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Influence of Native Flowering Plant Strips on Natural Enemies and Herbivores in Adjacent Blueberry Fields

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ABSTRACT Conservation plantings of native wildflowers were established adjacent to highbush blueberry (*Vaccinium corymbosum* L.) fields to test the hypothesis that provision of resources for natural enemies increases their abundance in adjacent crop fields without increasing the abundance of pest insects. For two growing seasons, natural enemies and herbivorous insects were sampled in fields with flowering borders and in control fields where growers maintained standard mown grass perimeters. Insects were categorized according to their trophic level and their potential pest status, and their abundance was compared between years and between treatments. Syrphid flies (Diptera: Syrphidae) were significantly more abundant in fields with conservation strips, as were plant bugs (Hemiptera: Miridae), thrips (Thysanoptera: Thripidae), and hoppers (Hemiptera: Auchenorrhyncha). Aphids (Hemiptera: Aphididae), thrips, fruit flies (Diptera: Tephritidae), and pirate bugs (Hemiptera: Anthocoridae) decreased significantly in abundance from 2007 to 2008. Beneficial insect abundance in crop fields increased in the latter half of the season in both years and this increase was more pronounced in fields adjacent to conservation plantings. We discuss the implications of these findings for pest management and conservation of biodiversity in farmland.

KEY WORDS conservation biocontrol, habitat management, fruit, integrated pest management (IPM), blueberry

There has been growing interest in recent years regarding the economic and environmental benefits of reincorporating natural habitats into agricultural systems (Jackson and Jackson 2002, Kleijn and Sutherland 2003, Landis et al. 2005, Bianchi et al. 2006), in part because of declines in populations of beneficial insects (Biesmeijer et al. 2006). The suspected reasons for these declines include pesticide use, loss of habitat, and a paucity of flowering plants within agricultural landscapes (Landis et al. 2000, Carvell et al. 2006, Holzschuh et al. 2008). Many farms in regions of intensive crop production lack the habitats that historically provided resources to beneficial insects, and this lack has compromised the ability of farmers to rely on natural enemies for pest control (Tilman et al. 2002, Landis et al. 2005, Tscharntke et al. 2005, Losey and Vaughan 2006). To counteract this trend, habitat management by using flowering plants provided in and around crop fields has been proposed as a means of supporting beneficial insects to increase their abundance and increase biological control (Hickman and Wratten 1996, Barbosa 1998, Gurr et al. 2004, Isaacs et al. 2009). Flowering plants provide many essential resources for beneficial arthropods including nectar, pollen, alternate prey, and shelter (Landis et al. 2000, van Emden 2002).

Cover crops can also provide vegetative and floral diversity to support natural enemies in crop fields (Bugg and Waddington 1994, Nicholls et al. 2000, Kinkorová and Kocourek 2000). However, the placement of resource plants directly inside crop fields can cause disturbance or death of beneficial insects if the crop is cultivated or treated with broad-spectrum insecticides (Lee et al. 2001). Placement of conservation plantings outside the crop area provides a more benign environment for beneficial insects where they can feed on nectar and pollen, use alternate hosts, and find refuge in an area not impacted by harmful disturbance (Sotherton 1984, Thomas et al. 1991). For farmers to benefit from this provision of resources however, it is essential that the beneficial insects disperse from the plantings into the crop habitat.

Natural or seminatural components of landscapes surrounding cropped areas have consistently been shown to support beneficial insects (Kremen et al. 2002, 2004; Steffan-Dewenter 2003; Bianchi et al. 2006; Greenleaf and Kremen 2006), but this is something that most growers cannot manipulate easily. Land adjacent to fields is often not owned by the grower, may be managed for purposes other than to support natural enemies, or may be urbanized. Integrating refuge and flower resources directly into the field border is more likely to be adopted as a strategy to create habitat for beneficial insects.

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The insect targets of habitat management respond at different scales to habitat diversification (Banks 2000, Tscharntke et al. 2007, Fraser et al. 2008, Werling and Gratton 2008). For example, parasitoid wasps may respond at a relatively small scale (m) to the addition of flowering resources to a field, whereas larger organisms (e.g., lady beetles (Coccinellidae spp.) Gardiner et al. 2009) respond to resource availability at larger spatial scales (km). The scale at which these insects respond is important from a practical standpoint, because individual farmers are more likely to implement habitat management if there is a measurable benefit at the field scale (Tilman et al. 2002, Kurkalova et al. 2006, Wossink and Swinton 2007).

The effectiveness of habitat management as a means of conservation biological control can also vary depending on the nature of the disturbance regime of the target crop (Landis et al. 2000). Generally, habitat management has had more success in perennial crops, especially orchards and vineyards (Doutt and Nakata 1973, Nicholls et al. 2000, Kinkorová and Kocourek 2000), where less intensive herbicide and tillage regimes lead to increased stability of beneficial insect populations (van Emden and Williams 1974, Landis and Menalled 1998). Thus, producers of highbush blueberry (Ericaceae: *Vaccinium corymbosum* L.) might be expected to benefit from this type of habitat management because their plantings are productive for >40 yr (Shoemaker 1975) and the disturbance regimes are less intensive than most annual crops. However, application of insecticides in crop fields may compromise the ability of perimeter plantings to provide beneficial insects that can survive in those fields.

This study focused on potential biocontrol agents of aphids, because their populations can be regulated by parasitoid wasps (Völkl et al. 2007), which respond at small scales to supplemental wildflower plantings (Langhof et al. 2005, Lee and Heimpel 2005). The effect of adding wildflower strips on other groups of insects, including herbivores, was also examined because of their potential to benefit from increased floral resources (Norris and Kogan 2000, 2005; Lavandero et al. 2006). Prudent design and evaluation of conservation plantings for use in crop systems requires the determination of their effect on both natural enemies and on potential pests (Baggen et al. 1999, Bone et al. 2009).

We tested the hypotheses that: 1) natural enemy populations benefit from the presence of conservation flower plantings, 2) natural enemy abundance declines with distance from conservation plantings, 3) herbivore populations benefit from the presence of additional flower resources, and 4) conservation plantings in field margins buffer beneficial insect populations from the effects of disturbance in crop fields.

Methods

Nine species of native flowering plants rated as highly attractive to beneficial insects and with different periods of peak bloom (Fiedler and Landis 2007a, b; Tuell et al. 2008), and one native grass (Table 1)

Table 1. Scientific and common names of the flowering plant species planted in 2006 in flower conservation strips next to blueberry fields

Scientific name	Common name	Approx. peak bloom date[a]
Penstemon hirsutus	Hairy beardtongue	June 8
Potentilla fruticosa	Shrubby cinquefoil	July 1
Monarda fistulosa	Bee balm	July 12
Veronicastrum virginicum	Culver's root	July 30
Solidago juncea	Early goldenrod	Aug 3
Lobelia siphilitica	Blue lobelia	Aug 15
Silphium terebinthinaceum	Prairie dock	Aug 16
Agastache nepetoides	Yellow giant hyssop	Aug 17
Aster laevis	Smooth aster	Sept 17
Schizachyrium scoparius[b]	Little bluestem	–

[a] Peak bloom dates were estimated from field observations in 2007 and 2008.
[b] No bloom data were collected for this plant.

were planted as plugs (1-yr-old plants) in spring 2006 (WildType Native Plant Nursery, Mason, MI). Three sets of ten 4-m^2 plots containing 20 plugs of each of the 10 native plants were arranged along a 60- × 2-m strip in a randomized design in the border of blueberry fields. These strips were established at four commercial blueberry farms in Van Buren County (two sites: 42° 24′ 27.60"N, 86° 6′ 36.86"W, and 42° 15′ 28.52"N, 86° 13′ 51.66"W); and Ottawa County (two sites: 42° 53′ 6.52"N, 86° 9′ 12.86"W, and 42° 52′ 13.69"N, 86° 7′ 32.41"W) (Fig. 1).

At each of the four commercial blueberry farms, two 5- to 10-ha fields were selected at least 120 m apart. One field was adjacent to the established flower strip (flower) and one field was adjacent to a typical mown field border (control) (Fig. 1). The borders were separated from the crop fields by a narrow drive lane used for machinery. At all fields (n = 8), unbaited Pherocon AM yellow sticky traps (Trécé Inc., Adair, OK) were placed along three transects into the field in four positions: field border, first blueberry bush (0 m), and 20 m and 40 m into the field. Yellow sticky traps were hung for 1-wk intervals from June to August 2007 and 2008. To minimize annual variations in insect abundance from climatic differences between years, the start of the 2008 sampling period was set to match the growing degree-day accumulation of the first sample from 2007.

Natural enemies trapped with yellow sticky traps were counted and identified in the laboratory by using a magnifier lamp, dissecting scope, or both as needed. A combination of taxonomic keys, photographic guides, and natural history references were used to sort insects into major groups (Borror et al. 1992, Flint and Dreistadt 1998, Marshall 2006). Insects were identified to the taxonomic level necessary for determination of whether a particular specimen could be classified as a natural enemy (i.e., predator or parasitoid) or herbivore. Voucher specimens are deposited in the Albert J. Cook Arthropod Research Collection at Michigan State University.

Insect counts were $\log(x + 1)$ transformed to meet the assumptions of normality. Analysis of insect counts

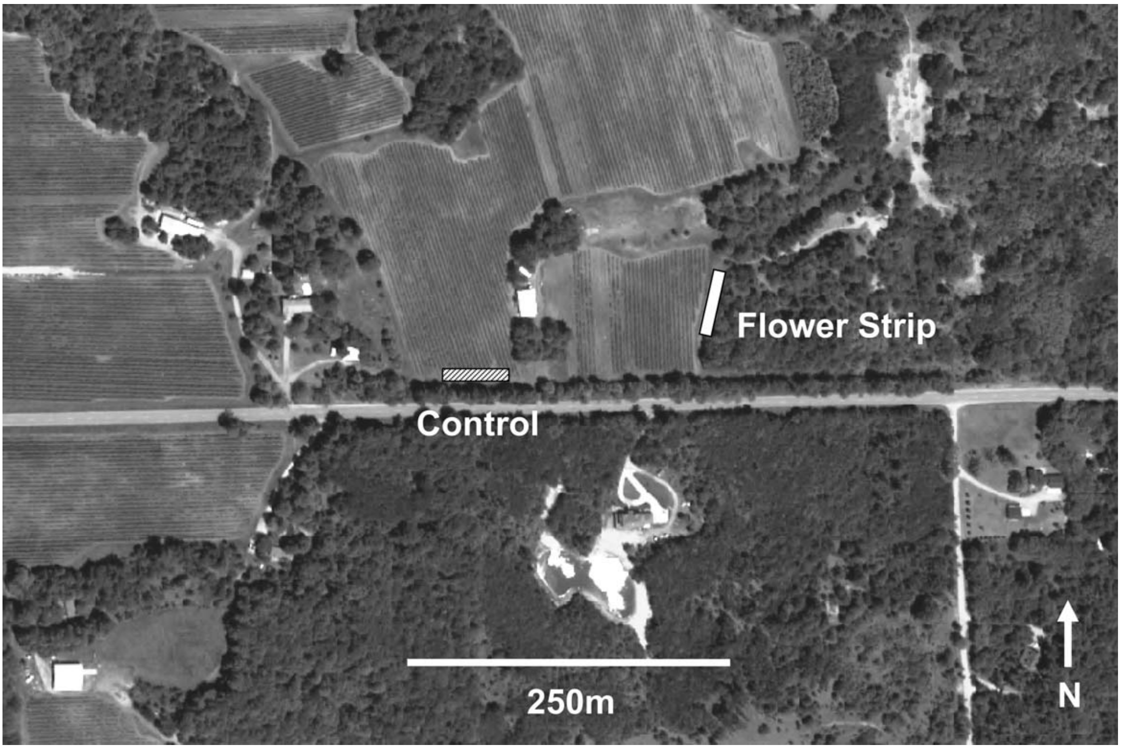

Fig. 1. Aerial view of one of the study sites showing the location of a field with an adjacent flowering plant strip (Flower) and a control field adjacent to an unmodified border (Control). Photograph courtesy of the U.S. Department of Agriculture's Aerial Photography Field Office.

was performed by repeated measures general linear mixed model analysis of variance (ANOVA) (PROC MIXED, SAS Institute 2003). The full model included site as a random variable, and treatment (flower versus control), distance, week, and all possible interactions as fixed effects. Week was specified as the repeated measure effect with the transect by distance interaction as the subject (nested within site by treatment by distance) and a compound symmetry covariance structure.

For comparison between years, data from each transect, distance, and week were pooled. The pooled data did not fit the assumption of normality for all taxonomic groups, so a nonparametric analysis was performed by ranking the observations and using the ranks in the analysis. The model for this analysis included year, treatment, and their interaction as fixed effects. Site and its interactions with year and treatment were included as random effects (PROC MIXED, SAS Institute 2003).

Results

In 2 yr of sampling a total of 20,961 natural enemies were collected on sticky traps (Table 2). Of these natural enemies, the majority were parasitoid wasps (Hymenoptera: Parasitica) (91% and 93% in 2007 and 2008, respectively). Other important groups of natural enemies included pirate bugs (Hemiptera: Anthocoridae) (3% of the sample in 2007 and 1% in 2008) and syrphid flies (Diptera: Syrphidae) (1% in 2007 and 2% in 2008).

In both years, natural enemy abundance decreased with distance from the field border ($F_{2007} = 20.88$, df = 4, 24, $P < 0.0001$; $F_{2008} = 20.07$, df = 3, 18, $P < 0.0001$) (Fig. 2). Pairwise comparisons by distance revealed that the field border trap catches were significantly greater than all in-field measurements (Fig. 2). To eliminate this source of variation and more accurately describe the effect of the flower strips on insect abundances inside the blueberry fields, these data were analyzed separately from the in-field trap catches.

After removal of the field border data, natural enemy abundance varied significantly with distance in 2007, but not in 2008 ($F_{2007} = 5.95$, df = 2, 12, $P = 0.016$; $F_{2008} = 2.91$, df = 2, 12, $P = 0.09$). Captures varied by week in both years ($F_{2007} = 53.9$, df = 5, 374, $P < 0.0001$; $F_{2008} = 25.78$, df = 5, 377, $P < 0.0001$) (Fig. 3). Overall, the abundance of natural enemies was significantly higher in fields adjacent to flower strips than control field perimeters in 2007 ($F_{2007} = 11.59$, df = 1, 3, $P = 0.04$), but not in 2008 ($F_{2008} = 2.92$, df = 1, 3, $P = 0.09$). In 2007, there was a significant interaction between treatment and week ($F_{2007} = 4.25$, df = 5, 374, $P = 0.0009$) (Fig. 3). For example, there were significantly more natural enemies in the fields near flower strips compared with control fields only in the

Table 2. The arthropod community caught on yellow sticky traps in 2007 and 2008 in blueberry fields adjacent to flowering strips (Flower) or adjacent to unmodified field borders (Control)

Taxonomic group	Mean no. of insects per farm ± SEM[a]			
	2007		2008	
	Flower	Control	Flower	Control
Beneficials:				
Neuroptera	19 ± 11	20 ± 6	15 ± 6	11 ± 2
Diptera				
Syrphidae	39 ± 14a	22 ± 7b	54 ± 14a	28 ± 5b
Coleoptera				
Coccinellidae	14 ± 9	8 ± 3	9 ± 5	7 ± 1
Misc. predators	11 ± 4	6 ± 3	11 ± 3	17 ± 3
Hymenoptera				
Parasitica	2086 ± 408	1942 ± 280	1868 ± 233	1315 ± 81
Aculeata				
Apoidea	24 ± 8	20 ± 4	22 ± 15	11 ± 1
Vespoidea	5 ± 2a	0.50 ± 0.50b	10 ± 4c	8 ± 1d
Hemiptera				
Anthocoridae	97 ± 28a	46 ± 13a	23 ± 10b	10 ± 3b
Pentatomidae	2 ± 1	1 ± 1	0.5 ± 0.3	0.25 ± 0.25
Nabidae	2 ± 0.70	1 ± 0.55	2 ± 0.69	1 ± 0.57
Herbivores:				
Hemiptera				
Miridae	94 ± 53a	35 ± 6b	89 ± 30a	32 ± 8b
Tingidae	5 ± 3a	4 ± 1a	1 ± 0.69b	1 ± 0.47b
Auchenorrhyncha	2071 ± 688a	1293 ± 305b	1571 ± 476a	963 ± 110b
Aphididae	12651 ± 3363a	10449 ± 1654a	4047 ± 1281b	2902 ± 224b
Thysanoptera				
Thripidae	22792 ± 5761a	11060 ± 1837b	5504 ± 1058c	2298 ± 475d
Coleoptera				
Scarabaeidae	1 ± 0.48	0	0.25 ± 0.25	0
Diptera				
Tephritidae	19 ± 13a	11 ± 7a	0.49 ± 0.28b	1 ± 0.74b
Lepidoptera	21 ± 5	21 ± 6	15 ± 3	12 ± 2
Hymenoptera				
Symphyta	51 ± 48	12 ± 5	8 ± 4	11 ± 6
Indet.[b]:				
Diptera				
Unknown	6571 ± 1156a	5393 ± 714b	6353 ± 1251a	5557 ± 1119b
Dolichopodidae	1524 ± 521	1131 ± 114	894 ± 300	694 ± 90
Coleoptera	472 ± 95a	372 ± 56a	296 ± 35b	228 ± 37b
Hymenoptera				
Formicidae	129 ± 39	60 ± 2	65 ± 20	80 ± 38
Hemiptera				
Thyreocoridae	11 ± 7	4 ± 3	1.5 ± 0.64	3.5 ± 1.7
Aranae	18 ± 5	10 ± 4	16 ± 4	17 ± 4

Values within a row followed by letters are significantly different; those followed by the same letter are not significantly different ($P > 0.05$).
[a] Means and standard errors are based on total trap catch per farm (n = 4) sorted by treatment border (Control/Flower) and year.
[b] The indeterminate (Indet.) category contains arthropods whose identity or impact on agriculture were not determined.

first two (Treatment*Week, day 222, t = 2.6 df = 499 P = 0.01; day 229, t = 3.27 df = 499 P = 0.001) and last two weeks in the 2007 season (Treatment*Week, day 222, t = 2.6 df = 499 P = 0.01; day 229, t = 3.27 df = 499 P = 0.001) (Fig. 3). In 2008 during the second year of flowering, this interaction was not statistically significant, but the same trend was evident numerically (Treatment*Week, F_{2008} = 1.82 df = 5, 377 P = 0.11) (Fig. 3).

The analysis of natural enemy abundance in the field borders revealed a significant interaction between treatment and week in 2007 (F_{2007} = 3.3, df = 5, 125, P = 0.0073), and significant variation among weeks in both years (F_{2007} = 18.23, df = 5, 125, $P <$ 0.0001; F_{2008} = 22.2, df = 5, 126, P = <0.0001). The significant treatment by week interaction was because of there being numerically more natural enemies in the control borders during the first five weeks sampled, but more natural enemies in the flower borders in the last sample of the 2007 season. In 2008, in contrast, natural enemies were consistently more abundant numerically in flower borders compared with controls, but this difference was not statistically significant (F_{2008} = 2.83, df = 1, 3, P = 0.19) (Fig. 3).

In the herbivore group, thrips (Thysanoptera: Thripidae) were the most abundant insects, comprising 57% of the herbivores sampled in 2007 and 45% of those herbivores sampled in 2008. Aphids (Hemiptera: Aphididae) were the second most abundant group comprising 38% and 40% of the herbivores sampled in 2007 and 2008, respectively. Leafhoppers and planthoppers (Hemiptera: Auchenorrhyncha) were the third most abundant group comprising 6% and 15% of the herbivores sampled in 2007 and 2008, respectively.

Insect pests of blueberry represented a very small proportion of the insects captured on yellow sticky

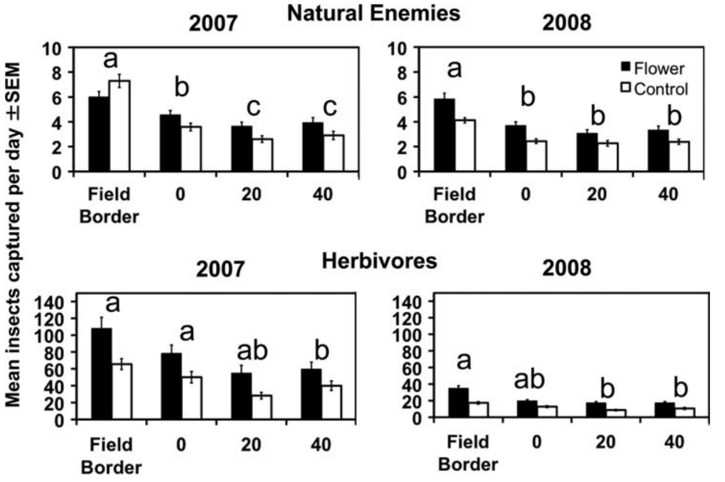

Fig. 2. Abundance of natural enemies and herbivores in blueberry fields adjacent to flowering plant strips (Flower) and fields adjacent to unmodified borders (Control). There was no significant difference between treatments at each distance ($P > 0.05$). Distances with the same letter are not significantly different ($P > 0.05$).

traps. The group of flies containing blueberry maggot (Diptera: Tephritidae) was <1% of all the herbivores sampled in both years, and many of the species trapped were nonpests. The group containing Japanese beetle (Coleoptera: Scarabaeidae, *Popillia japonica* Newman) made up <0.01% of the herbivores caught in both years. The group containing cranberry fruitworm (Lepidoptera, *Acrobasis vaccinii* Riley) comprised <1% of the sample in both years.

In both years, when field border and in-field trap counts of herbivores were analyzed together there was a significant effect of distance, with a trend toward more herbivores in the field borders ($F_{2007} = 3.91$, df = 3, 18 $P = 0.03$; $F_{2008} = 5.69$, df = 3, 18, $P = 0.01$) (Fig. 2). Thus, the herbivore counts from the field border and in-field traps were analyzed separately.

The analysis of the in-field herbivore trap catch revealed significant variation in herbivore abundance among weeks ($F_{2007} = 38.0$, df = 5, 374, $P < 0.0001$; $F_{2008} = 35.86$, df = 5, 377, $P < 0.0001$). There was also a significant distance by week interaction in both years ($F_{2007} = 2.55$, df = 10, 374, $P = 0.006$; $F_{2008} = 2.25$, df = 10, 377, $P = 0.01$), and a significant week by treatment interaction in 2007 only ($F_{2007} = 3.05$, df = 5, 374, $P = 0.01$; $F_{2008} = 1.42$, df = 5, 377, $P = 0.22$). Herbivores were significantly more abundant in fields adjacent to flower strips compared with control fields in June and early July of 2007 (day 166: $t = 2.52$, df = 374, $P = 0.01$; day 175: $t = 3.0$, df = 374, $P = 0.003$; day 186: $t = 2.56$, df = 374, $P = 0.01$) (Fig. 3).

Analysis of herbivore abundance in the field perimeters showed significant variation by week in both years ($F_{2007} = 14.53$, df = 5, 125, $P < 0.0001$; $F_{2008} = 24.61$, df = 5, 126, $P < 0.002$). In 2008, there were significantly more herbivores in flower borders than controls ($F_{2008} = 10.81$, df = 5, 126, $P = 0.046$). Also in 2008, there was a significant interaction between treatment and week ($F_{2008} = 4.13$, df = 5, 126, $P = 0.0017$). There were significantly more herbivores in the flower strips than the control borders during the first four weeks sampled in 2008 (day 184: $t = 3.64$, df = 126, $P < 0.001$; day 191: $t = 3.52$, df = 126, $P = 0.003$; day 198: $t = 4.04$, df = 126, $P < 0.0001$; day 226: $t = 2.27$, df = 126, $P = 0.02$) (Fig. 3).

To examine the response of insect taxonomic groups individually across years, the data were pooled by distance, transect, and week (Table 2). This data revealed that syrphid flies (Syrphidae) were significantly more abundant in fields with flowering plant strips in both years ($F = 18.06$, df = 1, 6, $P = 0.0054$). Plant bugs (Miridae) were also significantly more abundant in fields with flowering plant strips ($F = 7.87$, df = 1, 6, $P = 0.031$), as were the hoppers (suborder Auchenorrhyncha) ($F = 11.32$, df = 1, 6, $P = 0.015$), and thrips (Thripidae) ($F = 13.32$, df = 1, 6, $P = 0.011$). Predatory wasps (superfamily Vespoidea) were more abundant in fields with flowering plant strips ($F = 6.10$, df = 1, 6, $P = 0.049$) and were the only group that was significantly more abundant in 2008 than in 2007 ($F = 13.59$, df = 1, 3, $P = 0.035$). Pirate bugs (Anthocoridae) significantly decreased in abundance from 2007 to 2008 ($F = 29.29$, df = 1, 3, $P = 0.012$), as did aphids (Aphididae) ($F = 62.83$, df = 1, 3, $P = 0.004$), thrips ($F = 59.34$, df = 1, 3, $P = 0.005$), and fruit flies (Tephritidae) ($F = 25.76$, df = 1, 3, $P = 0.015$). Parasitoid wasps were numerically more abundant in 2008 than 2007 but this difference was not statistically significant ($F = 3.92$, df = 1, 3, $P = 0.14$) (Table 2).

Discussion

This study shows that native flowering plant strips can increase the abundance of some natural enemies in adjacent commercial blueberry fields, and that this increase can occur rapidly within a single season. Overall, these results agree with a number of other studies showing that the introduction of attractive flowering plants into agricultural settings leads to in-

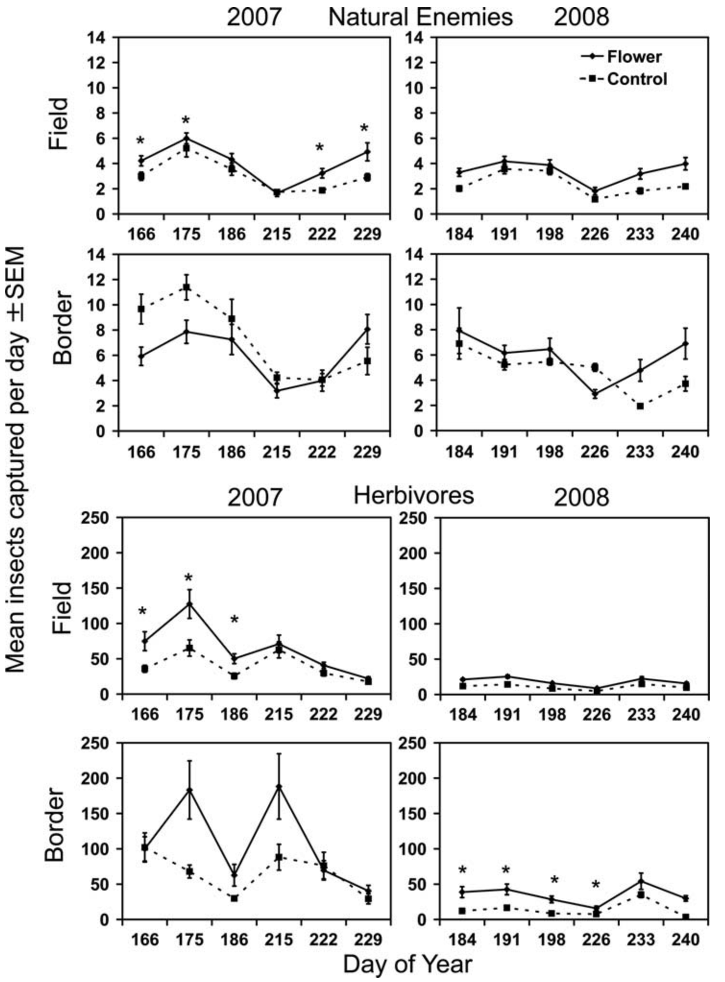

Fig. 3. Abundance of natural enemies and herbivores in blueberry fields (Field) and field borders (Border), with either a flower strip (Flower) or a mown field border (Control). Asterisks indicate that abundances for that day of the year were significantly different between flower and control treatments ($P < 0.05$).

creased arthropod natural enemy abundance (White et al. 1995, Hickman and Wratten 1996, Wyss 1996, Long et al. 1998, Pfiffner and Wyss 2004, Lee and Heimpel 2005, Rebek et al. 2005).

Syrphid populations responded particularly well to the conservation strips as did predatory wasps, which suggests that these groups benefited from the food, nesting resources, or both provided there. Syrphid flies are well known to respond to the amount of flowering resources in farmland (White et al. 1995, Hickman and Wratten 1996, Biesmeijer et al. 2006), and these conservation strips can provide resources that are limiting to these insects in agricultural landscapes.

Parasitoid wasps comprised the majority of the natural enemy community in both years, and within years parasitoid wasps were more abundant in fields adjacent to the conservation strips (Fig. 2). However, this group's population increase from 2007 to 2008 was not statistically significant (Table 2). This information suggests that this group's short-term population dynamics are more affected by the conservation strips than their long-term population dynamics. However, it may be more biologically significant that parasitoid wasp populations did not decrease from 2007 to 2008 as the populations of many other groups of insects did (Table 2).

That pirate bug populations declined between the two years is interesting, and may be linked to the concomitant decrease in populations of insect groups that they prey on (aphids and thrips, Table 2). *Orius* bugs are facultatively phytophagous (Coll and Guershon 2002) but exhibit increased fecundity when provided with prey food in addition to plant-derived foods (Kiman and Yeargen 1985). In this study, the amount of flower resources may have had less of an effect on abundance of these predators than availability of prey insects, as suggested by the observed change in density of anthocorids from 2007 to 2008 (Table 2).

Flowering plant strips also affected the abundance of a number of herbivorous groups of insects. Within years, some herbivores were more abundant adjacent to conservation strips. The leafhoppers and planthoppers for example were consistently more abundant in fields adjacent to flower strips (Table 2, Auchenorrhyncha). While these insects are not considered major pests of blueberry, they could cause damage in other agricultural systems where they are important disease vectors (Redak et al. 2004, Weintraub and Beanland 2006). The Miridae were also more abundant in and around the flower strips (Table 2). The mirids are a somewhat enigmatic group because certain species can be very economically damaging in some crops (Snodgrass et al. 2006, Swezey et al. 2007) while other species are predatory and/or omnivorous and are considered beneficial in other crops (Sanchez et al. 2003, Rosenheim et al. 2004). These findings underscore the need for system-specific evaluation of conservation strips for enhancing beneficial insects so that specific pest-attractive plants are avoided and pests of major concern to growers are not enhanced by the addition of these plantings.

The two most abundant herbivore groups, thrips and aphids, both showed substantial declines in abundance from 2007 to 2008. Actually, four out of nine herbivore groups declined significantly from 2007 to 2008, and none increased (Table 2). The cause of this decline cannot be determined from our data, but this trend does not support the hypothesis that herbivores as a group benefited from the presence of flowering plant strips in this study.

The hypothesis that the flowering plant strips would buffer natural enemies from the effects of disturbance in the crop was supported by late season differences between the abundance of natural enemies in control and flower fields. Blueberry harvest across the study region generally lasts from mid-July to mid-August (days 197–228, Fig. 3), and can be a period of broad-spectrum insecticide and fungicide use for control of key contaminant insects and fruit rots (Isaacs and Mason 2008). The observed decrease in natural enemy abundance between early July and August in both years is likely related to these disturbances in crop fields at this time, and the flowering strip can provide a refuge from this disturbance allowing more rapid recolonization of crop fields by natural enemies. Indeed, the late season recovery of natural enemies after harvest in both years was earlier and of a greater magnitude in fields adjacent to flowering plant strips. The presence of alternative hosts and nutritional resources in the flowering plant strips may have facilitated this rebound in abundance of natural enemies after disturbance, an effect that has also been reported in corn planted with refuge strips (Lee et al. 2001). Also, the largest area of flowers in the flower strips was present in late summer (data not shown), which may help explain the significant increases in natural enemy abundance adjacent to flowering strips late in the season (Fig. 3). Floral area has been shown to be a strong predictor of natural enemy abundance in native conservation plantings (Fiedler and Landis 2007b).

Thorough quantitative economic analysis of this type of conservation biocontrol practice is currently lacking (Cullen et al. 2008). This is likely because of the paucity of data regarding the benefits that farmers can expect from conservation strips to enhance pest biological control. The costs are easily estimated based on prices for seeds or plants prices, labor for planting, and maintenance costs, and if crop production is replaced with conservation plantings then the cost of withholding acreage from production can be determined (Lovell and Sullivan 2006, Wossink and Swinton 2007, Cullen et al. 2008). For example, at 2006 bulk seed prices the seed for a 120- m^2 flower strip with 10 species of native flowering plants in Michigan would have cost $\approx$15 dollars (U.S.). A farmer deciding whether or not to establish a flowering plant strip needs to know whether this cost and that of preparation, sowing, and maintenance will be recovered through a reduction in pest control costs. This study does not provide quantitative measures of pest control benefit of these flowering plant strips, but this is an area of active research.

Many studies assessing the effects of conservation biocontrol in farmland measure increases in biodiversity as a measure of success. This study focused on insect abundance rather than diversity, because abundance can be more affected by local features such as the presence of a flower planting (Wyss 1996). In the absence of evidence for a direct relationship between biodiversity and biological control, farmers are not likely to invest in biodiversity conservation (Van Buskirk and Willi 2004, Norris and Kogan 2005, Tscharntke et al. 2007, Letourneau and Bothwell 2008). Alternatively, if a direct connection between local natural enemy abundance and pest control can be demonstrated, then growers will be more likely to implement conservation strategies to reduce their dependence on costly chemical methods of insect control (Lovell and Sullivan 2006, Pascual and Perrings 2007, Wossink and Swinton 2007, Cullen et al. 2008). These changes to their farm landscape may also be funded in part by government cost-share programs. Ultimately, adoption of native plant conservation plantings is expected to cause an increase in the quality of farmland as habitat for insects that can provide services to farmers.

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