *Frankliniella fusca* (Hinds) and *Odontothrips loti* (Haliday) were also identified from specimens, but were rarely caught and not enumerated from each sticky card.

The proportion of western flower thrips on sticky cards located at the orchard periphery on all dates was >71% for orchard A, 93% for orchard B, 92% for orchard C, 77% for orchard D, 74% for E and 87% in orchard F (Pearsall 1998). The dark and pale forms of western flower thrips, *H. kurdjumovi* and *T. fallaciosus* were the main species that were captured on sticky cards on the orchard periphery during April. There was an increased diversity of thrips species caught

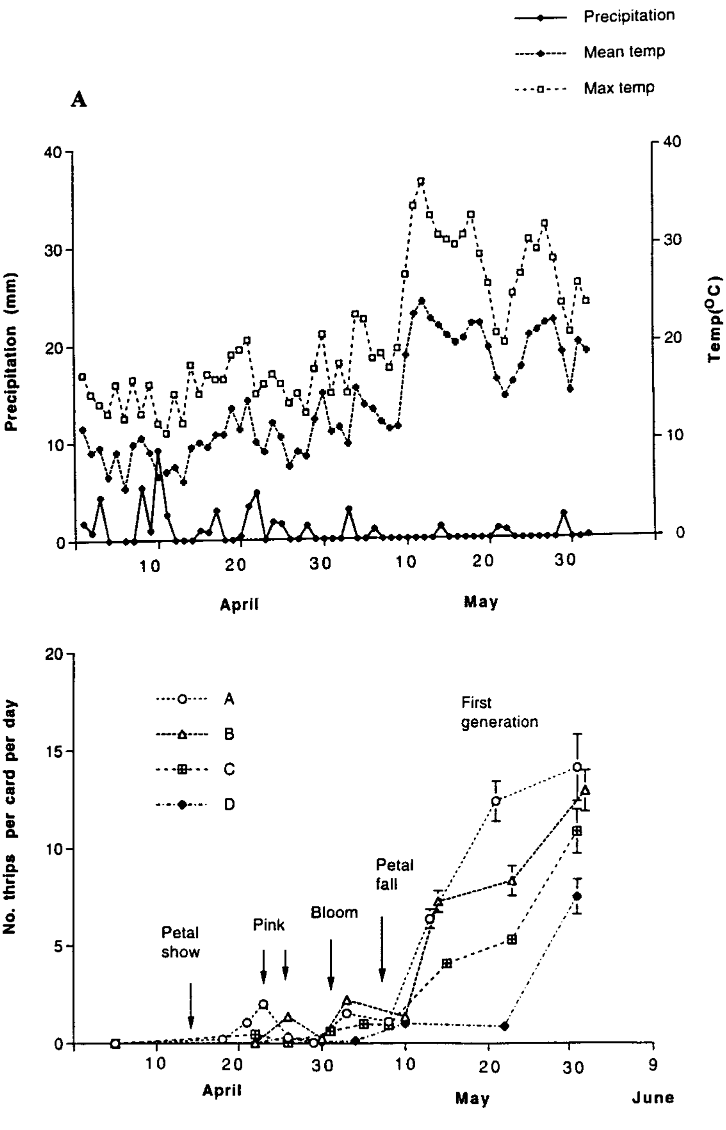


Fig. 2. Daily mean air temperatures (°C) and precipitation (mm) and mean densities of adult thrips caught per card per day from peripheral posts located around (A) orchards A–D and (B) orchards E and F from 5 April–1 June 1993.

beginning in early May, with initial catches of *Aeolothrips* sp., *H. halophilus*, *T. treherni*, and *T. tabaci*. By the end of May, the numbers of species caught increased further, and there were in addition to the above species, catches of *H. verbasci*, *T. vulgatissimus*, *Neohydatothrips* sp., and *F. minuta*, as well as a variety of other species that remain unidentified. *Haplothrips verbasci* was found only in the northern orchards. The predacious *Aeolothrips* sp. increased in all orchards in mid-May. *Thrips treherni* also became common in May, particularly in those orchards with a dense ground cover of dandelion (A and B), in which it is apparently commonly found (Steve Nakahara, personal communication). Species caught in the northern and southern orchards were very similar.

Although western flower thrips were not separated by sex for most dates, we found only females in the early spring and the males did not occur until after the emergence of the first generation in mid-May. The pale morph was far more common than the dark morph in all orchards studied and ratio of light to dark morphs ranged from 15:1 in orchard A to 2:1 in orchard D. Orchard D was unique in the high frequency of dark morphs and that it was surrounded by other orchards, and thus not adjacent to any patches of wild land.

Species of thrips in orchard interiors and in wild land were similar to those found on the cards placed at the edges of orchards (Pearsall 1998). Total catches over the sampling period amounted to 6,745, 6,783, 4,618, 2,325, 989, 488, and 874 thrips in A and B wildland, B–F interior posts, respectively. The proportion of dark western flower thrips was slightly lower on traps in wild areas adjacent to orchards A and B than

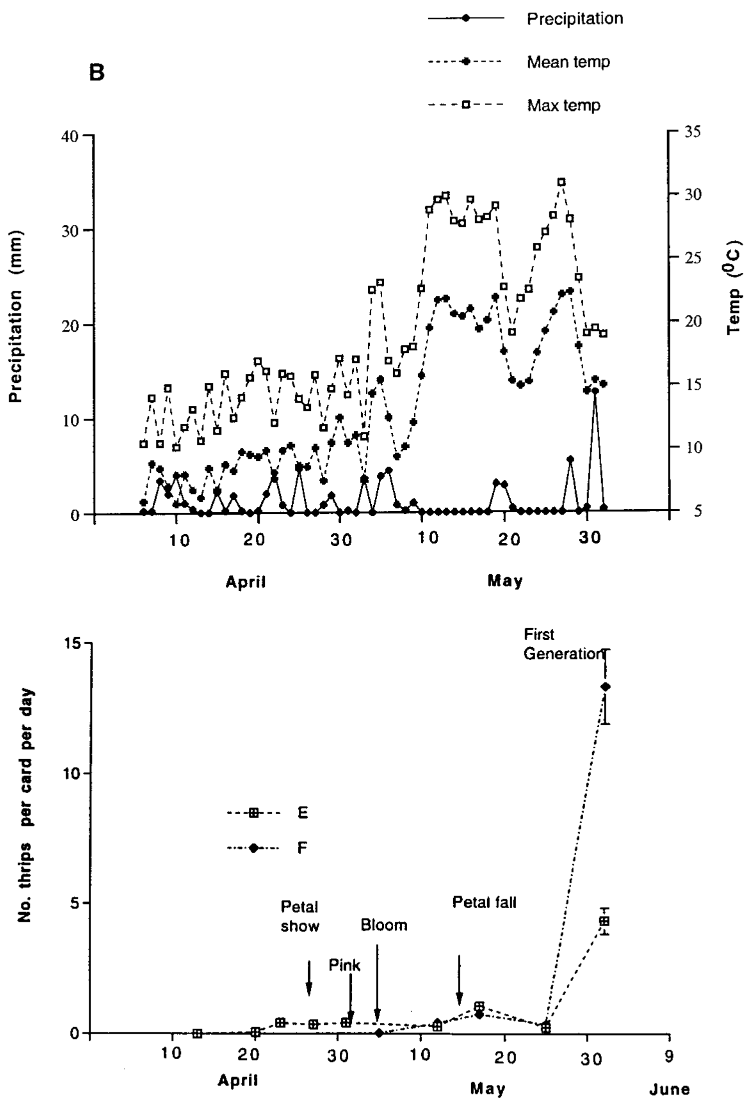


Fig. 2. Continued

on the peripheral traps of those same orchards (6 and 9% of total captures in the orchards versus 1 and 3% in wild land).

Patterns of Flight Over the Season Indicated by Peripheral Traps Around Orchards. Peaks in abundance of thrips were seen at the pink and bloom stages in the southern orchards, particularly in orchards A and B, but such peaks were not readily apparent in the northern orchards. In all six orchards, densities of thrips flying into orchards increased after petal fall, when the first generation emerged from the ground (Fig. 2).

Comparisons of total numbers of western flower thrips per post during the whole sampling period in southern orchards showed that orchards on the hillside (A and B) had higher densities than orchard C, with the lowest densities overall occurring in orchard D, located far from any wild land ($F = 20.23$; df = 3, 43; $P < 0.001$). For the northern orchards, higher densities were found in orchard F adjacent to wild land than in orchard E ($t = 3.74$, df = 22, $P = 0.001$). A direct comparison of total western flower thrips trapped over the whole study period in southern versus northern orchards, showed that densities were higher in the southern orchards ($t = 6.24$, df = 70, $P < 0.001$).

Height of Flight as Assessed from Orchard Peripheral Traps. Using two-way ANOVA to test the differences in western flower thrips caught at the two to five different heights, orientation (in-facing versus outfacing) as well as the interaction term, we found that the height term was significant ($P < 0.05$) for almost all dates in all southern orchards except for orchard D (Pearsall 1998). In orchards A, B, C, and F, the num-

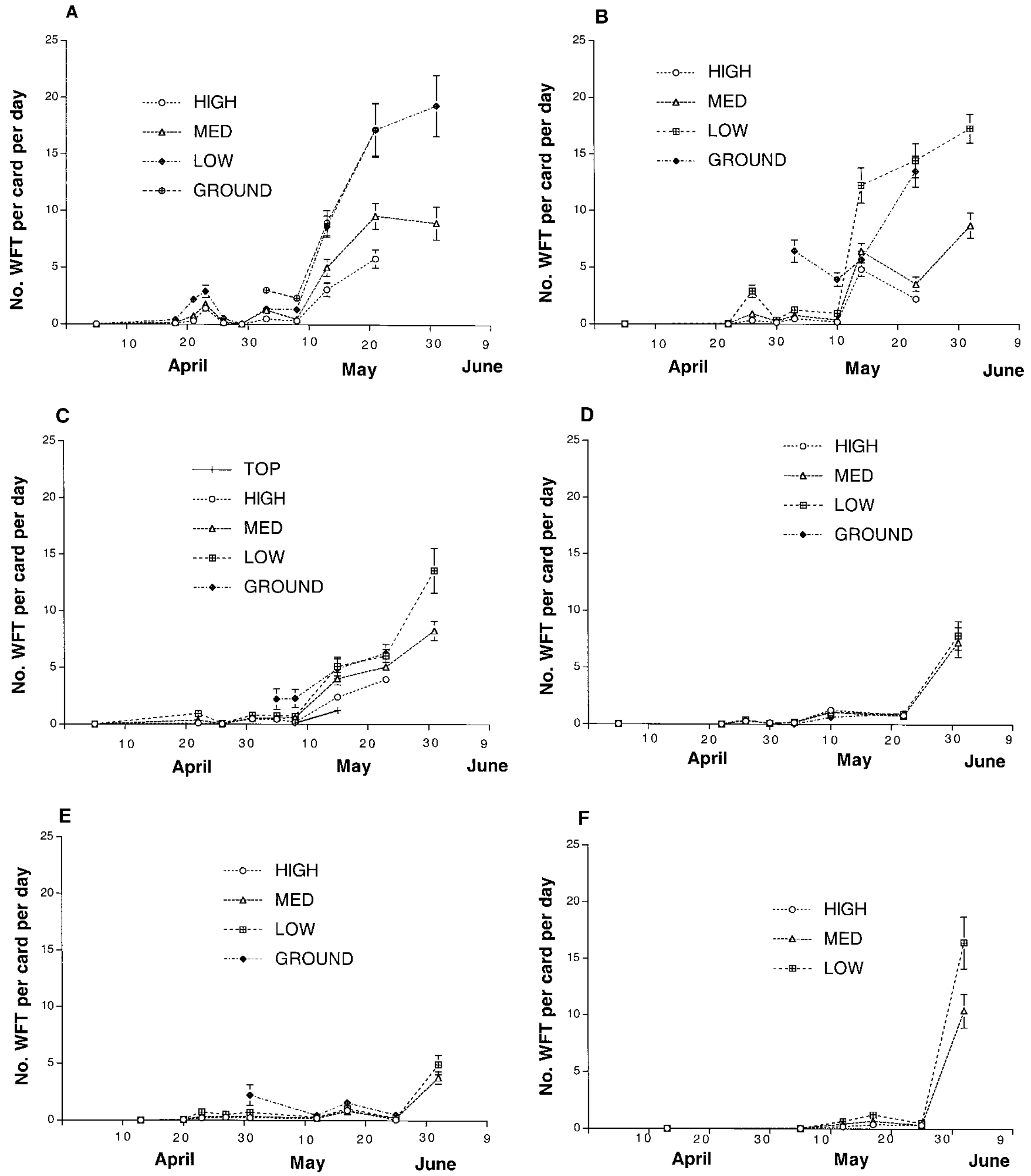


Fig. 3. Number of western flower thrips per sticky card per day caught at each of three to five different heights (G, L, M, H, and T) on peripheral posts for orchards A–F for several sampling dates between 5 April and 1 June 1993.

bers of western flower thrips were always highest on the lowest cards available or at the height of ground vegetation (0.7 m in late summer) (Fig. 3; Pearsall 1998).

Patterns were less clear in orchard E (Pearsall 1998), but western flower thrips here also tended to be flying low. In orchard D, there were basically no differences in western flower thrips captures among heights.

During dandelion bloom, greater numbers of western flower thrips were caught on the ground cards in orchard B, which had the highest dandelion density overall, than on the ground cards of the other southern orchards. The lowest numbers were captured on the ground cards in orchard D, where there were very few dandelions (4 May: $KW = 58.82$, df = 3, $P < 0.001$; 10 May: $KW = 28.35$, df = 3, $P < 0.001$; 13 May: $KW = 8.45$, df = 2, $P = 0.02$; 22 May: $KW = 64.93$, df = 3, $P < 0.001$).

Orientation of Flight. Significant orientation effects were found for some dates in orchards A and C and E, with more western flower thrips found on cards facing out of orchards rather than into orchards. Thus, we assumed that for those dates, greater numbers of western flower thrips were flying into rather than out of the orchards (Fig. 4). In most cases, however, this factor was not significant ($P > 0.05$; Pearsall 1998).

Direction of Flight. In 65 of 76 analyses, the direction of flight of western flower thrips into and out of orchards was significant based on the Rayleigh *R* test of mean angles indicated by captures on sticky cards (Pearsall 1998). In 57 of those cases, *P* values were <0.001. Orchard A lies adjacent to a mountain side and is bounded by wild land along one edge (Fig. 1). Here the mean direction of flight into the orchard based on numbers caught per trap was always from the direction of the wild land over the season (Figs. 5A and 1A). In orchard B, the mean direction of flight was also from the wild land that bounded it on one side (Fig. 5B). In orchard C, which is not located near any major patches of sagebrush, analysis of catches indicated that most flight occurred from the direction of an adjacent peach, *Prunus persica* (L.), orchard (Fig. 5C). In the case of orchard D, located in the valley bottom and without any wild land nearby, the direction of flight of thrips into the orchard did not depart significantly from randomness on two dates (Figs. 5D and 1B). On the two occasions that the mean direction of flight into the orchard was significantly concentrated, thrips were coming from the direction of an adjacent apricot orchard.

In orchard E, the mean direction of flight into the orchard was significant for six of eight dates and was mainly from the direction of an adjacent patch of wild land (Fig. 5E). In orchard F, most flight also originated from the patch of wild land that lies on the southeastern side of this orchard (Fig. 5F).

Winds in the two different valleys predominantly move in two directions, the wind in the Keremeos Valley moves either from the NW (toward the SE) or from the SE (toward the NW). In the Summerland Valley, wind either moves predominantly from the NE (toward the SW) or from the SW (toward the NE) (Fig. 5 A–E). The flight of thrips into orchards A, B, D, and F did not follow the patterns expected from the predominant wind patterns, although flight of thrips into orchards C and E, which are both highly exposed, could be wind driven.

The direction of flight of thrips out of the orchards appeared to differ from flight into the orchards for orchards B, D, and F, and was also generally more variable in direction in orchards B and F (Fig. 5 B, D, and F). Flight of western flower thrips out of orchards B and D appeared likely to be wind driven, unlike flight into these orchards. However, flight of western flower thrips into and out of orchards A, C, and E was fairly similar (Fig. 5 A, C, and E). Again, flight out of orchards E and C appeared to be affected by the patterns of wind flow in these two different valleys. Flight out of orchard A appeared to be much more affected by the direction of wind in this valley than was flight into this orchard (Fig. 5A).

Thus, in general, mean direction of flight was from areas of wild land for those orchards which lie adjacent to large patches of wild land. Interestingly, mean direction of thrips flight varied among the four southern orchards and also between the two northern orchards, which suggests that something other than the major wind flow is responsible for affecting the direction of thrips flight.

Levels of concentration (*r*) were generally low in each orchard, which is not surprising given the high mobility of this insect (Table 1). However, *r* values tended to be higher in April than later in the spring and summer, except for orchard D where concentration was always low.

Movement of Thrips in Wild Lands. Only on 22 April ($t = 2.6$, df = 7, $P = 0.05$) and 3 May ($t = 3.0$, df = 7, $P = 0.02$) were there significantly higher numbers of western flower thrips per card on cards facing wild lands ('out') as compared with the cards facing orchards ('in') on posts located in wild land adjacent to orchard A. In wild land adjacent to orchard B, there were significantly higher numbers of thrips on cards facing wildlands ('out') only on 14 May ($t = 2.5$, df = 7, $P = 0.04$). All other dates of comparisons showed no significant differences between cards facing toward the orchard or the wildland (paired *t*-tests: df = 7, $P > 0.05$). Overall, however, 13 of 17 comparisons between 18 April and 1 June tended to be in favor of cards capturing thrips flying from wildlands adjacent to orchards A and B toward the orchards (Pearsall 1998).

The patterns of flight on posts located within wild land and around the orchards were fairly synchronous (see Fig. 2A and 6). However, the densities of western flower thrips per card within wildlands were much higher in April at the time of thrips emergence from their overwintering sites. Densities were similar between posts in wild land and orchard peripheral posts at the time of the second main peak in May, which occurred when the new generation of adult western flower thrips emerge.

In general, movement out of wildlands tended to be greater than movement of thrips into orchards. For almost all dates of comparison between 18 April and 1 June, there were greater densities of western flower thrips on the 'out' cards trapping thrips leaving wild areas than on 'out' peripheral cards in orchards A and B located at a similar level (1 m), with the exception of later in May, when densities were generally much higher and did not differ between the orchard periphery and wild areas (orchard A: independent *t*-tests, for five out of nine dates: df = 18, $P < 0.02$; orchard B: independent *t*-test, for six out of eight dates: df = 18, $P < 0.02$; Pearsall 1998). Thus, the western flower thrips is most common in wild land, which is no doubt the major source area for this insect, and densities of these thrips appear to become reduced as they move toward orchards, passing by numerous weed and wildflower species at the orchard edge.

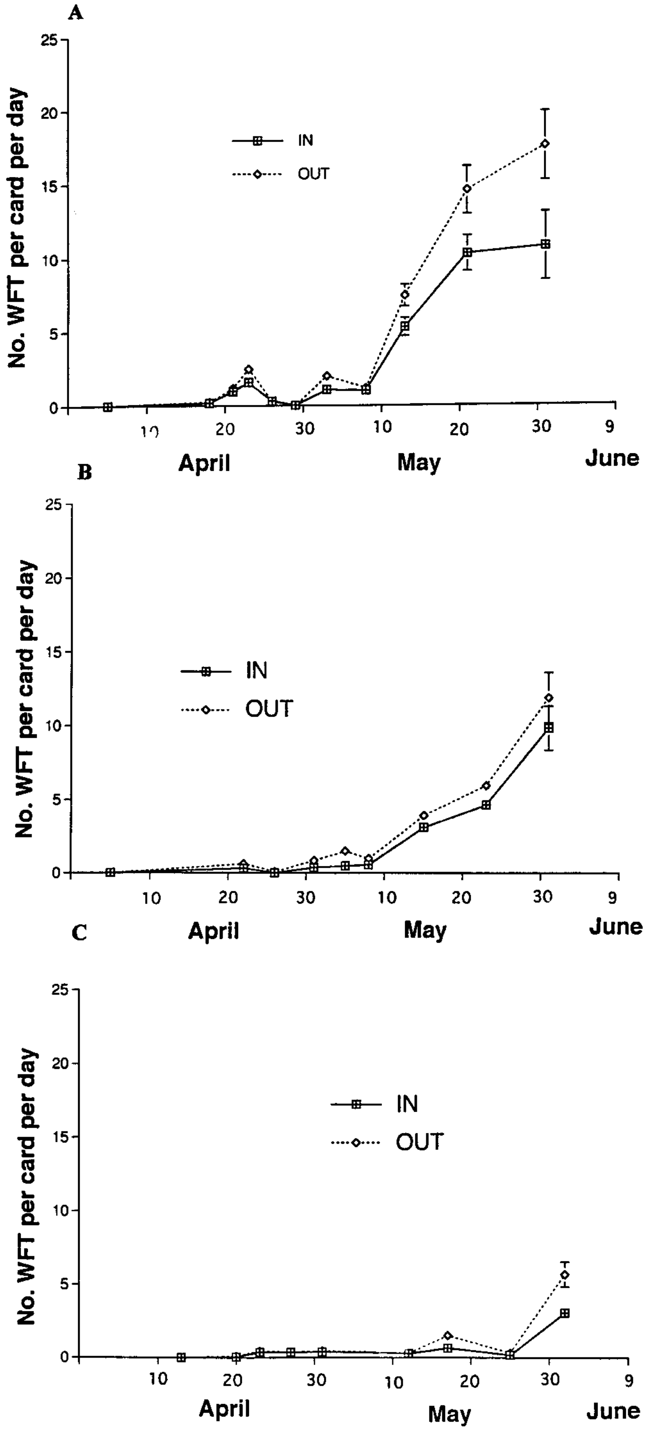


Fig. 4. Number of western flower thrips per sticky card per day caught at each of two different orientations ('in' [facing orchard] and 'out' [facing wildland]) on peripheral posts for (A) orchard A, (B) orchard C, and (C) orchard E for several sampling dates between 5 April and 1 June 1993.

Movement of Thrips in Orchard Interiors. Patterns of western flower thrips density per card from the interior posts were compared with the density of western flower thrips on the outside posts throughout the season (Fig. 2 and 7). The patterns of western flower thrips abundance on the interior cards from all the

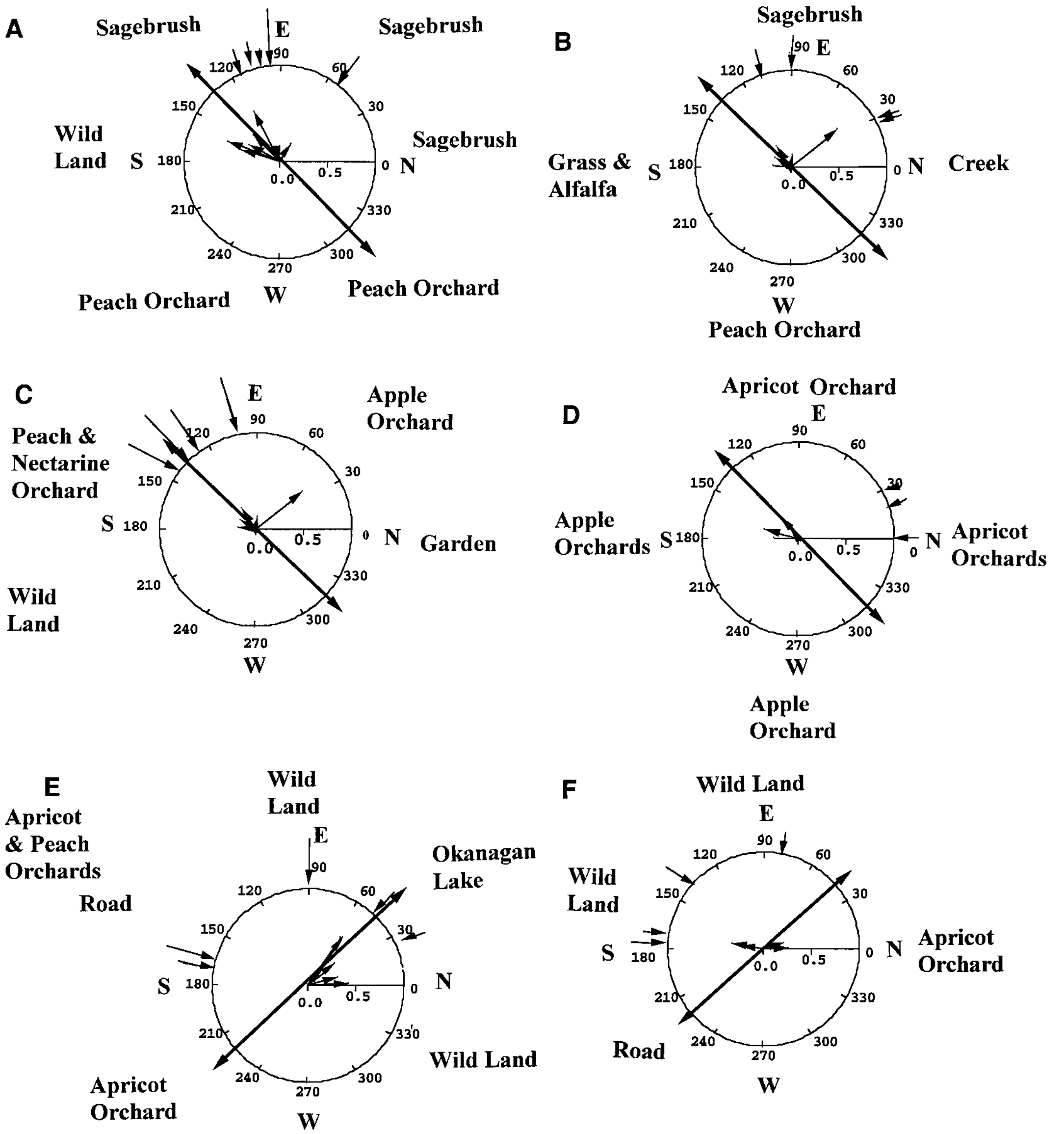


Fig. 5. Mean direction of flight into and out of orchards A–F as shown using circular statistics. Arrows pointing in toward the center of circles display mean movement into the orchard for those dates that it was found to be statistically significant (from catches on 'out' cards), whereas arrows pointing from the center of the circle toward the perimeter display mean movement out of the orchard for those dates that it was found to be statistically significant (from catches on 'in' cards). The length of each vector equals r, and r cannot be >1, which is the radius of the circle. The bidirectional thick arrow shows in each case the main direction of wind flow through the valley.

orchards were very similar to that found on cards from the peripheral posts.

In orchard B, with a dense mat of dandelions, the density of western flower thrips on the interior ground cards was higher than the interior tree level cards for all sample dates in May, as was the case for sticky cards on the peripheral posts (independent t-test: df = 22; $P < 0.01$ for 3, 10 and 23 May; Pearsall 1998). In all other orchards surveyed, the number of western flower thrips at canopy and ground levels were the same (independent t-tests: df = 22 for orchards C and D; df = 14 for orchard E; $P > 0.05$ for all dates; Pearsall 1998). The presence of dandelions therefore appears to affect distribution and abundance of western flower thrips.

Discussion

Western flower thrips were by far the most abundant thrips species captured on the sticky cards throughout spring and the early summer in this region of British Columbia. Western flower thrips, together

Table 1. Measure of concentration (r) as given by Raleigh's test of mean angles for thrips flying out of orchards ('in' cards), and into orchards ('out' cards) as assessed by catches on sticky cards in April, early May and late May/early June in orchards A–F, 1993

Orchard	Date	In cards	Out cards
A	18–23 April	0.57–0.60	0.30–0.61
A	3–13 May	0.21–0.38	0.19–0.27
A	21–31 May	0.09–0.15	0.15–0.19
B	26–30 April	0.15–0.63	0.19–0.23
B	3–14 May	0.13–0.26	0.08–0.36
B	23 May–1 June	0.09–0.18	0.02–0.04
C	22 April	0.60	0.67
C	1–15 May	0.19–0.66	0.38–0.61
C	23–31 May	0.02–0.31	0.06–0.38
D	26 April	0.24	0.17
D	10 May	0.14	0.08
D	22–31 May	0.25–0.35	0.08–0.25
E	20–27 April	0.41–0.60	0.21–0.35
E	1–12 May	0.36–0.43	0.16–0.33
E	17 May–1 June	0.04–0.33	0.26–0.55
F	5–12 May	0.23–0.25	0.19–0.25
E	17 May–1 June	0.24–0.32	0.26–0.37

Ranges denote minimum and maximum levels of concentration determined for the different sampling dates within any one month.

with the flower thrips, *Frankliniella tritici* (Fitch), and the soybean thrips, *Neohydatathrips variabilis* (Beach), were the most abundant thrips found in nectarine orchards in Georgia (Yonce et al. 1990), although the relative abundances varied each year. In peach and nectarine orchards in Pennsylvania, western flower thrips, together with flower thrips, *Frankliniella tritici*, and pear thrips, *Taeniothrips inconsequens* (Uzel), were found to cause injury to fruit (Felland et al. 1995). Other studies of thrips in nectarine orchards in California, Italy, and France also have shown that western flower thrips are sufficiently common to cause serious fruit damage and to warrant insecticide applications (LaRue et al. 1972, Cravedi et al. 1983, Cravedi and Molinari 1984, Grasselly et al. 1993). In Greece, damage to nectarines is caused primarily by *Frankliniella intonsa* (Trybom) and *Taeniothrips inconsequens* (Uzel) (Kourmadas et al. 1982), whereas in New Zealand, damage to nectarines is attributed to the New Zealand flower thrips *Thrips obscuratus* (Crawford) (Thysanoptera: Thripidae) (Teulon and Penman 1996). The type of fruit damage caused by western flower thrips varies in different locations. In France, Italy, Pennsylvania, and the southeastern United States, most damage is apparent as a silvering of the fruit surface, caused by female oviposition and feeding activity at the time of fruit swell. In California, damage caused by larval feeding at petal fall is found in addition to the silvering injury. These differences may be due to variation in the timing of emergence or immigration of western flower thrips. In British Columbia, emergence of western flower thrips from overwintering locations in wild land close to orchards is well timed with the early stages of nectarine bud development, thus damage is primarily in the form of russetting due to larval feeding (Pearsall 1998).

The species composition of thrips in this study was similar among areas of wild land and within orchards located both close to and far from areas of wild land, although there did appear to be a higher proportion of the dark morph of western flower thrips caught on sticky cards at the periphery of orchards as compared with cards placed in wild lands. One possibility is that the pale morph is more highly attracted to the nectarine blooms than is the dark morph, thereby resulting in an apparent reduction in the relative prevalence of the former as assessed by sticky card catches in orchards. There also tended to be higher proportions of the dark morph in orchard D, which was isolated from wildlands, than in all other orchards. Because this

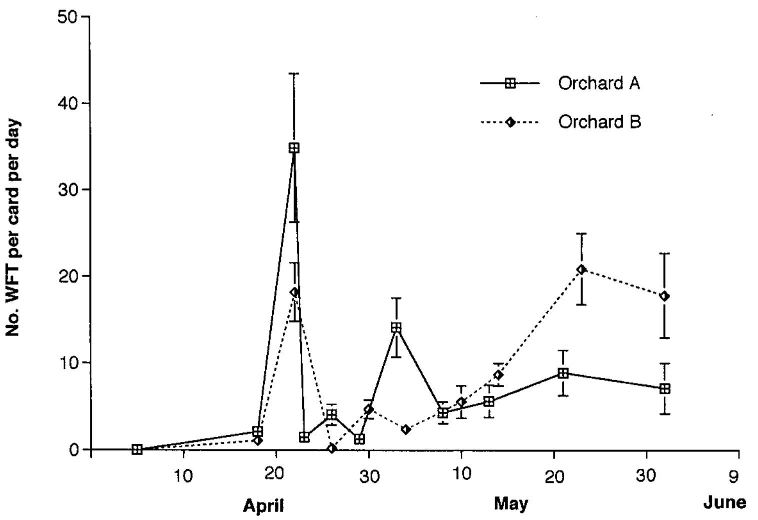
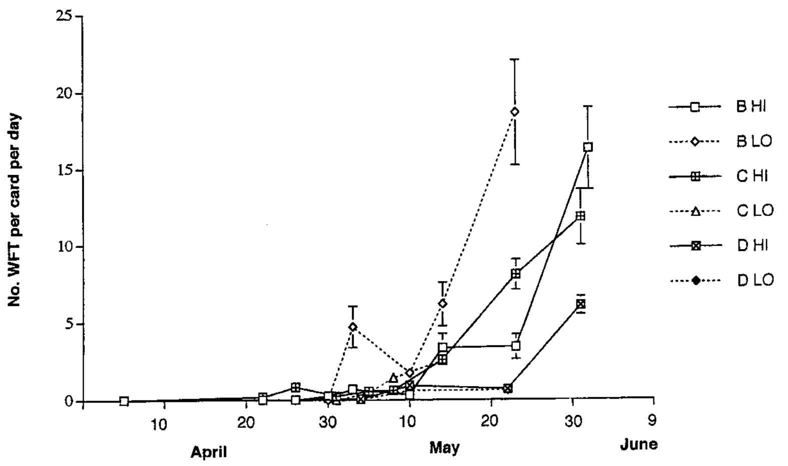


Fig. 6. Numbers of western flower thrips caught per day per card from a total of 16 sticky cards located on eight posts * two orientations ('in' [facing orchard] and 'out' [facing wildlands]) in wildland adjacent to orchards A and B from 5 April–1 June 1993.

A



B

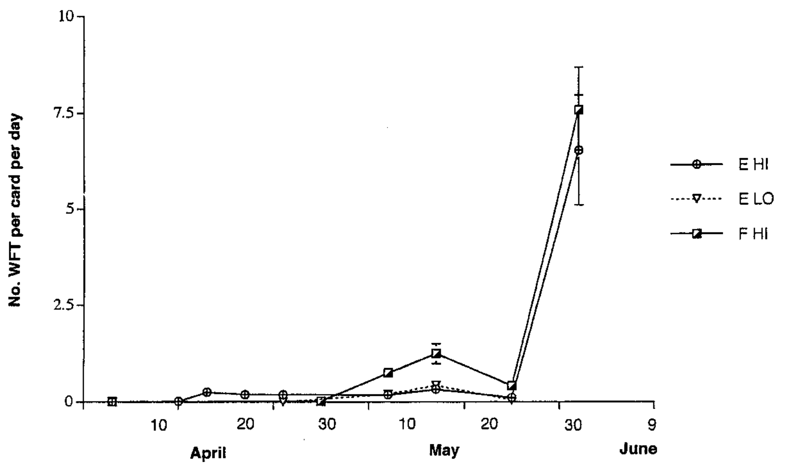


Fig. 7. Number of western flower thrips caught per day per card from sticky cards located on interior posts (two cards from each of four to six posts for one to two heights [canopy 'HI' and ground level 'LO']) from (A) orchards B–D and (B) orchards E and F from 5 April to 1 June 1993.

orchard is fully surrounded by other orchards, the thrips caught on sticky cards may be a resident population from the orchard and the surrounding blocks of trees. This orchard may not receive high levels of immigration from the vast areas of wild land in the region, from which huge numbers of the pale morph appear to emanate in the early spring. The three species most commonly found on sticky cards: the western flower thrips, *F. occidentalis;* a new and only recently described species, *Thrips fallaciosus* Nakahara; and the Phlaeothripid *Haplothrips kurdjumovi* Karny also were identified as the only species found within nectarine blossoms in a separate study (Pearsall and Myers 2000). Much lower densities of western flower thrips were captured on sticky cards located in the interior of orchards, as compared with the catches in wild lands. This low trap catch within the orchard may result from these thrips being more attracted to nectarine and ground cover blooms within the orchard than they are to the sticky cards.

Temperature more than any other physical factor is known to influence aerial dispersal of both winged and nonwinged invertebrates (Taylor 1963). Western flower thrips were caught on sticky cards as soon as the mean daily temperature reached 9°C and the maximum temperature reached 15°C and populations of thrips in flight appeared to increase rapidly in mid-May as the temperatures rose. Most of the thrips appeared to move into orchards at ground level in the early spring. This may be because low temperatures do not permit the production of thermal updrafts, which can carry thrips to higher levels later in the season. Thus, they probably enter orchards in a series of jumps at ground level. After nectarine bloom, thrips moved into the other orchards equally at ground level and at the 1-m level, which is the height of the bottom of the tree canopy. Even when there was no bloom left on trees, thrips were still moving into orchards located close to wild lands (A and B) primarily at the ground and low levels. This suggests that thrips are moving down the mountain sides at the height of 1 m or less, which is the approximate height of the sagebrush and other wild land vegetation. Thus, the distribution of thrips is probably related to the position of available blooms. Movement of thrips within orchards, as assessed by catches on the interior sticky cards, was equal at canopy level and at the ground cover level except for in orchard B, with a very high density of dandelions and high catches of western flower thrips at ground level.

Western flower thrips densities were higher on sticky cards in orchards located in the South as compared with the North. In general, the early stages of nectarine development were delayed in the North relative to the South, and mean and maximum temperatures were much higher in the southern than the northern orchards. Emergence and development of thrips through to pupae was delayed ≈1 wk in the northern orchards compared with those in the South (Pearsall 1998). The lower spring catches of adult thrips in the northern orchards may simply be due to reduced flight activity in these orchards in the spring because of the lower temperatures.

Densities of western flower thrips on cards in wild areas were always higher than on cards located at a similar level (1 m) at the periphery of orchards A and B. In general, results also indicated that there were higher numbers of thrips entering orchards that were located close to patches of wild land, particularly those orchards flanked on one or more sides by the vast tracts of wild land that is located on the hillsides in this region. In a parallel study we found that orchards on the hillside had higher densities of buds infested by larval western flower thrips, and higher levels of fruit scarring than orchards that were fully surrounded by other trees, such as orchard D (Pearsall and Myers 2000).

Although western flower thrips overwinter within orchards (Pearsall and Myers 2000), it appears that many more thrips immigrated from areas of wild land, and thus orchards adjacent to wild areas appear to be most at risk. If movement into orchards occurred as one distinct peak, a management strategy at the time of emergence and immigration might be successful. However, even though there were distinct peaks of flight, movement into orchards appeared to occur as a gradual and continuous stream of insects. This greatly reduces the likelihood of successful control at this point in the life cycle.

Cho et al. (1989) and Puche et al. (1993) suggested that adult thrips are unlikely to travel very great distances. The mean direction of movement varied among orchards, and even in closely positioned orchards such as E and F, movement was in opposite directions but in both cases from wild areas of weeds, wildflowers and sagebrush to the orchard. These results suggest that the type of vegetation surrounding an orchard plays an important role in the direction of dispersal of these insects. In general, western flower thrips appeared to move into orchards from the direction of patches of wild land, regardless of the wind flow patterns, but moved out of orchards in accordance with the dominant wind patterns. The protected orchard (D), not only received generally low densities of western flower thrips, but thrips in this orchard showed neither consistent directional movement nor a height differential in flight.

It is generally believed that thrips are unable to direct the course of their flight in anything stronger than the slightest breeze. However, at very low wind speeds it is possible that they may control their direction. There are many calm days or periods of days when this could occur in the interior of British Columbia. The range of air-speeds for thrips probably varies between 10 cm per second for small Terebrantia and 50 cm per second for the largest Tubulifera (Lewis 1973). For medium sized Terebrantia, such as western flower thrips, the mean flight speed is probably something in the order of 15 cm per second. At higher wind speeds, it is likely that the thrips cannot direct their direction of flight and may be impacted onto cards. In this case, the density of thrips at any particular height is a measure of the density of this "aerial plankton." It was impossible to make a correction for wind speed in this study because winds were variable over time and sticky cards were placed out for a number of days. However, on the occasions that wind speeds were measured using a hand-held anemometer, wind speed at the high and medium card levels (2 and 1.5 m) were always much higher than the speeds at the low and ground levels (1 m and 25 cm) (Pearsall 1998). Thus, the densities at the high and medium levels would be even lower relative to those at low and ground levels if we were to correct for wind speed. Thrips at ground level are likely to be hopping onto cards, and thus numbers may be substantially elevated at this level when attractive ground cover blooms are present. Results suggested that most movement of western flower thrips, at least in these orchards, was close to ground level, where wind speeds also were often low enough to allow control of the direction of movement. This is in disagreement with the results of several other studies using sticky cards to assess the relative density of western flower thrips which have shown that the greatest numbers were caught on sticky cards placed just above the crop canopy (e.g., Brodsgaard 1989, Gillespie and Vernon 1990).

The lack of orientation found in this study might be due to the wind forming eddies around a flat surface (Lewis 1959) and thus thrips initially approaching one side of a sticky card, may be carried around the edges of cards to become trapped on the opposite side from which they originated. However, the significant variation in directional movement into and out of orchards, exemplified by cases in which thrips appeared to enter an orchard mainly from one direction, but leave mainly in another, suggests that thrips can be oriented in their movement.

In conclusion, our results indicate that local movement of emerging thrips into orchards in the early spring occurred primarily at ground level, and was greatest into orchards located adjacent to wild land. Western flower thrips were by far the most abundant species of thrips trapped on sticky cards, although there were variations in the proportions of the dark and pale color morphs, with more pale morph females caught in areas of wild land, and more dark morph females caught in the orchards that were not located adjacent to wild land. This work suggests that thrips can direct their movement into orchards: perhaps by a combination of "hopping" from plant to plant and remaining at ground level, western flower thrips can avoid the effects of higher wind speeds at higher levels above ground level and thus have some control of their direction. Finally, height of flight appeared to be affected by the height and type of vegetation both surrounding and within orchards.

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