Occurrence of the Western Flower Thrips, *Frankliniella occidentalis*, and potential predators on host plants in near-orchard habitats of Washington and Oregon (Thysanoptera: Thripidae)

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ABSTRACT

One hundred thirty species of native and introduced plants growing in uncultivated land adjacent to apple and pear orchards of central Washington and northern Oregon were sampled for the presence of the western flower thrips (WFT) *Frankliniella occidentalis* (Pergande, 1895) and potential thrips predators. Plants were sampled primarily while in flower. Flowering hosts for WFT were available from late-March to late-October. Adult WFT occurred on 119 plant species and presumed WFT larvae were present on 108 of 119 species. Maximum observed WFT density on several plant species exceeded 100 individuals (adults and larvae) per gram dry weight of plant material. The most abundant predator was *Orius tristicolor* (White, 1879) (Heteroptera: Anthocoridae). It was collected on 64 plant species, all of which were hosts for WFT. The second most abundant predators were spiders (Araneae). Small spider immatures (first and second instars) of several species were common on certain host plants, and are likely to feed on WFT.

Key Words: *Frankliniella occidentalis*, western flower thrips, host plants, predators, *Orius tristicolor*, Araneae, spiders.

[1]INTRODUCTION

The western flower thrips (WFT) *Frankliniella occidentalis* (Pergande, 1895), was originally distributed throughout western North America (Kirk and Terry 2003). In the past 30 years WFT has spread to much of the rest of North America and now also occurs throughout Europe and parts of North Africa (Kirk and Terry 2003). It is a pest in both the field and the greenhouse, attacks a large number of crops, and causes damage by feeding, oviposition, and most importantly, transmission of Tospoviruses (Reitz 2009). WFT is an important secondary pest of certain apple varieties in the Pacific Northwest, producing a pale, cosmetic blemish known as a pansy spot that forms around the site of oviposition (Venables 1925; Madsen and Jack 1966). Although the damage is superficial, affected fruit may be downgraded at harvest (Madsen and Jack 1966; Terry 1991). Control of WFT on apple can be challenging because it occurs on trees primarily when pollinators, especially honeybees, *Apis mellifera* Linnaeus, 1758, are active in the orchard canopy. It has also been difficult to determine when, during fruit formation, damage-causing oviposition occurs and, consequently, when control measures are most needed (Cockfield *et al*. 2007).

Host plant utilization by WFT is very broad. Bryan and Smith (1956) found it on 139 plant species (representing 45 families) in California, which is within the pest's original geographic range. In areas to which it has spread, host plant utilization is also broad, and in Hawaii it was found on 48 plant species on the island of Maui (Yudin *et al*. 1986). Chellemi *et al*. (1994) found it on 24 of 37 plant species surveyed in Florida within a decade after its first detection. In a study done barely ten years after the insect was first reported all 49 plant species sampled in Turkey harbored WFT (Atakan and Uygur 2005). In Chile, where it has become a serious

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agricultural pest, WFT occurred on 50 of 55 plant species and appears to have supplanted a native species of *Frankliniella* as the most common thrips species (Ripa *et al.* 2009).

A number of predators are known to attack WFT (Sabelis and Van Rijn 1997). Few of the studies that have reported on WFT's occurrence on non-crop plant species have also reported on the presence of predator species. Northfield *et al.* (2008) studied the population dynamics of WFT on seven uncultivated host plants and also reported on the occurrence of the important thrips predator *Orius insidiosus* (Say, 1832) (Heteroptera: Anthocoridae). Tommasini (2004) monitored *Orius* populations on known host plants of WFT in Italy and found that several species of Orius commonly occurred at high densities on a number of these host plants, apparently in association with WFT.

In this study, we surveyed native and introduced plant species in fruit-growing regions of central Washington and northern Oregon where WFT is a secondary pest of certain apple varieties. Our objectives were to 1) gain an understanding of WFT utilization of non-cultivated host plants typical of near-orchard habitats in the study areas, 2) develop a better understanding of WFT phenology across the season, and 3) improve our understanding of known and potential WFT predators occurring on these non-cultivated host plants, with emphasis on minute pirate bugs (Heteroptera: Anthocoridae) and spiders (Araneae).

MATERIALS AND METHODS

Study Sites. This study was conducted at 11 sites in Washington State and two sites in northern Oregon (Table 1). Virtually all sampling was done in native habitat immediately adjacent to orchards, generally within 100 m of an orchard edge; a few plant species of interest that occurred in the understory of orchards were also sampled. Most of the sites were in Yakima County, Washington, located in the south-central part of the state. Two sites were near Hood River in northern Oregon (Table 1).

With one exception, each tract of native habitat was at least several hectares in area and adjacent to orchard habitat. The only exception was a tract comprising a 25 m wide strip of native vegetation occurring between an orchard and an irrigation canal. Native habitat at all Yakima County and the Grant County locales was sagebrush steppe (Table 1). Sagebrush steppe at Hambleton, Durey, and Sunset fell within the lithosol zone of Taylor (1992), and is characterized by thin, rocky soils and a diverse flora. In mid-May at these locations we noted 25 or more plant species in flower simultaneously. Sagebrush steppe at the remaining Yakima County sites and the Grant County site fell within the standard-type zone (Taylor 1992), characterized by moderately deep soil and vegetation dominated by grasses and tall sagebrush, *Artemisia tridentata* Nutt. (Asteraceae). The Ing, Wells, and Alway sites consisted of mixed hardwood/coniferous woodland. Trees included *Pinus ponderosa* Dougl. (Pinaceae), *Pseudotsuga menziesii* (Mirbel) Franco (Pinaceae), *Acer macrophyllum* Pursh (Aceraceae), and *Quercus garryana* Dougl. (Fagaceae). Understories at all three sites consisted of a variety of shrubs and forbs.

Sampling for thrips and predators. The Yakima County study sites were visited at approximately weekly intervals during 2002 from early April to late October. Due to greater travel distances the Grant County site was visited bi-weekly, and the Chelan County and Oregon sites were visited monthly from April to July. Sampling in 2003 was limited to selected plant species (see below) at sites in Yakima County. Durey and Hambleton were visited weekly from late March to late October, while the other Yakima County sites were visited when species of interest were in flower. During each visit, observations were made of plants in flower and whether a species was at early, full, or late bloom. Notes were also made of species that had recently passed out of bloom and of those that were about to come into bloom.

Samples were collected by removing inflorescences or individual flowers with scissors or pruning shears and immediately placing them in 3.8L, self-sealing, plastic bags. Care was taken when removing flowers to avoid dislodging insects and spiders. Since

Table 1.
Sampling sites, habitat type at each site, and sampling frequencies.

			Sampling frequency[1]	
Site	**Location (county)**	**Habitat**	**2002**	**2003**
Hambleton	3.5 km N Tieton (Yakima)	Sagebrush-steppe	W	W
Durey	4.5 km NNW Tieton (Yakima)	Sagebrush-steppe	W	W
Sunset	4.5 km S Tieton (Yakima)	Sagebrush-steppe	W	I
Carlson	3 km SSE Union Gap (Yakima)	Sagebrush-steppe	W	I
Leach	6 km NNE Zillah (Yakima)	Sagebrush-steppe	W	I
Lynch	5.5 km NE Zillah (Yakima)	Sagebrush-steppe	W	I
Hattrup	5 km SSE Moxee (Yakima)	Sagebrush-steppe	W	I
Valicoff	6.5 km SSE Moxee (Yakima)	Sagebrush-steppe	W	I
USDA	18 km ESE Moxee (Yakima)	Sagebrush-steppe	W	I
Knutson	10 km SE Mattawa (Grant)	Sagebrush-steppe	BW	--
Alway	Peshastin (Chelan)	Mixed hardwoods and conifers	M	--
Ing (Oregon)	2 km SSE Hood River (Hood River)	Mixed hardwoods and conifers	M	--
Wells (Oregon)	6 km SSE Hood River (Hood River)	Mixed hardwoods and conifers	M	--

[1] W, weekly; BW, bi-weekly; M, Monthly; I, irregularly.

WFT is primarily associated with flowers, non-flower plant parts such as leaves and stems were kept to a minimum in samples during the bloom periods. Samples taken outside of the bloom period included primarily rapidly growing vegetative tissue. Samples were transported in a cooled ice chest to the laboratory where they were held in a refrigerated room until processed, generally within 24 h. The amount of plant material collected for a sample varied from species to species depending upon its abundance at a site and the nature of its inflorescence. Abundant species with large or bulky inflorescences were collected in sufficient quantity to loosely fill a bag. Smaller quantities were obtained of less abundant species and those with small, more difficult to collect flowers. Blooms were collected from several individual plants per species at a site to obtain a sample. The number of individual plants sampled per species depended upon the density of that species at the site.

We were interested in each plant species primarily during its bloom period. A single, flowering period sample was obtained for some species, but many were sampled more than once during bloom. Several species were sampled weekly while in flower with additional samples taken during the pre-bloom and post-bloom periods. The extreme example was bitterbrush *Purshia tridentata* (Pursh) DC

(Rosaceae), which was sampled weekly at the Durey site from 16 April to 28 October 2003, for a total of 29 sample dates. Most species were sampled at one or two locations, but samples from arrowleaf balsamroot *Balsamorhiza sagitatta* (Pursh) Nutt. (Asteraceae), a common, widespread species, were obtained at nine sites. In 2002, most of the plant species at each site were sampled on at least one date. Based on the 2002 findings, 16 species that supported high numbers of thrips and predators were monitored in 2003.

Extraction of arthropods. Thrips and predatory arthropods were extracted from plant material using Berlese funnels. Heat from 40 watt light bulbs was used to force arthropods out of the plant material and into 500 ml plastic jars each containing 50 ml of 70% isopropyl alcohol. Samples were held in the funnels for 24-48 h depending on the quantity of plant material. This length of time was sufficient to dry the plant material, which was then weighed on an electronic balance. We calculated thrips numbers per gram dry weight of plant material.

Processing of samples. WFT was the only thrips identified to species (by comparison with vouchers). Species other than WFT were generally few in number (see Results). Larval thrips were counted but were not identified. When the adult thrips in a sample were exclusively WFT we assumed that all larval thrips were that species. If adults of more than one species were present the number of larval WFT was estimated based on the proportion of adult WFT in the sample. If the number of thrips in a sample appeared to be less than 300, an exact count was made. For samples that obviously contained a greater number, the number of thrips was estimated by counting a subsample (an exception was made for the maximum density from each plant species, which was always determined by an exact count). To obtain estimates from subsamples, the thrips (in alcohol) were poured into a plastic Petri dish inscribed on the bottom with six squares each 1 cm x 1 cm in size. The dish was agitated until the thrips were distributed approximately uniformly over the bottom of the dish. The thrips within each square were counted, the average number per square was computed, and this average was multiplied by the area of the dish to obtain an estimate of the total.

Exact counts were made of all predators. For minute pirate bugs, *Orius* spp., the number of males, females, and each of the five nymphal instars was determined. Samples were composed almost entirely of *Orius tristicolor* (White, 1879), although scattered individuals of *Orius diespeter* Herring, 1966 were likely present in the Peshastin samples (Lewis *et al.* 2005). Immature spiders of several species were common in some samples. In most cases it was possible to identify these to species based on our familiarity with the local fauna. It was also possible to estimate the nymphal stage of many of these spiders based on comparison with reference specimens of known stage.

RESULTS

Host plant characteristics. One hundred and thirty plant species were sampled, representing 34 plant families and 101 genera (Table 2). Ninety-nine species were native to the study area, while 31 species were introduced. The Asteraceae was represented by the most species (32), and the wild buckwheat genus *Eriogonum* (Polygonaceae) was the best represented genus with seven species. Samples from red clover *Trifolium pratense* L., white clover *Trifolium repens* L., and alfalfa *Medicago sativa* L. (all Fabaceae) were collected only within orchards. Plant growth form varied, but perennial forbs were the most common (62 species) followed by shrubs (20 species) and annual forbs (16 species).

Host plant utilization by *Frankliniella occidentalis*. Adult WFT were extracted from 119 plant species, while thrips larvae were extracted from 108 of these same 119 species (Table 2). Plant species that harbored both adult and larval WFT are assumed to be reproductive hosts for the insect. Of the 11 species that did not yield WFT, eight were sampled only once, five have rather small or inconspicuous flowers, and one blooms early in the spring. Two of the species that did not yield WFT, (*Lomatium triternatum* (Pursh) Coult. and Rose and *Erigeron pumilus* Nutt.) had congeneric species that yielded both adult WFT and larval thrips. It is likely that more

Table 2

Plant species sampled for *Frankliniella occidentalis* (WFT) indicating presence (+) or absence (-) of WFT and presumed WFT larvae. Max. WFT density is the maximum density (# of adults plus larvae per gram dry weight of plant material) recorded for a plant based on an exact count. Abbreviations: N=native species; I=introduced species; F=forb; H=herb; S=shrub; T=tree; V=vine; A=annual; B=biennial; P=perennial.

Host plant	Plant Origin	Type of plant	WFT adults	WFT larvae	Max. WFT density	No. of samples
ACERACEAE						
Acer macrophyllum Pursh	N	T	+	-	0.7	2
APIACEAE						
Daucus carota L.	I	BF	+	+	0.2	1
Lomatium columbianum Mathias and Constance	N	PF	+	+	0.5	1
Lomatium grayi Coult. and Rose	N	PF	+	+	21.6	8
Lomatium nudicaule (Pursh) Coult. and Rose	N	PF	+	+	0.2	2
Lomatium triternatum (Pursh) Coult. and Rose	N	PF	-	-	0	1
APOCYNACEAE						
Apocynum androsaemifolium L.	N	PF	+	+	24.8	5
ASCLEPIADACEAE						
Asclepias speciosa Torr.	N	PF	+	+	255.9	8
ASTERACEAE						
Achillea millefolium L.	N	PF	+	+	62.5	63
Agoseris glauca (Pursh) Raf.	N	PF	+	+	0.2	2
Ambrosia artemisiifolia L.	I	AF	+	+	1.2	1
Artemisia tridentata Nutt.	N	S	+	+	30.4	80
Artemisia sp.	N	S	+	+	15.3	6
Balsamorhiza hookeri Nutt.	N	PF	+	+	20.4	6
Balsamorhiza sagittata (Pursh) Nutt.	N	PF	+	+	27.8	57
Centaurea cyanus L.	I	AF	+	+	21.8	4
Centaurea diffusa Lam.	I	A/BF	+	+	9.9	13
Chaenactis douglasii (Hook.) Hook. and Arn.	N	B/PF	+	+	29.1	14
Chrysothamnus viscidiflorus (Hook.) Nutt.	N	S	+	+	58.7	84
Cirsium arvense (L.) Scopoli	I	PF	+	+	34.4	12
Cirsium undulatum (Nutt.) Spreng.	N	B/PF	+	+	1.8	2
Crepis acuminata Nutt.	N	PF	+	+	15.7	14
Crepis occidentalis Nutt.	N	A/PF	+	+	0.7	4
Crocidium multicaule Hook.	N	AF	+	-	11.4	1
Dieteria canescens (Pursh) Nuttall	N	B/PF	+	+	17	10
Ericameria nauseosa (Pall. ex Pursh) G. Nesom and G. Baird	N	S	+	+	132.2	76
Erigeron filifolius (Hook.) Nutt.	N	PF	+	+	10.5	8
Erigeron linearis (Hook.) Piper	N	PF	+	+	4.3	8
Erigeron pumilus Nutt.	N	PF	-	-	0	1
Eriophyllum lanatum (Pursh) J. Forbes	N	PF	+	+	0.3	5
Helianthus cusickii A. Gray	N	PF	+	+	61.1	7
Iva axillaris Pursh	N	PF	+	+	107.2	7

Host plant	Plant Origin	Type of plant	WFT adults	WFT larvae	Max. WFT density	No. of samples
Lactuca serriola L.	I	AF	-	-	0	6
Layia glandulosa (Hook.) Hook. and Arn.	N	AF	+	+	1.9	3
Nothocalais troximoides (A. Gray) Greene	N	PF	+	+	1.3	5
Pyrrocoma carthamoides Hook.	N	PF	+	+	0.6	8
Senecio integerrimus Nutt.	N	BF	+	+	6.2	4
Solidago lepida DC	N	PF	+	+	35.5	15
Stephanomeria tenuifolia (Raf.) H. M. Hall	N	PF	+	+	0.8	3
Tragopogon dubius Scop.	I	A/BF	+	+	13	8
BERBERIDACEAE						
Berberis aquifolium Pursh	N	S	+	+	0.8	5
BORAGINACEAE						
Amsinckia lycopsoides Lehm ex Fisch. and C.A. Mey	N	AF	+	+	36.8	8
Amsinckia tessellata A. Gray	N	AF	+	+	62.1	10
Cynoglossum grande Dougl. ex Lehm.	N	PF	-	-	0	2
Lithospermum ruderale Dougl. ex Lehm.	N	PF	+	-	1.2	3
Mertensia longiflora Greene	N	PF	+	+	1	2
BRASSICACEAE						
Chorispora tenella (Pall.) DC	I	AF	+	-	0.4	1
Descurania sophia (L.) Webb and Prantl	I	AF	+	+	25.1	5
Erysimum capitatum (Dougl. ex Hook.) Greene	N	B/PF	+	+	2.2	2
Lepidium perfoliatum L.	I	A/BF	+	+	10.7	3
Phoenicaulis cheiranthoides Nutt.	N	PF	+	+	7	1
Sisymbrium altissimum L.	I	A/BF	+	+	60.7	9
Thelypodium laciniatum (Hook.) Endl.	N	BF	+	+	27.5	4
CAPRIFOLIACEAE						
Lonicera ciliosa (Pursh) Poir. ex DC.	N	PV	-	-	0	1
Sambucus cerulea Raf.	N	S	+	+	31.7	4
Symphoricarpos albus (L.) Blake	N	S	+	+	6.2	8
CHENOPODIACEAE						
Kochia scoparia (L.) Schrad.	I	AF	+	+	30.4	8
Chenopodium album L.	I	AF	+	+	9	5
Grayia spinosa (Hook.) Moq.	N	S	+	+	18.2	10
Salsola tragus L.	I	AF	+	+	75.7	12
CLUSIACEAE						
Hypericum perforatum L.	I	PF	+	+	1.2	1
CORNACEAE						
Cornus sericea L.	N	S	+	+	<0.1	2
FABACEAE						
Astragalus sp.	N	PF	+	+	14.9	3
Cytisus scoparius (L.) Link	I	S	+	+	4.9	3
Lupinus lepidus Dougl. ex Lindl	N	PF	+	+	23	4
Lupinus wyethii Wats.	N	PF	+	+	36.9	10

Host plant	Plant Origin	Type of plant	WFT adults	WFT larvae	Max. WFT density	No. of samples
Medicago sativa L.	I	A/PF	+	+	138.7	14
Melilotus officinalis (L.) Lam.	I	A/PF	+	+	178.2	19
Trifolium macrocephalum (Pursh) Poir	N	PF	+	+	1.9	2
Trifolium pratense L.	I	B/PF	+	+	28.4	3
Trifolium repens L.	I	PF	+	+	128.4	22
GROSSULARIACEAE						
Ribes aureum Pursh	N	S	+	+	0.9	1
Ribes cereum Dougl.	N	S	+	+	1	2
HYDRANGEACEAE						
Philadelphus lewisii Pursh	N	S	+	+	89.4	7
HYDROPHYLLACEAE						
Phacelia hastata Dougl. ex Lehm.	N	PF	+	+	231.3	13
Phacelia linearis (Pursh)Holz.	N	AF	+	+	10.8	5
IRIDACEAE						
Olsynium douglasii A. Deitr.	N	PF	-	-	0	1
LAMIACEAE						
Agastache occidentalis (Piper) Heller	N	PF	+	+	29.4	18
Salvia dorrii (Kellogg) Abrams	N	S	+	+	17.6	2
LILIACEAE						
Allium acuminatum Hook.	N	PF	+	+	25.8	2
Asparagus officinalis L.	I	PF	+	+	26.2	1
Calochortus macrocarpus Dougl.	N	PF	+	+	1.9	1
Triteleia grandifora Lindl.	N	PF	+	+	4.1	2
Zigadenus venenosus S. Wats.	N	PF	+	-	0.3	4
MALVACEAE						
Sphaeralcea grossulariifolia (Hook. and Arn.) Rydb.	N	PF	+	+	6.9	4
Sphaeralcea munroana (Dougl ex Lindl.) Spach ex Gray	N	PF	+	+	40.1	3
ONAGRACEAE						
Epilobium angustifolium L.	N	PF	+	+	4	1
PLANTAGINACEAE						
Plantago major L.	I	PF	-	-	0	1
POACEAE						
Bromus tectorum L.	I	AH	+	+	1.1	1
Schedonorus arundinaceus (Schreb.) Dumort.	I	PH	-	-	0	1
Secale cereale L.	I	A/BH	+	+	1.8	1
POLEMONIACEAE						
Collomia grandiflora Dougl. ex Lindl.	N	AF	+	+	0.9	4
Ipomopsis aggregata (Pursh) V. Grant	N	B/PF	+	+	<0.1	1
Phlox hoodii Richards	N	PF	+	+	3.5	10
Phlox longifolia Nutt.	N	PF	+	+	57.1	5
Phlox speciosa Pursh	N	PF	+	+	2.6	6
POLYGONACEAE						

Host plant	Plant Origin	Type of plant	WFT adults	WFT larvae	Max. WFT density	No. of samples
Eriogonum compositum Dougl. ex Benth.	N	PF	+	+	61.5	6
Eriogonum elatum Dougl.	N	PF	+	+	150.9	86
Eriogonum heracleoides Nutt.	N	PF	+	+	48.2	6
Eriogonum microthecum Nutt.	N	PF	+	+	35.8	15
Eriogonum niveum Douglas ex Benth.	N	PF	+	+	23.4	7
Eriogonum strictum Benth.	N	PF	+	+	76.4	4
Eriogonum thymoides Benth.	N	PF	+	+	1.1	4
Rumex crispus L.	I	PF	+	+	12.9	7
RANUNCULACEAE						
Clematis ligusticifolia Nutt.	N	PV	+	+	77.1	28
Delphinium nuttallianum Pritz. ex Walp.	N	PF	+	+	0.9	3
RHAMNACEAE						
Ceanothus integerrimus Hook. & Arn.	N	S	+	+	4.1	6
Ceanothus velutinus Dougl. ex Hook.	N	S	+	+	0.1	2
Frangula purshiana (DC.) Cooper	N	S/T	+	+	2.5	2
ROSACEAE						
Amelanchier alnifolia (Nutt.) Nutt. ex M. Roemer	N	S/T	+	+	0.4	6
Crataegus douglasii Lindl.	N	S/T	+	-	<0.1	2
Holodiscus discolor (Pursh) Maxim.	N	S	+	+	40.3	3
Prunus avium (L.) L.	I	T	+	+	11.2	4
Prunus emarginata (Dougl. ex Hook.) D. Dietr.	N	S/T	+	+	0.5	2
Prunus virginiana L.	N	S/T	+	-	1.4	4
Purshia tridentata (Pursh) DC	N	S	+	+	18.7	71
Rosa woodsi Lindl.	N	S	+	+	88.7	11
Rubus armeniacus Focke	I	S/V	+	+	23.4	4
RUBIACEAE						
Galium aparine L.	N	AF	-	-	0	1
SALICACEAE						
Salix exigua Nutt.	N	S/T	+	+	57.7	15
SANTALACEAE						
Commandra umbellata (L.) Nutt.	N	PF	+	+	0.9	7
SAXIFRAGACEAE						
Heuchera cylindrica Dougl. ex Hook.	N	PF	+	-	0.6	2
Lithophragma parviflorum (Hook.) Nutt.	N	PF	-	-	0	2
SCROPHULARIACEAE						
Castilleja thompsoni Pennell	N	PF	+	+	34.1	9
Collinsia parviflora Lindl.	N	AF	-	-	0	1
Linaria dalmatica (L.) Mill.	I	PF	+	+	1.2	2
Penstemon humilis Nutt. ex Gray	N	PF	+	+	8.8	6
Verbascum blattaria L.	I	BF	+	-	0.1	1
Verbascum thapsus L.	I	BF	+	-	<0.1	2
URTICACEAE						
Urtica dioica L.	N	PF	+	+	9.3	1

intensive sampling would have found WFT on both *L. triternatum* and *E. pumilus*.

Frankliniella occidentalis reached very high densities on some host plants, exceeding 100 individuals per gram dry weight of plant material in samples from eight species (Table 2). Many of our nearly 1200 samples contained several thousand thrips. For example, an exact count of thrips from an 86.2 g sample of flowering *Ericameria nauseosa* (Pall. ex Pursh) G. Nesom and G. Baird (Asteraceae) yielded 10,320 adult WFT, 26 unidentified adult thrips, and 1,079 larvae. A 25.2 g sample of flowering *Asclepias speciosa* Torr. (Asclepiadaceae) produced 5,503 adult WFT, 26 unidentified adults, and 951 larvae. This was the highest density recorded during the study, at 255.9 WFT per gram of plant tissue. WFT was by far the most abundant species of Thysanoptera on the majority of the host plants sampled during this study. Samples from *Eriogonum elatum* Dougl. (Polygonaceae) (86 samples over two years) yielded 26,255 total adult thrips and 61,162 larvae. Only an estimated 143 adults (<1%) were not WFT.

These other thrips included a species tentatively identified as another *Frankliniella*. This thrips occurred on most Asteraceae and in some samples equaled or exceeded WFT in number. The most extreme example was *Pyrrocoma carthamoides* Hook. (Asteraceae). This plant was sampled for eight consecutive weeks in 2002 from the pre-bloom stage to the post-bloom stage. Although WFT was found in each sample it was greatly exceeded in abundance by the second putative *Frankliniella* species. Other genera of Thysanoptera were also abundant on occasion. A species of *Haplothrips* (probably *Haplothrips verbasci* (Osborn, 1897); Horton and Lewis 2003) was dominant on *Verbascum thapsus* L. (Scrophulariaceae). A sample of *V. thapsus* late in its 2002 flowering period yielded 1040 Haplothrips (adults and larvae) but only four WFT.

Plant phenology and thrips counts. We present phenology data from two extensively sampled sites (Durey and Hambleton; Table 1) west of Tieton (Fig. 1); the two sites are separated by approximately 1 km. Plant diversity was high in the habitat adjacent to the orchards at both sites. Plants in flower were present at the two sites on all dates between early-April and mid-October (Fig. 1). Species that bloomed early included *Balsamorhiza sagittata* and other forbs. Late-flowering species included *Chrysothamnus viscidiflorus* (Hook.) Nutt. (Asteraceae) and *Eriogonum microthecum* Nutt. (Polygonaceae) (Fig. 1). One plant species, *Eriogonum elatum*, had a very long flowering period, first showing blooms in late-June and flowering well into October (Fig. 1).

WFT was present, often in large numbers, throughout the sampling period at these sites (Fig.1). Generally, WFT occurred at only low densities on plants in the weeks preceding bloom. WFT density increased during the flowering period, and larval thrips greatly outnumbered adults in some samples from some plant species. For example, a peak bloom sample from *Phacelia hastata* Dougl. ex Lehm. (Hydrophyllaceae) yielded 297 WFT adults and 2594 thrips larvae. Post-bloom densities of thrips were usually low, and the near disappearance of the insect during the immediate post-bloom period could be rapid (see also section on thrips and predator phenology, below). The perennial E. elatum was notable for its lengthy flowering period and relatively high densities of thrips. Throughout the flowering period WFT was present at densities as high as 150.9 per gram dry weight of *E. elatum* plant material. Densities on *E. elatum* remained high well into October when most other plant species had passed out of bloom (Fig. 1). From late June to late September larvae usually outnumbered adults and comprised up to 90% of a sample. Since WFT were virtually the only adult thrips in our samples most larvae were undoubtedly this species. Thus *E. elatum* appears to be an excellent reproductive host for WFT.

Shrubs, which remain relatively green and succulent throughout the season, often supported WFT even when not in flower. *Chrysothamnus viscidiflorus*, *Ericameria nauseosa*, and *Artemisia tridentata* flower in late-summer or fall, but pre-bloom samples as early as mid-May from all three species yielded WFT adults and thrips larvae at low densities (<1.0/gram dry weight).

Purshia tridentata presented an interesting case. *Purshia* flowers heavily for about four weeks in late-spring (Fig. 1). WFT density peaked late in the flowering period or during early post-bloom and then declined gradually over the next several weeks. From mid-July to early-September it was present at very low densities, and no adults were found in some samples. Then, in mid-September, adults began to show up in increasing numbers and were present through the end of October (Fig. 1), despite the absence of blooms. These late season individuals were almost exclusively females. WFT was found in the surface soil and litter beneath *Purshia* shrubs in late autumn, apparently in preparation for overwintering (unpublished observations).

Predators of *Frankliniella occidentalis* and predator phenology. Minute pirate bugs (*O. tristicolor*) were the most abundant thrips predators collected. Adult and/or nymphal pirate bugs were collected from 64 host plants (Table 3) all of which also hosted WFT. *Orius* generally attained its highest densities on host plants that also supported high densities of WFT, such as *Achillea*, *Medicago*, *Eriogonum*, *Clematis*, and *Trifolium* (Tables 2 and 3). Plants on which both insects reached high densities tended to have long flowering periods, and 18 of the 20 species on which the highest WFT densities were recorded had flowering periods lasting a minimum of four weeks. A second factor that may contribute to high *Orius* and WFT densities on some plants may be flowering phenology. *Chrysothamnus viscidiflorus*, *Ericameria nauseosa*, and *Artemisia tridentata* flowered during late summer and fall. This phenological pattern may have tended to concentrate insects on these plants because fewer species are in flower so late in the season (Fig. 1).

Orius phenology appeared to track bloom and thrips phenology. The phenologies of the bloom, the WFT, and *Orius* on three plant species chosen because of differences in flowering times are compared in Figure 2: *Achillea millefolium* L. (Asteraceae) (early bloom), *Chrysothamnus viscidiflorus* (late bloom), and *Eriogonum elatum* (season-long bloom). The samples were obtained at the Hambleton site in 2002. Densities of *Orius* appeared to peak during bloom, and at or just following peak numbers of thrips (Fig. 2). Densities of both insect species declined rapidly following bloom. In Figure 3, we show age structure of the *Orius* specimens for each

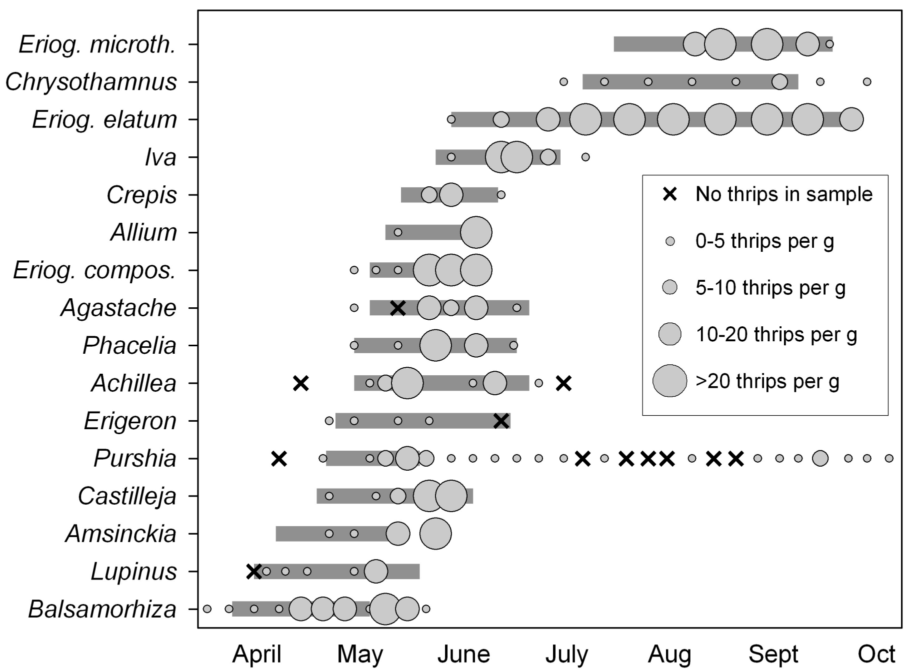

Figure 1. Flowering periods (shaded bars) of selected WFT host plants based on the Durey and Hambleton sites near Tieton, WA, and densities of WFT in pre-bloom, bloom, and post-bloom collections. Most plant species occurred at both sites.

of these host plants. Adults and nymphs were present in virtually all samples in which *Orius* was collected. The results for *E. elatum* suggest that *Orius* completed two generation on this one host species (Fig. 3). Females dominated the last two collections on *E. elatum* (Fig. 3).

The other common taxon of predators found during this study was the Araneae. Eleven families and at least 20 genera of spiders were collected from 69 plant species (Table 3). The spiders occurred in large numbers and considerable diversity on several plant species. In general, those plant species on which WFT was abundant also had high spider abundance.

Several spider species were found on certain host plants primarily as first and second instar spiderlings (Table 3). Because of their small size, prey for these young spiders is probably restricted to small arthropods. Given its great abundance on many of the host plants, WFT would appear to provide a readily available supply of prey for these small predators. Thirty-seven plant species had one or more spider genera represented by small spiderlings, among the more important plants being *Achillea*, *Chrysothamnus*, *Medicago*, *Agastache*, *Eriogonum elatum*, and *Clematis*. Small crab spiderlings in the genus *Xysticus* (Thomisidae), especially *Xysticus cunctator* Thorell, 1877, occurred on 33 of the plants. A second thomisid, *Misumenops lepidus* (Thorell, 1877), was found as small spiderlings on 13 plants.

Generally, positive species identification of spiders requires examination of adults. Because of our familiarity with the local fauna, however, we were able to identify many of the immatures in our samples. The genus *Xysticus* was represented primarily by *X. cunctator*, *Misumenops* by *M. lepidus*, and *Sassacus* (Salticidae) by *Sassacus* papenhoei Peckham and Peckham, 1895. Local *Phidippus* species (Salticidae) are difficult to distinguish during the first two or three instars. Based upon our knowledge of the local fauna, the *Phidippus* complex in our samples probably included *Phidippus johnsoni* (Peckham and Peckham, 1883), *Phidippus comatus* Peckham and Peckham, 1901, *Phidippus clarus* Keyserling, 1885, and *Phidippus audax* (Hentz, 1845). All seven of these species occur in local orchards.

Predators other than *Orius* and spiders were found on 38 species of plants, but were uncommon compared to those two groups. Fourteen insect families were represented. Predaceous Miridae (*Deraeocoris brevis* (Uhler, 1904) and *Campylomma verbasci* (Meyer-Dür, 1843)) were extracted from18 host plants. Several species of lady-beetle adults and larvae (Coccinellidae) were extracted from 17 plant species, but the number found in a given sample was rarely more than five individuals. The next most common families were: Geocoridae (found on 13 plant species), Chrysopidae (9), Hemerobiidae (6), Anthocoridae (*Anthocoris* spp.) (6), Phymatidae (6), Nabidae (6), and Reduviidae (5). The remaining families were each taken on only one or two plant species: Raphidiidae, Melyridae, Syrphidae, Coniopterygidae, and Cleridae.

Ants (Formicidae) occurred in samples from 64 plant species and were represented primarily by workers, although an occasional alate form was taken. The number of specimens in a sample was rarely more than two or three, and many collections from host plants sampled multiple times contained no specimens. For example, 56 samples were collected from *Artemisia tridentata* at seven sites in 2002, but ants occurred in only two of them. Some ant species are predaceous, but we made no attempt at identification below the family level.

DISCUSSION

The western flower thrips, causative agent of pansy spot on apple, was found on 92% of the plant species sampled in near-orchard habitats during this study. These results (indicating a broad utilization of available, non-cultivated host plants) are in agreement with findings from other parts of the thrips' native range (Bryan and Smith 1956; Yudin *et al.* 1986) and also regions into which WFT has been introduced (Chellemi *et al.* 1994; Atakan and Uygur 2005). Madsen and Jack (1966), Pearsall (2000), and Cockfield *et al.* (2007) reported WFT from a number of non-cultivated host plants in near-orchard habitats

Table 3

Occurrence and maximum density (# per gram dry weight of plant material) of *Orius* spp. and spiders on sampled host plants. Maximum spider density includes all spiders found in the sample. Plants on which neither *Orius* nor spiders were found are not included. *Orius* stages: m=male; f=female; 1, 2, 3, 4, 5 indicate the five nymphal instars. Abbreviations for spider taxa: A=*Anyphaena*; Ar=*Araneidae*; C=*Coriarachne*; D=*Dictynidae*; E=*Ebo*; H=*Hololena*; Ha=*Habronattus*; L=*Linyphiidae*; M=*Misumenops*; Mi=*Misumena*; O=*Oxyopes*; P=*Phidippus*; Pe=*Pelegrina*; Ph=*Philodromus*; Ps=*Phanias*; S=*Sassacus*; T=*Theridion*; Te=*Tetragnatha*; Ti=*Tibellus*; X=*Xysticus*. [1]Indicates a spider taxon represented primarily by 1st and 2nd instar spiderlings. See text for further explanation.

Host plant	*Orius* stages present	Max. *Orius* density	Spider taxa present	Max. spider density
Acer	--	--	L	<0.1
Daucus	5	0.1	M[1]	0.2
Lomatium grayi	--	--	D	<0.1
L. columbianum	--	--	L	<0.1
Apocynum	m,2,3,4	<0.1	X[1],M,D,L	<0.1
Asclepias	f,m,3,4,5	0.6	X[1],Ph,S,P,D	0.5
Achillea	f,m,1,2,3,4,5	2.9	X[1],M[1],S,P[1],Pe,T,Ph,Mi,C,A,L,D	0.7
Ambrosia	f	<0.1	--	--
Artemisia sp.	f,m,2,4,5	0.3	X[1],S,Pe	<0.1
A. tridentata	f,m,1,2,3,4,5	<0.1	X,M,S,Pe,T,Ph,L,D,H,Ha	0.2
Balsamorhiza hookeri	3,4	<0.1	M	<0.1
B. sagittata	f,m,1,2,3,4,5	0.6	M,S,T,O,L	0.1
Centaurea cyanus	--	--	Ar	<0.1
C. diffusa	f,m,2,3,5	0.1	--	--
Chaenactis	f,m,1,2,3,4,5	0.7	X[1],M[1],L	0.2
Chrysothamnus	f,m,1,2,3,4,5	2.3	X[1],M[1],S[1],P[1],Ph,Pe,D	0.4
Cirsium arvense	f,m,1,2,3,4,5	0.9	X[1],M[1],P[1],Ph,A,D,L	0.4
C. undulatum	m,3,4	0.2	X[1]	0.1
Crepis acuminata	m,5	<0.1	X[1],L	<0.1
C. occidentalis	m	<0.1	--	--
Ericameria	f,m,1,2,3,4,5	1.3	X,M[1],S[1],P,Pe,A,Ph,L,D	<0.1
Erigeron filifolius	2,3,4	0.4	--	--
E. linearis	2,3,5	0.4	X[1]	0.1
Helianthus	f,m,1,2,3,4,5	0.5	--	--
Iva	f,m,1,2,3,4,5	0.8	X[1],L	<0.1
Lactuca	--	--	T	<0.1
Layia	--	--	M	<0.1
Dieteria	2	<0.1	D,L	0.1
Nothocalais	--	--	S	0.3
Pyrrocoma	f,1,2,5	<0.1	X,E	<0.1
Solidago	f,m,1,2,3,4,5	1.3	X[1],M[1],P,S,Pe,L	<0.1
Tragopogon	--	--	X[1]	<0.1
Berberis	--	--	T,O,L	<0.1
Amsinckia lycopsoides	1,4	0.3	L	<0.1
A. tessellata	f,3,4,5	<0.1	X[1],L	<0.1
Descurania	2	<0.1	--	--
Lepidium	--	--	L	<0.1
Thelypodium	2,3,4	0.2	--	--
Lonicera	--	--	T	<0.1
Sambucus	m	<0.1	--	--
Symphoricarpos	--	--	L	<0.1
Kochia	1,2	<0.1	M[1],Pe	<0.1
Chenopodium	1,2,3,4,5	0.4	M,D	<0.1
Grayia	f,4	<0.1	--	--
Salsola	f,1,2,3,4,5	0.3	T,Ph,Ps,L,D	0.2
Hypericum	3,4,5	0.2	--	--

Host plant	*Orius* stages present	Max. *Orius* density	Spider taxa present	Max. spider density
Lupinus lepidus	3	<0.1	S	<0.1
Medicago	f,m,1,2,3,4,5	4.8	X[1],M[1],S[1],Ph,Pe	<0.1
Melilotus	f,m,1,2,3,4,5	1.3	X[1],S,Ph	<0.1
Trifolium macrocephalum	--	--	L	<0.1
T. pratense	f,1,2,3,4,5	1.7	P[1]	<0.1
T. repens	f,m,1,2,3,4,5	5.2	X[1],M[1],P[1],Ph,T,L	0.2
Ribes aureum	--	--	M,T	<0.1
R. cereum	--	--	S	<0.1
Philadelphus	f,m	0.7	X[1],S,Pe	<0.1
Phacelia hastata	f,m,2,3,4,5	0.8	X[1]L	0.3
P. linearis	m,1	0.2	X[1]	0.2
Agastache	f,m,1,2,3,4,5	4.0	X[1],M[1],L	1.5
Salvia	f	<0.1	--	--
Sphaeralcea grossulariifolia	2,4,5	0.1	X[1],M	<0.1
S. munroana	f,m,1,2,3,4,5	0.5	X[1],Ph	<0.1
Phlox hoodii	f,2,4	<0.1	S,Ph,T,L	0.2
P. longifolia	f	<0.1	--	--
Eriogonum compositum	f,m,2,3,4,5	0.5	--	--
E. elatum	f,m,1,2,3,4,5	7.7	X[1],M[1],S[1],P[1],Pe[1],O[1],T,D,L	0.4
E. heracleoides	f,m,1,2,3,4,5	0.8	X[1]	<0.1
E. microthecum	f,m,1,2,3,4,5	0.3	X[1],M,S[1],P,Pe	0.1
E. niveum	f,m,1,2,4	0.1	M,S	<0.1
E. strictum	f,m,1,2,3,4,5	0.7	X[1],L	0.2
Rumex	f,m,1,2,3,4,5	2.2	X[1]	<.1
Clematis	f,m,1,2,3,4,5	4.0	X[1],M[1],S[1],P[1],A[1],D[1],Pe,Ps,L	2.0
Ceanothus integerrimus	--	--	M,Mi,D	<0.1
C. velutinus	--	--	D	<0.1
Frangula	--	--	D	<0.1
Crataegus	--	--	H	<0.1
Holodiscus	5	<0.1	M,Pe	<0.1
Purshia	f,m,1,2,3,4,5	<0.1	X[1],M,S,P[1],Pe[1],Ph,Ti,D,L	<0.1
Rosa	m,1	<0.1	X[1],Pe,O,Ph,D,L	<0.1
Rubus	f,m,1,2,3,4,5	0.7	M	0.1
Salix	m,2,3	<0.1	D	<0.1
Castilleja	f,m,2,3,4,5	0.3	X[1]	<0.1
Verbascum thapsus	m,3,4,5	0.3	--	--
Urtica	f,1,2,3,4,5	2.6	X[1]	<0.1

of the Pacific Northwest and discussed implications for damage to apples and nectarines. Our study concentrated on plants growing outside of orchards, but several species that are common components of orchard understories, including red clover, white clover, and alfalfa, also supported large numbers of WFT. Venables (1925) remarked on the occurrence of WFT on alfalfa growing in orchards and its possible bearing on pansy spot of apple.

Frankliniella occidentalis, like other winged thrips, is a highly mobile insect, and active or passive flights are the primary means of dispersal among thrips as a group (Lewis 1973). Gravid females of many species make local flights among host plants apparently as they search for oviposition sites (Lewis 1997). Flower-loving species like WFT may detect changes in the quality of these short-lived resources prompting movement within or between plants as their food value declines (Terry 1997). Madsen and Jack (1966), Cockfield *et al.* (2007), and Pearsall (2000) discussed movement of WFT between successively blooming host species and flowering orchards. At some of our sites, dozens of host plant species were available over the course of the season in the near-orchard habitat, and additional species were present in the orchard ground cover.

Cultural control of WFT by elimination of alternate hosts does not seem to be a viable option (Cockfield *et al*. 2007), and alternate hosts that flower concurrently with the crop may even mitigate damage by diluting the thrips population (Beers *et al*. 1993). Pearsall (2000) did not believe that a trap crop would effectively reduce damage in nectarines. Natural enemies are rare in nectarine orchards in British Columbia during the spring (Pearsall 2000), and we noted few natural enemies in apple flowers (unpublished observations). In apple orchards, careful monitoring of WFT densities and application of a suitable insecticide timed to eliminate females that are laying eggs on developing apples (while avoiding harm to pollinators) may be the best management approach (Madsen and Jack 1966; Cockfield *et al*. 2007). In some cases it may be possible to limit sprays to border rows (Miliczky *et al*. 2007).

Many of the same plants that were hosts for WFT also hosted known and potential thrips predators, sometimes in considerable numbers. *Orius* spp. are important thrips predators throughout the world (Lewis 1973). The minute pirate bug, *O. tristicolor*, was the most abundant predator on many plants

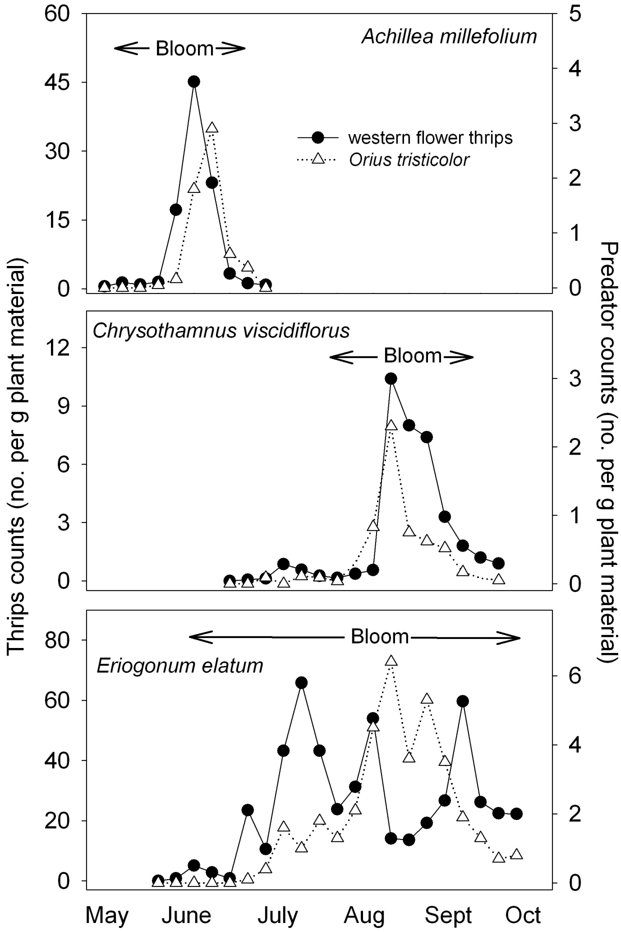

Figure 2. Correspondence between flowering period, WFT abundance, and abundance of the important thrips predator *Orius tristicolor* on three important WFT host plants in flower at different times during the season. Figure is based on 2002 data from the Hambleton site.

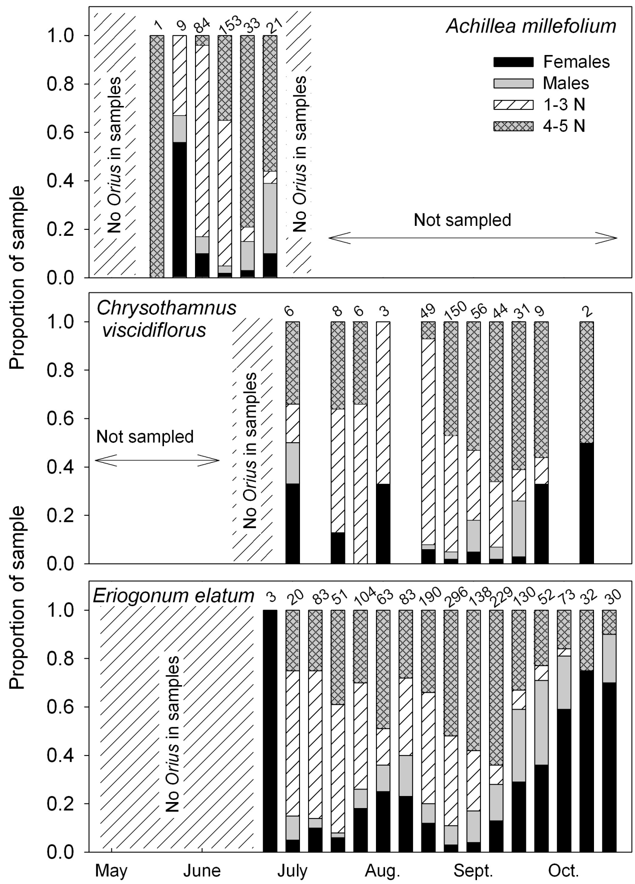

Figure 3. Age structure of *Orius tristicolor* in collections from the same three host plants as in Fig. 2 at the Hambleton site in 2002. Number at the top of each column indicates the total number of *Orius* in the sample.

sampled in this study. Barber (1936) noted that *O. insidiosus* could be "swept from almost any plant association", and Kelton (1963) commented on the abundance of *Orius* spp. on the flowers of various plants. Numerous plant species supported populations of *O. insidiosus* near apple orchards in Virginia (including other crops and various weeds) (McCaffrey and Horsburgh 1986). Kakimoto *et al*. (2006) found a significant correlation between the density of *Orius sauteri* (Poppius, 1909) and thrips on spring weeds in Japan. Tommasini (2004) showed that non-cultivated host plants of WFT in Italy also supported species complexes of minute pirate bugs. *Orius tristicolor* occurred on 32 flowering plant species in north-central California, in all cases feeding on thrips, most frequently WFT (Salas-Aguilar and Ehler 1977). The early-season presence of thrips in Indiana soybean fields led to colonization of the crop by *O. insidiosus* and, in some years, the predator was then able to hold the later arriving soybean aphid *Aphis glycines* Matsumura, 1917 at low levels (Yoo and O'Neil 2009).

While *Orius* seem to prefer thrips as prey, they are generalist predators and a variety of other small prey items including mites, aphids, scale insects, leafhoppers, and Lepidoptera eggs and larvae are fed upon (McCaffrey and Horsburgh 1986). Pirate bugs may feed and partially develop on pollen (Kiman and Yeargan 1985; McCaffrey and Horsburgh 1986). Thus, an association with flowers gives *Orius* spp. access to both animal and plant food.

Sabelis and Van Rijn (1997) noted that

surprisingly little was known about spider predation on thrips, although they predicted that thrips were most likely to be important components of the diets of smaller species. Thrips comprised 9% of the prey of the small, cribellate spider *Dictyna arundinacea* (Linnaeus, 1758) (Heidger and Nentwig 1985), and webs of *Dictyna coloradensis* Chamberlin, 1919 often captured thrips, most of which were probably WFT (Miliczky and Calkins 2001). A recent greenhouse study using caged pepper plants infested with WFT indicated that in the presence of second instar *Xysticus kochi* Thorell, 1872, thrips damage to the peppers was reduced, and the peppers produced were of higher quality (Zrubecz *et al*. 2008).

The present study indicates that at certain times when thrips are abundant, they likely comprise a substantial portion of the diet of the early instars of various spiders. Early instars of these spiders, because of small size, are restricted to small prey. Due to the nature of the sampling procedure employed in this study actual predation of thrips by spiders was not observed. However, during a previous study (Miliczky and Horton 2007) in which beneficial arthropods were collected by beating several of the same plant species at the same locations, small spiderlings of the species referred to above were observed with thrips prey in their mouthparts (unpublished observations).

In summary, the great majority of flowering plant species that occur in uncultivated land adjacent to eastern Washington apple orchards, as well as some ground cover species within the orchards, are hosts to WFT. WFT colonizes host species primarily while they are in flower, reproduces on many of them, and often reaches very high population levels. Small, immature spiders (especially first and second instars) of several species were numerous on some of the same plant species. WFT, because of its small size, great abundance, and ubiquitous occurrence is probably an important component in the diet of these small, young spiders, which because of their size, are restricted to suitably small prey. These spiders, as they mature and grow, will switch to larger prey. *Orius tristicolor*, an important thrips predator, occurs on many of the same plant species as WFT, is also able to reproduce on many of them, and builds up high numbers on some species. Both WFT and *O. tristicolor* appear to track available host plants, moving from one to the other as successive species come into flower.

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