Annual Cycles of *Frankliniella* spp. (Thysanoptera: Thripidae) Thrips Abundance on North Florida Uncultivated Reproductive Hosts: Predicting Possible Sources of Pest Outbreaks

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ABSTRACT *Frankliniella* spp. (Thysanoptera: Thripidae) thrips damage a variety of crops, feed on a broad range of hosts, and often migrate into cropping systems from adjacent vegetation. To determine potential sources of *Frankliniella* spp. thrips on crops, annual cycles of abundance of *Frankliniella occidentalis* (Pergande), *Frankliniella fusca* (Hinds), *Frankliniella bispinosa* (Morgan), and *Frankliniella tritici* (Fitch) were evaluated on seven common, uncultivated reproductive hosts. These hosts included *Raphanus raphanistrum* L., *Rubus trivialis* Michx., *Rubus cuneifolius* Pursh., *Vicia sativa* L., *Trifolium repens* L., *Solidago canadensis* L. and *Chenopodium ambrosioides* L. Thrips were collected from *R. cuneifolius*, and *T. repens* in the spring, *R. raphanistrum* in the summer, and *C. ambrosioides* and *S. canadensis* in the fall. The most common *Frankliniella* species on every plant species was *F. tritici*, and a fifth species, *Pseudothrips inequalis* (Beach), was collected in the fall on *C. ambrosioides* and *S. canadensis*. All thrips species were highly aggregated in the flowers or flower racemes, rather than leaves or fruit, and they were generally only collected from flowering plants. *R. raphanistrum* supported large populations, and they may be an important link for thrips between spring and fall. In addition, it may be an essentially enemy free host, as only one *O. insidiosus*, an important thrips predator, was collected from this host. *S. canadensis* also supported large thrips populations in the fall, and it may be a source of thrips migrating into crops the following spring. Controlling thrips on these hosts in their respective seasons may limit the number migrating into cropping systems.

KEY WORDS *Frankliniella* spp., population dynamics, thrips

The population dynamics of crop pests are studied to predict outbreaks and develop more efficient integrated pest management programs. A major component of studying population dynamics is monitoring annual cycles of abundance. We use the term annual cycles of abundance to describe the periodic increase and decrease of populations that occurs over time. Because many crop pests also use uncultivated host plants, population dynamics outside the crop must be examined to understand how vegetation in the landscape affects pest populations in cropping systems (Chellemi et al. 1994, Groves et al. 2002, Norris and Kogan 2005). Our research focused on the cycles of abundance of a polyphagous group of crop pests: the flower thrips (*Frankliniella* spp.) (Thysanoptera: Thripidae).

Flower thrips cause extensive economic damage to many types of crops through feeding that causes a silvering of plant tissue and a reduction in photosynthesis (Shipp et al. 1998, Kirk 2002), or ovipositional scarring that causes halo-spotting on tomato fruit (Salguero Navas et al. 1991). In addition, many thrips are vectors of Tospoviruses, including Tomato spotted wilt virus, one of the most damaging plant viruses worldwide (Prins and Goldbach 1998). The genus *Frankliniella* contains several crop pests, the most researched of which is the globally distributed species, *Frankliniella occidentalis* (Pergande) (for review, see Kirk and Terry 2003). Other *Frankliniella* species occurring in North Florida are *Frankliniella fusca* (Hinds), *Frankliniella bispinosa* (Morgan), and *Frankliniella tritici* (Fitch), all three of which are native to the southeastern United States (Kirk 2002, Kirk and Terry 2003), and they are pests of numerous crops (Childers et al. 1990, Puche et al. 1995, Reitz et al. 2003). Vectors of Tomato spotted wilt virus include *F. occidentalis*, *F. fusca*, and *F. bispinosa*, but not *F. tritici* (Sakimura 1953 as cited by Sakimura 1962, Sakimura 1963, de Assis Filho et al. 2005, Avila et al. 2006).

To improve the control of thrips, it is necessary to study annual cycles of thrips abundance, because this knowledge may lead to the ability to take preventative measures such as varying planting timings or optimizing management programs by timing control measures to coincide with pest outbreaks (Funderburk 2002). These cycles have been studied extensively in crops

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such as tomatoes (Reitz 2002, Nault et al. 2003), citrus (Childers et al. 1990), nectarines (Felland et al. 1995, Pearsall and Myers 2000), and small grains (Buntin and Beshear 1995), but less intensive research has been conducted on uncultivated plant hosts (but see Chamberlin et al. 1992, Chellemi et al. 1994, Cho et al. 1995, Toapanta et al. 1996, Groves et al. 2002). It is important to note that these past studies either did not monitor thrips populations over the entire year (Chamberlin et al. 1992, Cho et al. 1995, Toapanta et al. 1996, Groves et al. 2002), or they did not present quantitative values for each plant host (Chellemi et al. 1994). Thrips often overwinter in patches of uncultivated plants and migrate into cropping systems in the spring (Pearsall and Myers 2001, Groves et al. 2002). Because thrips often migrate from uncultivated hosts into cropping fields in the spring and during other seasons (Kirk 1997, Pearsall and Myers 2001, Groves et al. 2002), cropping systems can often serve as a sink, with sources of insect populations occurring in field margins and fencerows. For example, several thrips species often cause extensive economic damage to tomatoes through feeding on the flowers and developing fruit, but tomato plants are poor reproductive hosts for thrips (Reitz 2002). Therefore, economically damaging populations are dependent on surrounding vegetation for growth. Studying annual cycles of abundance on uncultivated hosts is therefore necessary to identify potential sources of thrips populations. In addition, this migration may be the source of primary Tospovirus infection as thrips spread the virus from uncultivated to cultivated hosts (Puche et al. 1995).

Reproductive hosts are more important to population growth than adult feeding hosts, and they may serve as bridges to build thrips populations that migrate into cropping systems. We therefore sampled seven reproductive hosts growing in field margins and determined the cycles of abundance of *Frankliniella* species on each plant species. We selected plants that are known reproductive hosts for one or more *Frankliniella* species, as identified by Chamberlin et al. (1992), Cho et al. (1995), Groves et al. (2002), Heagle (2003), and Paini et al. (2007). Furthermore, the hosts selected were either known Tomato spotted wilt virus hosts or species for which congeneric species have been identified as hosts (Parrella et al. 2003).

In addition to locating potential sources of thrips populations, we tested the hypothesis that temporal dynamics were the same for all thrips species. If thrips react to host phenological and seasonal changes similarly, the temporal population dynamics should be similar for all thrips species. However, there may be differences between species, and comparing the temporal patterns of abundance for different thrips species on a single plant species allowed us to evaluate the species-specific differences in how host use changes over time.

Materials and Methods

Sampling Procedure. The study was conducted at the North Florida Research and Education Center in Gadsden County, FL, which is a representative of agroecosystems in northern Florida and southern Georgia. There were a variety of cropping systems growing in the vicinity of sample locations during all times when thrips were present. The plants sampled were *Raphanus raphanistrum* L. (Brassicaceae), *Rubus trivialis* Michx. (Rosaceae), *Rubus cuneifolius* Pursh. (Rosaceae), *Vicia sativa* L. (Fabaceae), *Trifolium repens* L. (Fabaceae), *Solidago canadensis* L. (Asteraceae), and *Chenopodium ambrosioides* L. (Chenopodiaceae). Each species was sampled biweekly, when available, between 19 November 2003 and 5 November 2004.

On each sample date, 10 sites for each available plant species were randomly selected, and one plant was sampled from each site. A site consisted of a spatially explicit patch of a single plant species. For each plant, 20 leaves, flowers, and fruit (or 20 racemes and leaves for *C. ambrosioides*, and *S. canadensis*) were placed in vials containing 70% ethanol. For *T. repens*, four racemes were sampled per plant because of the low number and large size of the racemes. For *V. sativa*, which has prominent terminal buds, four buds were sampled per plant, in addition to the flowers, fruit, and leaves. The contents of each vial were placed in a petri dish, and the plant parts were dissected to extract thrips. Adult thrips were identified under a microscope by using 6.5–40× magnification. Larvae were counted, but they were not identified to species, because no morphological keys are available. The total numbers of flowers, fruit, and leaves per plant also were estimated. The numbers of leaves, flowers, and fruit (or racemes) were counted directly when part numbers were low (<30), otherwise a section of a plant was selected, and the numbers of leaves, flowers, and fruit (or racemes) were extrapolated from the number of each part in a section and the number of sections on the plant. Because adult thrips were highly aggregated in the flowers or racemes (see Results), the numbers of each thrips species per flower and the number of flowers per plant were used to estimate the total number of each thrips species per plant. In addition, the numbers of a common thrips predator, *Orius insidiosus* (Say), were recorded.

Data Analysis. Repeated measures analysis of variance (ANOVA) analyses (PROC MIXED, SAS Institute 2000) and Tukey's tests were used to determine the effect of plant part and date on combined thrips densities (adults and larvae of all species) for data collected when all plant parts were present. A simple, one-way ANOVA was conducted to analyze plant part means of *R. cuneifolius*, because all three parts were only present on one sample date (29 April 2004).

Because adult thrips were highly aggregated in the flowers or racemes, the numbers of thrips per flower or raceme were used in the comparison of patterns of abundance of the different thrips species, and the calculation of the number of thrips per plant over the course of the season. Repeated measures ANOVA analyses (PROC Mixed, SAS Institute 2000) were conducted on each plant to analyze differences in the density of adults of each thrips species and the effect

Table 1. Total number of adults and larvae collected from each plant species and the percentage collected from each part for seven host plants collected from 19 November 2003 to 5 November 2004 at the North Florida Research and Education Center in Gadsden County, FL

Plant species	*n*	Adults (%)				*n*	Larvae (%)			
		Flowers or racemes	Fruits	Leaves	Buds		Flowers or racemes	Fruits	Leaves	Buds
R. raphanistrum	3,042	97	1	2		1,607	89	5	7	
R. trivialis	150	64	26	10		77	38	47	16	
R. cuneifolius	851	95	4	1		323	33	60	7	
V. sativa	57	81	18	2	26	64	59	11	2	28
T. repens	503	98	N.A.	2		195	98	N.A.	2	
S. canadensis	265	99	N.A.	1		576	100	N.A.	0	
C. ambrosioides	103	97	N.A.	3		212	98	N.A.	2	

N.A., not applicable.

of date on thrips abundance. In addition, the interaction of *Frankliniella* species by date was used to compare the patterns of abundance of the different thrips species (Littell et al. 1996). This analysis allowed us to test the hypothesis that the patterns of abundance on a host plant were the same for all thrips species (i.e., all species use the host plant at the same time). For each host plant sampled, the two most abundant species represented >90% of the thrips present, so post hoc contrast procedures on the species × date interaction were conducted on the two most abundant species to determine whether patterns of abundance were significantly different for the two species. Contrast procedures were conducted on the interaction between date and the means of *F. tritici* and *F. bispinosa* on three hosts: *R. raphanistrum*, *R. cuneifolius*, and *T. repens*, and contrast procedures were conducted on the interaction between date and the means of *F. tritici* and *F. fusca* on *R. trivialis*. For *S. canadensis*, no contrast procedure was conducted due to the low numbers of *F. fusca*, *F. bispinosa*, and *F. occidentalis*. A fifth thrips species, *Pseudothrips inequalis* (Beach) was abundant on *C. ambrosioides*, so it was included in the analysis and a contrast procedure was conducted on the interaction between date and the means of *F. tritici* and *P. inequalis*. *P. inequalis* is rarely studied, and the biology of the species is therefore not well understood. Voucher specimens for *P. inequalis* were sent to the Florida State Collection of Arthropods (Division of Plant Industry, Florida Department of Agriculture and Consumer Services, Gainesville, sample E2007-4803-1) for confirmation. For comparing species abundances on *V. sativa*, a simple one-way ANOVA was conducted, because adult thrips were only present on one sample date (1 April 2004). Effects were considered significant when $P \leq 0.05$. Data were only analyzed on dates when at least one species of thrips was present on the plant. Dates analyzed for each plant species were *R. raphanistrum*, 15 April–22 July 2004; *R. trivialis*, 15 April–29 April 2004; *R. cuneifolius*, 29 April for plant part comparisons (due to low numbers of fruiting plants on 15 April), and 15 April–29 April 2004 for species comparisons; *V. sativa*, 18 March–1 April for plant part comparisons and 1 April for species comparisons (due to low numbers of adults on 18 March); *T. repens*, 15 April–27 May 2004; *S. canadensis*, 9 September–21 October 2004; and *C. ambrosioides*, 26 August–21 October 2004. The number of larvae per female on each host was calculated, and plants were considered good reproductive hosts if the ratio was greater than 1, indicating that the population size was increasing. Because thrips are facultatively parthenogenetic, the larva-to-female ratio was used rather than larvae per adult, because males are not necessary for reproduction.

All analyses were conducted using SAS (SAS Institute 2000). An autoregressive (to account for the fact that observations close in time are more correlated than more distant observations), heterogeneous (to account for nonconstant variances over time) covariance structure was used in PROC MIXED. Degrees of freedom were estimated using the Kenward–Roger method (Littell 1998), and species data were square-root transformed before analyzing, because of a Poisson distribution.

Results and Discussion

From the seven plant hosts, 2,068 samples in total were collected and 8,112 individual thrips were extracted, of which 62% were adults. The adult thrips collected were *F. tritici* (75.9%), *F. bispinosa* (14.7%), *F. fusca* (3.5%), *F. occidentalis* (1.1%), and non-*Frankliniella* species (4.8%). On plant species with racemes and leaves (*T. repens*, *S. canadensis*, and *C. ambrosioides*), 98.8% of the thrips were found in the racemes and 1.2% in the leaves (Table 1). On plant species with flowers and fruit (*R. raphanistrum*, *R. trivialis*, *R. cuneifolius*, and *V. sativa*), 89.1% of thrips were collected from flowers, 7.0% were collected from fruit, and 3.9% were collected from leaves. However, this distribution varied by plant species and thrips life stage (Table 1). The general trend that more thrips were found on flowers than leaves or fruit of all sampled plants suggests that there is a preference for flowers, and this has been shown in other studies (Brodbeck et al. 2001, 2002; Hansen et al. 2003), but it is rarely evaluated in uncultivated hosts across an entire year. Furthermore, thrips were only present on flowering plants, indicating that when evaluating sources of *Frankliniella* spp. populations only flowering hosts need to be considered. By feeding in flowers that provide favorable

Table 2. Repeated measures ANOVA results from the analysis of the number of combined thrips adults and larvae of all thrips species per plant part and date for seven reproductive hosts

Plant species	Plant part			Date			Date × part interaction		
	df	*F*	*P*	df	*F*	*P*	df	*F*	*P*
R. raphanistrum	2, 26	68.04	<0.0001	7, 48	12.21	<0.0001	14, 63	62.60	<0.0001
R. trivialis	2, 7	6.96	0.0015	2, 13	25.39	<0.0001	4, 15	19.74	<0.0001
R. cuneifolius[a]	2, 25	11.73	0.0003						
V. sativa	3, 35	5.67	0.0029	1, 33	11.75	0.0016	3, 33	3.32	0.031
T. repens	3, 36	44.20	<0.0001	5, 36	7.61	<0.0001	5, 36	6.77	0.0001
S. canadensis	1, 11	9.92	0.0089	2, 15	3.52	0.056	2, 15	3.50	0.057
C. ambrosioides	1, 21	29.46	<0.0001	5, 26	2.30	0.075	5, 26	2.28	0.076

A simple one-way ANOVA was conducted on *R. cuneifolius*, because all plant parts were only present on one sample date.
[a] Only one date analyzed.

microclimates and small refuges from larger predators thrips may reduce the risk of desiccation and predation, both of which exert strong selection pressures on phytophagous insects (Strong et al. 1984). In addition, several studies have shown that the addition of pollen in thrips diets greatly enhances their reproductive capacity (Wäckers et al. 2007).

The results from the analysis comparing thrips abundances by plant part are presented in Table 2, and the analysis comparing abundances of different thrips species is presented in Table 3. Two tests for the effects of date are presented. The effect of date presented in Table 2 (testing for effects of plant part) includes dates when all plant parts were present, and uses the sum of all adults and larvae to make comparisons. The effect of date presented in Table 3 (testing for effects of thrips species) presents data in flowers and only compares the number of adults for each date, because larvae could not be identified to the species level.

Plant species with the highest *Frankliniella* spp. adult densities were *T. repens* and *R. cuneifolius* in the spring, *R. raphanistrum* in the summer, and *S. canadensis* in the fall (Table 4). Plants with the most larvae were *T. repens* in the spring, *R. raphanistrum* in the summer, and *S. canadensis* and *C. ambrosioides* in the fall (Table 4).

R. raphanistrum. *R. raphanistrum* flowered from 5 December 2003 to 22 July 2004 (Fig. 1), but thrips were rarely collected before 15 April (Fig. 2). There were significantly more thrips on flowers than on leaves or fruit ($P < 0.0001$; Tukey's test), and there was a significant effect of date and an interaction between date and part, indicating that the patterns of abundance were different on different plant parts (Table 2). However, this interaction was not considered biologically significant, because thrips were so highly aggregated in the flowers. There were so few thrips present on leaves and fruit that the patterns of abundance were different simply due to the lack of thrips on leaves and fruit on dates when thrips were present.

There was a significant effect of thrips species, date, and interaction between species and date (Table 3). The most abundant thrips species were *F. tritici* and *F. bispinosa*, making up 74.5 and 19.9% of adults, respectively. There were more *F. tritici* and *F. bispinosa* adults collected from *R. raphanistrum* than from most plants, suggesting that *R. raphanistrum* is a good feeding host for adults of both species. There was a significant interaction between date and the means of *F. tritici* and *F. bispinosa*, indicating that the patterns of abundance were different for the two species ($F = 4.54$; df = 6, 63; $P = 0.0012$). The interaction seems to be due to the extremely low numbers of both species collected on 10 June due to unknown circumstances. *F. tritici* was more abundant than *F. bispinosa* on the dates immediately preceding and after 10 June (Fig. 1). However, low numbers of both species on 10 June caused both population abundances to approach the same value. This rapid decrease and increase in population abundances of *F. tritici* relative to *F. bispinosa* before and after 10 June caused them to have different patterns of abundance.

Table 3. Repeated measures ANOVA results from the analysis of the number of each adults of each thrips species per flower and date for seven reproductive hosts

Plant species	Species			Date			Species × date interaction		
	df	*F*	*P*	df	*F*	*P*	df	*F*	*P*
R. raphanistrum	3, 42	83.98	<0.0001	6, 63	24.35	<0.0001	18, 94	7.09	<0.0001
R. trivialis	3, 13.2	4.94	0.0163	2, 20	2.28	0.1284	6, 22	1.72	0.1638
R. cuneifolius	3, 26	30.77	<0.0001	1, 36	3.74	0.0611	3, 36	1.35	0.2723
V. sativa[a]	3, 91	1.66	0.1995						
T. repens	3, 57	35.01	<0.0001	3, 60	11.27	<0.0001	9, 78	4.52	<0.0001
S. canadensis	3, 36	21.5	<0.0001	2, 30	5.06	0.0128	6, 34	4.46	0.002
C. ambrosioides	4, 33	9.13	<0.0001	4, 64	0.19	0.9407	16, 91	1.62	0.0784

Analysis of *V. sativa* was only conducted on one date, so a simple ANOVA was conducted only on the species effect.
[a] Only one date analyzed.

Table 4. Mean number (± SEM) of adult *Frankliniella tritici* (Ft), *F. fusca* (Ff), *F. bispinosa* (Fb), *F. occidentalis* (Fo), *P. inequalis* (Pi), larvae and non-*Frankliniella* sp. per plant for seven plant species on selected dates, collected at the North Florida Research and Education Center in Gadsden County, FL

Plant species	Dates when present	Adults per plant					Larvae per plant
		Ft	Ff	Fb	Fo	Pi	
R. raphanistrum	13 May–24 June	208.58 (73.85)	4.39 (1.39)	45.35 (16.88)	3.05 (1.07)	0 (0)	1.09 (0.26)
R. trivialis	1–15 April	3.65 (1.85)	0.2 (0.15)	0 (0)	0.1 (0.07)	0 (0)	1.41 (0.48)
R. cuneifolius	29 April	48.25 (20.52)	0.12 (0.08)	3.25 (1.18)	0.23 (0.13)	0 (0)	7.83 (3.66)
V. sativa	15 April	4.79 (4.32)	0.25 (0.14)	0.31 (0.31)	0 (0)	0 (0)	1.85 (0.79)
T. repens	29 April–27 May	146.55 (50.71)	3.39 (1.06)	24.88 (9.1)	0.33 (0.23)	0 (0)	32.38 (11.43)
S. canadensis	21 Oct.	621.52 (293.54)	0 (0)	0 (0)	7.13 (7.13)[a]	6.77 (6.77)	2,024.75 (1,108.59)
C. ambrosioides	26 Aug.–21 Oct.	70.22 (72.29)	0 (0)	0 (0)	0 (0)	359.35 (115.67)	703.45 (196.56)

[a] Predicted from the presence of only one thrips.

The larva-to-female ratio was 0.54 before 10 June 2004 and 3.10 from 24 June to 22 July 2004, indicating that *R. raphanistrum* was used as a reproductive host for a smaller proportion of the females early in the season than in midsummer. The high ratio of larva to female after 10 June 2004 and the high mean numbers of *F. tritici* and *F. bispinosa* per plant for *R. raphanistrum* indicate that use of *R. raphanistrum* as a feeding and reproductive host may be important for summer population dynamics of both species. Furthermore, *R. raphanistrum* is a host for Tomato spotted wilt virus (Parrella et al. 2003); therefore, it may be a source of virus infection in thrips populations. *R. raphanistrum* is also common in most of the United States (USDA, NRCS 2004), and it may be an important factor in thrips–Tospovirus epidemiology.

Although *R. raphanistrum* flowered from 5 December to 2 August, there were no thrips collected from the flowers until 15 April. The reasons for the delay in abundance of thrips on *R. raphanistrum* are unclear, because thrips were present on *R. trivialis* and *V. sativa* before 15 April. Thrips were not commonly found on *R. raphanistrum* until *R. cuneifolius* finished flowering on 13 May, and larva-to-female ratios were low in the spring, suggesting that *R. raphanistrum* may only be an important reproductive host late in the season, when few hosts are available. In addition, *R. raphanistrum* was mostly an enemy-free niche, because the only *O. insidiosus* collected from *R. raphanistrum* was collected from flowers on 27 May 2004. *O. insidiosus* are not common in the early spring in northern Florida, but they are important thrips predators in the summer (Funderburk et al. 2000, Reitz et al. 2006), and this enemy-free niche may be important to the maintenance of thrips populations during summer *O. insidiosus* abundance. Therefore, use of *R. raphanistrum* may be due in large part to complex ecological and physiological factors involved in host selection.

***Rubus* Species.** *R. trivialis* flowered from 4 March to 29 April 2004 (Fig. 1), and thrips were most abundant 1 April through 29 April (Fig. 3). No *O. insidiosus* were collected from *R. trivialis.* There were significantly more thrips on flowers than on fruit ($P = 0.0003$;

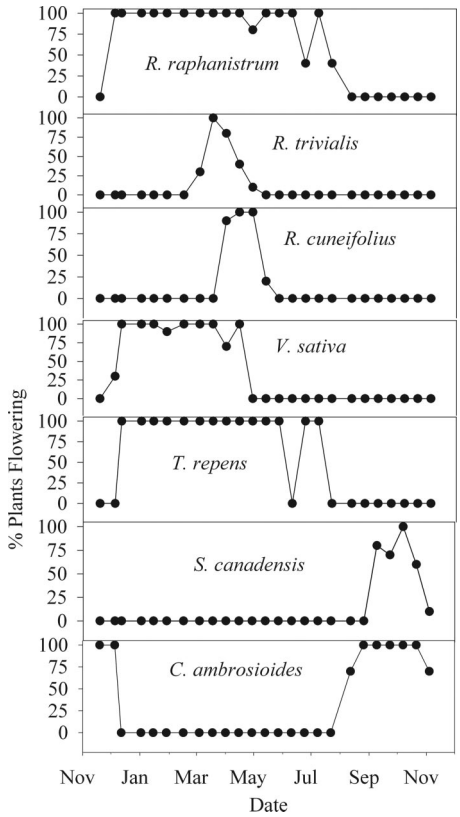

Fig. 1. Proportion of sampled plants that were flowering from 19 November 2003 to 5 November 2004.

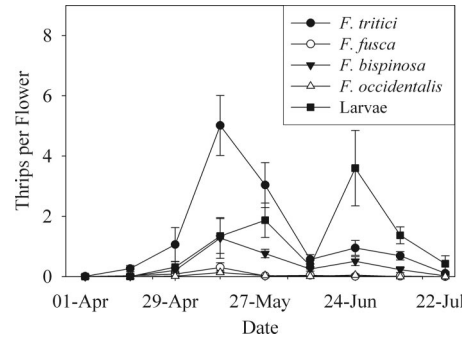

Fig. 2. Mean number (±SEM) of adult thrips species and larvae per flower collected from *R. raphanistrum.*

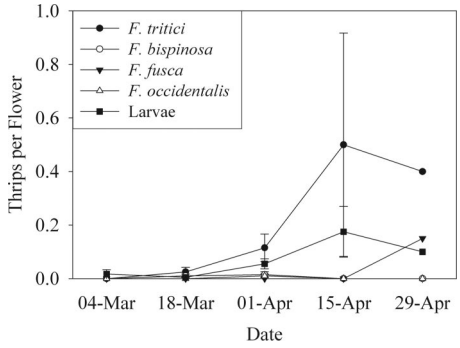

Fig. 3. Mean number (±SEM) of adult thrips species and larvae per flower collected from *R. trivialis*. Only one flowering plant was present on 29 April; thus, no SEM could be calculated.

Tukey's test) or leaves ($P = 0.0002$; Tukey's test), and there was a significant effect of date and interaction between date and plant part (Table 2). The date by plant part interaction indicates that there were differences in the patterns of thrips abundance on different plant parts. This interaction was due to the presence of thrips larvae on fruit late in the sampling period.

The most abundant thrips species were *F. tritici* and *F. fusca*, making up 73.0 and 19.8% of adults, respectively. However, *F. fusca* was only present on the last sample date when only one plant was present. There was a significant effect of thrips species, but no significant date effect or interaction between date and species (Table 3), indicating that thrips abundances were similar for all dates evaluated. The larva-to-female ratio calculated over all dates was 0.88, indicating that *R. trivialis* was not an excellent reproductive host. In addition, the low number of adults collected on *R. trivialis* suggests that it is not as good of a feeding host as some of the other species sampled.

R. cuneifolius flowered from 1 April to 13 May 2004 (Fig. 1), and thrips were most abundant on 29 April (Fig. 4). No *O. insidiosus* were collected from *R. cuneifolius* on any sample dates. There was a significant effect of plant part (Table 2), with significantly more thrips on flowers than on fruit ($P = 0.0019$; Tukey's

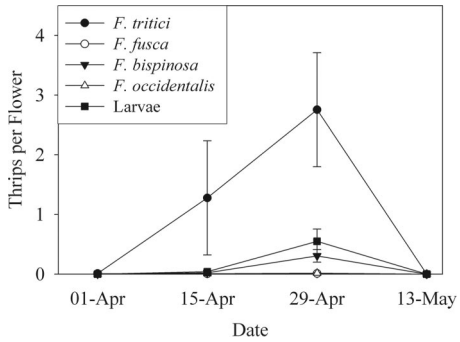

Fig. 4. Mean number (±SEM) of adult thrips species and larvae per flower collected from *R. cuneifolius*.

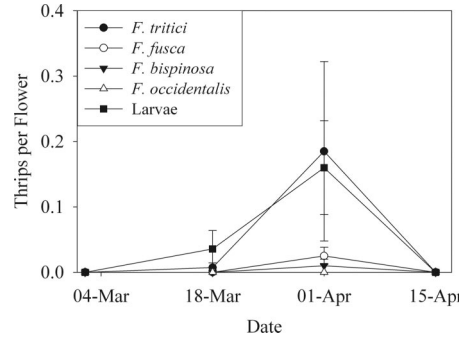

Fig. 5. Mean number (±SEM) of adult thrips species and larvae per flower collected from *V. sativa*.

test) or leaves ($P = 0.0174$; Tukey's test). The most abundant species were *F. tritici* and *F. bispinosa*, making up 87.5 and 7.3% of adults, respectively. There was a significant difference in densities of thrips species, but no significant date effect or interaction between date and species (Table 3). The larva-to-female ratio calculated over all dates was 0.68, indicating that *R. cuneifolius* was not an excellent reproductive host.

The abundance of larvae on *R. cuneifolius* and *R. trivialis* fruit when fruit were first present may be due to the inability of larvae to move to new flowers quickly. Flowers are much farther apart on *R. trivialis* and *R. cuneifolius* (often >1 m) than on *S. canadensis* and *R. raphanistrum*, and there were few adults collected from fruit on the same sample dates. This distance between flowers also may have been one of the reasons for relatively low larvae-to-female ratios collected from the *Rubus* spp. plants.

V. sativa. *V. sativa* flowered from 5 December 2003–15 April 2004 (Fig. 1), and thrips were collected from 18 March to 15 April (Fig. 5). No *O. insidiosus* were collected on any sample dates. There were significantly more thrips on flowers than on fruit ($P = 0.0035$; Tukey's test), leaves ($P = 0.0004$; Tukey's test), and buds ($P = 0.0250$; Tukey's test), and significant effects of date and the interaction between date and plant part (Table 2). The date by plant part interaction indicates that there were differences in thrips patterns of abundance on different plant parts. However, this interaction was not considered biologically significant, because thrips were so highly aggregated in the flowers.

The most abundant species were *F. tritici* and *F. fusca*, making up 81.9 and 15.3% of adults, respectively, but there was no significant difference in densities of thrips species (Table 3). The low number of adult thrips per plant collected from *V. sativa* suggests that it is not as good of a feeding host for adults as some of the other species sampled. The larva to female ratio calculated over all dates was 1.05, indicating that *V. sativa* was a mediocre reproductive host. However, the low number of thrips collected suggests that it was only used as a reproductive host by a small proportion of the population.

T. repens. *T. repens* flowered from 12 December 2003–8 July 2004 (Fig. 1), but thrips were only present

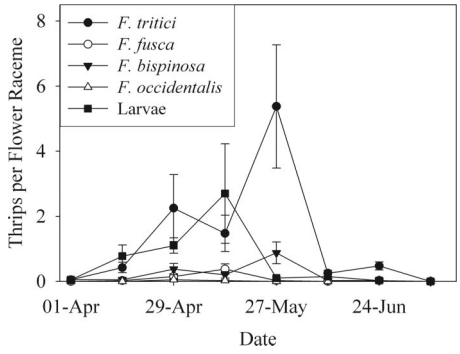

Fig. 6. Mean number (±SEM) of adult thrips species and larvae per flower raceme collected from *T. repens*.

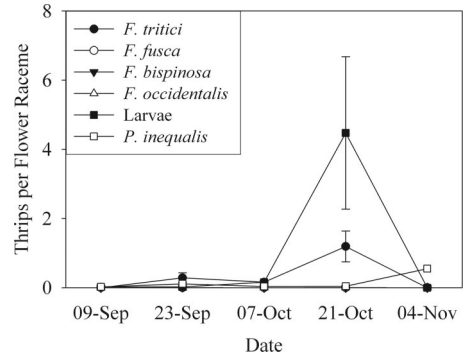

Fig. 7. Mean number (±SEM) of adult thrips species and larvae per flower raceme collected from *S. canadensis*. Only one flowering plant was present on 4 November; thus, no SEM could be calculated.

from 15 April through 24 June (Fig. 6). The only *O. insidiosus* collected from *T. repens* racemes was collected on 27 May 2004. There were significantly more thrips on racemes than leaves, and a significant effect of date and interaction between date and plant part (Table 2). This interaction was not considered biologically significant, because thrips were so highly aggregated in the flowers that the patterns of abundance were different simply due to the lack of thrips on leaves and fruit on dates when thrips were present.

There were significant effects of thrips species, date, and the interaction between species and date (Table 3). The date by species interaction indicates that there were differences in patterns of abundance of different species. The most abundant thrips species were *F. tritici* and *F. bispinosa*, making up 79.4 and 12.0% of adults, respectively. There was a significant interaction between date and the means of *F. tritici* and *F. bispinosa* ($F = 4.60$; df = 3, 60; $P = 0.0058$), indicating that there was a difference in the patterns of abundance of the two species. This difference in the patterns of abundance was due to the absence of *F. bispinosa* on 15 April and 24 June when *F. tritici* was present.

Fewer thrips per plant were collected from *T. repens* than from *S. canadensis* and *R. raphanistrum*, and this low abundance may be partially due to a lower number of flowers per plant during peak thrips abundance and the frequent mowing of *T. repens* during spring and summer. The larva to female ratio calculated over all dates was 0.62, indicating that *T. repens* was not an excellent reproductive host. However, this low ratio may have been affected by frequent mowing that may have killed developing eggs and larvae.

S. canadensis. *S. canadensis* flowered from 9 September to 4 November 2004 (Fig. 1). Thrips were present on *S. canadensis* from 23 September to 4 November, although 82% of thrips were observed on 21 October (Fig. 7). Four *O. insidiosus* also were collected from *S. canadensis* racemes on 21 October 2004. No *O. insidiosus* were collected on any other dates. There were significantly more thrips collected from racemes than leaves and the effect of date was almost significant, but there was no significant interaction between plant part and date (Table 2). Of the adults collected, 81.5% were *F. tritici* and 16.2% were *P. inequalis*, but *P. inequalis* was only collected on 4 November. There were significant effects of thrips species, date, and interaction between species and date, indicating that there were differences in the patterns of abundance for the different thrips species (Table 3). This interaction was due to the absence of *F. bispinosa*, *F. fusca*, and *F. occidentalis* during *F. tritici* abundance on 21 October 2004. *P. inequalis* was not included in the analysis, because on the date that *P. inequalis* was present there was only one plant with racemes present (Fig. 6).

The larva-to-female ratio over all sample dates was 4.14, and except for one *F. occidentalis* adult, *F. tritici* was the only adult *Frankliniella* species collected. These data suggest that *S. canadensis* is an excellent reproductive host for *F. tritici*. The high number of larvae per plant, and the widespread distribution of this plant species throughout the country (Butcko and Jensen 2002; USDA, NRCS 2004) suggest that *S. canadensis* may be an important source of *F. tritici* that migrate into fall crops. In addition, *S. canadensis* may be a source of larvae that overwinter as pupae in the soil. When temperatures rise, these pupae may develop into adults that initiate the build up in *F. tritici* population numbers in the early spring. If *S. canadensis* were not available to thrips, there may be a reduction in fall thrips populations and a delay in the spring population growth of thrips.

C. ambrosioides. *C. ambrosioides* flowered from 19 November to 5 December 2003 and from 12 August to 4 November 2004 (Fig. 8). Thrips were collected on 19 November 2003 (data not shown) and from 12 August to 4 November 2004 (Fig. 8). No *O. insidiosus* were collected. There were significantly more thrips collected from racemes than from leaves, but there was no significant date effect or interaction between date and plant part (Table 2). There was a significant difference in densities of thrips species, but no significant date effect or interaction between date and species, indicating that patterns of host use by *F. tritici* and *P. inequalis* were not significantly different (Table 3).

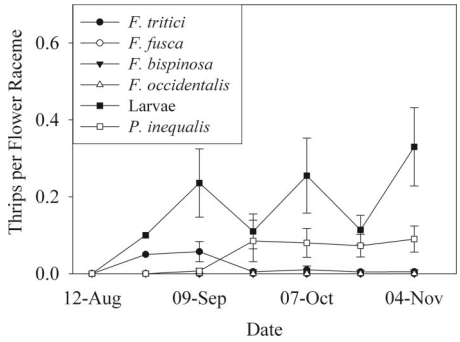

Fig. 8. Mean number (±SEM) of adult thrips species and larvae per flower raceme collected from *C. ambrosioides.*

The most abundant species were *P. inequalis* and *F. tritici*, making up 82.4 and 17.6% of adults, respectively.

There were high numbers of thrips per plant on *C. ambrosioides* and the larva-to-female ratio was 2.49, suggesting that *C. ambrosioides* is a good reproductive host for thrips. However, because the majority of females were *P. inequalis*, the data indicate that *C. ambrosioides* may not support as many reproducing crop pests (*Frankliniella* spp.) as the other plants sampled. Although there were no significant differences in the patterns of abundance between *F. tritici* and *P. inequalis*, *F. tritici* was present in *C. ambrosioides* flowers until *P. inequalis* became abundant and then were present in much lower numbers. This decrease in *F. tritici* abundance is especially interesting because population increase in *S. canadensis* was concurrent with the decrease in *C. ambrosioides.* This change in abundances suggests there may have been competitive interactions occurring between *F. tritici* and *P. inequalis* on *C. ambrosioides.* The two species also may prefer the plant at different phenological stages. *Pseudothrips beckhami* Beshear and Howell, a congeneric species to *P. inequalis*, seems to feed more on plants with increased levels of allelochemicals (Beshear and Howell 1976, Beecher et al. 1983, Bolser et al. 1998, Guillet et al. 2000, Funderburk et al. 2007), and *P. inequalis* may react to such chemicals similarly. Application of essential oils produced by *C. ambrosioides* can lead to increased mortality of *F. occidentalis*, and it also may lead to nonpreference for other *Frankliniella* species (Cloyd and Chiasson 2007). There may be an interaction between these chemicals accumulating in the plant and a simultaneous increase in *P. inequalis* and decrease in *F. tritici.* In addition, *S. canadensis* may be preferred by *F. tritici*, and thrips move from *C. ambrosioides* when *S. canadensis* becomes available. Future research on this interaction between the two thrips species and the plant phenology may lead to new information about the ecology and physiology of thrips.

***Frankliniella* spp. Host Range.** *Frankliniella* spp. thrips were frequently collected from *S. canadensis*, *R. raphanistrum*, *R. cuneifolius*, *T. repens*, and *C. ambrosioides*, and each plant species is from a different taxonomic family (Asteraceae, Brassicaceae, Rosaceae, Fabaceae, and Chenopodiaceae), demonstrating the broad feeding host range of thrips. By feeding on pollen in flowers, thrips may reduce the need to adapt to a wide range of host defenses, such as those encountered by generalist insects that feed on other plant parts (for review, see Strong et al. 1984, Jaenike 1990). Most of the research conducted on thrips reactions to plant chemical defenses has been conducted on other plant parts, such as leaves (de Jager et al. 1996, Agrawal et al. 1999, Agrawal and Klein 2000). However, this and other studies have shown that flower thrips spend the majority of time in flowers feeding on pollen and other floral parts, away from the defensive characteristics in leaves. There has been a great deal of work identifying defensive characteristics of pollen to pathogens (e.g., Hoffmann-Sommergruber 2000; Sheoran et al. 2006, 2007), but very few defensive characteristics have been identified against insects. Flower and pollen defense against insects may lead to a reduction in pollination (Irwin et al. 2004, Irwin and Adler 2006), and therefore defensive characteristics may be lower in flowers than in other plant parts. In addition, the ephemeral nature of flowers may lead to selective pressure toward host switching by thrips to maintain population growth as the phenology of host plants change. The ephemeral nature of flowers may therefore lead to the need for a broad host range for *Frankliniella* spp. thrips.

The variation in suitability for the plants sampled may be due to nutritional characteristics such as overall protein concentrations, or relative amino acid concentrations (Mollema and Cole 1996, Brodbeck et al. 2002) or flower/developing fruit morphological characteristics (Felland et al. 1995). Identifying the reasons for their suitability will allow researchers to target specific uncultivated host plants in future population dynamics studies. Furthermore, large populations of *Frankliniella* spp. thrips were supported by *R. raphanistrum* in the summer and *S. canadensis* in the fall, and these plants may ultimately be sources of crop infestations. Therefore, control measures such as seasonal mowing of these plants may decrease the immigration of thrips into cropping systems. Pearsall and Myers (2001) presented evidence of thrips migration from wild land into nectarine orchards, and the plant species sampled here may be sources of such migration in northern Florida cropping systems. However, it is not clear how far thrips migrate from host patch to host patch. New information on the flight range of *Frankliniella* spp. thrips may lead to information on the extent of mowing necessary to manage thrips populations migrating into cropping systems. Finally, in all of the reproductive hosts sampled, thrips were highly aggregated in the flowers, rather than leaves or fruit, and this aggregation should be considered when designing control methods.

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