Environmental Entomology, XX(XX), 2023, 1–8
https://doi.org/10.1093/ee/nvad016
Research

ENTOMOLOGICAL SOCIETY OF AMERICA
SHARING INSECT SCIENCE GLOBALLY
OXFORD

Biological Control - Parasitoids and Predators

A Field Survey of Syrphid Species and Adult Densities on Annual Flowering Plants in the Northeastern United States

Alina Harris-Cypher,[1] Caterina Roman,[2] Genevieve Higgins,[3] Susan Scheufele,[3] Ana Legrand,[4] Anna Wallingford,[2] and Rebecca Grube Sideman[2,5]

[1]Xerces Society for Invertebrate Conservation Regional Office, Durham, NH 03824, USA, [2]University of New Hampshire, 129 Main Street, Durham, NH 03824, USA, [3]University of Massachusetts Extension, 230 Stockbridge Road, Amherst, MA 01003, USA, [4]University of Connecticut, 1376 Storrs Road, Storrs, CT 06268, USA, and [5]Corresponding author, e-mail: becky.sideman@unh.edu

Subject Editor: Brett Hurley

Received on 31 August 2022; Editorial decision 22 January 2023.

Abstract

With the long-term goal of exploring the viability of conservation biological control of cabbage aphid *Brevicoryne brassicae* (L.) (Hemiptera: Aphididae) in the northeastern United States, adult syrphid flies (Diptera: Syrphidae) were observed on several species of annual insectary plants at farm sites in Connecticut, Massachusetts, and New Hampshire. Insectary plant species included alyssum, *Lobularia maritima* (L.) (Brassicales: Brassicaceae), buckwheat, *Fagopyrum esculentum* (Moench) (Caryophyllales: Polygonaceae), phacelia, *Phacelia tanacetifolia* (Bentham) (Boraginales: Hydrophyllaceae), calendula, *Calendula officinalis* (L.) (Asterales: Asteraceae) and ammi, *Ammi majus* (L.) (Apiales: Apiaceae). Among these insectary plants, alyssum had the longest bloom period and attracted the most syrphids. We identified 21 species of syrphid flies from insectary plants. The three most prevalent species collected were the aphidophagous *Toxomerus marginatus* (Say) (Diptera: Syrphidae) (70.1% of samples) and *T. geminatus* (Say) (Diptera: Syrphidae) (8.8% of samples), as well as the non-aphidophagous *Syritta pipiens* (L.) (Diptera: Syrphidae) (13.1% of samples). The benefits of including these insectary plant species as a companion to *Brassica* (L.) (Brassicales: Brassicaceae) cropping systems are discussed.

Key words: Syrphidae, insectary, alyssum, *Toxomerus marginatus*, aphidophagous

Syrphid flies (Diptera: Syrphidae), also known as hover flies or flower flies, are ubiquitous worldwide, and approximately one third of their species (mostly in the Syrphinae and Pipizinae subfamilies) prey on aphids and other soft-bodied insects during their larval stage (Skevington et al. 2019). During their adult stage, syrphid flies rely on nectar and pollen from flowers to survive and reproduce (Amorós-Jiménez et al. 2014). Syrphid flies have been observed feeding from a variety of flowering weeds on farms (Cowgill et al. 1993, Hickman et al. 1995), however, allowing weed species to flower and set seed is undesirable because it can increase the weed seed bank (Schwartz-Lazaro and Copes 2019).

Insectary plants are flowering plants purposefully grown near cash crops to host and augment natural enemies of pests. This habitat enhancement can facilitate conservation biological control. Several studies have shown that insectary plants encourage syrphid flies to stay within the crop field longer, which, in turn, increases aphid predation rates and reduces crop damage (Hickman and Wratten 1996, Pineda and Marcos-García 2008, Haenke et al. 2009, Amorós-Jiménez et al. 2014). In some cases, syrphid larvae can provide economically meaningful control of aphids (Hickman and Wratten 1996) or a measurable decrease in aphid populations (White et al. 1995).

The use of alyssum, *Lobularia maritima* (L.) (Brassicales: Brassicaceae) as an insectary intercrop to host syrphids has been successful for the management of aphids on crops in California, including broccoli, *Brassica oleracea* (L.) (Brassicales: Brassicaceae) and lettuce, *Lactuca sativa* (L.) (Asterales: Asteraceae) (Smith and Cheney 2007, Brennan 2016). This practice is untested in the northeastern U.S. where syrphid species and their seasonal variation may be different. Since syrphid species may differ by region, and only some species of syrphid larvae are predaceous, it is necessary to identify wild or native syrphid species to understand if they may act as biological control agents.

Recent surveys by the authors revealed that some organic growers in the northeastern U.S. have reduced or stopped growing fall brassicas because of inability to manage cabbage aphid. To explore the potential for using naturally occurring biological control agents to control cabbage aphid in the northeastern U.S., we focused our attention on insectary plants and syrphids, which have been shown to be an important biocontrol agent for this pest. The purpose of this study was to evaluate several annual flowering insectary plants in the field for their potential to support wild syrphids. Specifically, we had the following three objectives: (1) quantify syrphid fly densities on different insectary plants, using alyssum as a comparator species, (2) quantify insectary plant bloom periods; and (3) identify syrphid fly species collected from insectary plants in New England.

Materials and Methods

Field studies were conducted at the University of Connecticut Plant Science Research Farm in Storrs, Connecticut (CT) (in 2019), University of Massachusetts Crop and Animal Research and Education Farm in South Deerfield, Massachusetts (MA) (in 2017, 2018, and 2019) and the University of New Hampshire Woodman Farm in Durham, New Hampshire (NH) (in 2017, 2018, and 2019).

Insectary Plant Species

We selected annual flowering plants that would grow successfully in New England environments and have been previously studied for use in conservation biocontrol in crop fields (Brennan 2016, Hickman et al. 1995). The number of insectary plant species varied between sites and year, often due to variability in successful establishment and flowering (Table 1). For example, in NH in 2017, fennel (var. Grosfruchtiger) plants grew to be tall and robust, however, the plants did not bloom before frost, and thereafter, fennel was excluded as a treatment.

Insectary Plantings

Following the methods of Colley and Luna (2000), insectary plants were arranged in a randomized complete block design, using 0.9 x 1.5m plots with four replications. Plots were situated in rows with 1.8, 1.5, and 0.6m of unplanted ground between plots within rows in CT, MA, and NH, respectively. In CT, the experiment was surrounded by plots of winter rye, *Secale cereale* (L.) (Cyperales: Poaceae), cabbage, *Brassica oleraceae* (L.) (Brassicales: Brassicaceae), and willow, *Salix* spp. (L.) (Malpighiales: Salicaceae). In MA, the experiment was surrounded by plantings of sweet corn, *Zea mays* (L.) (Poales: Poaceae) and cucurbits, *Cucurbita* spp. (L.) (Cucurbitales: Cucurbitaceae) in all three years, lettuce and barley, *Hordeum vulgare* L. (Poales: Poaceae) in 2017 and 2018, broccoli in 2018 and 2019, sunn hemp, *Crotalaria juncea* (L.) (Fabales: Fabaceae) in 2017 and 2019, and winter rye and bok choy, *Brassica rapa* (L.) (Brassicales: Brassicaceae) in 2019. In all three years in NH, other plantings in close proximity (100 m) to this experiment included plots of alyssum, grape, *Vitis* spp. (L.) (Vitaceae), strawberry, *Fragaria* x *ananassa* (West.) Roz. (Rosales: Rosaceae), and Brussels sprout, *Brassica oleraceae* (L.) (Brassicales: Brassicaceae).

To attain continuous bloom, in several experiments, multiple succession plantings of the same species were made for species with shorter bloom periods. Seeding dates for all plantings are given in Table 1. In CT and NH, most of the insectary plant species were seeded into soilless media in 128-cell plug trays and transplanted into the field at a spacing of 10–15 cm between plants in three rows spaced 30 cm apart. In MA, most species were seeded in 72-cell trays and were transplanted into the field in four rows, at the same spacing. Exceptions included buckwheat, which was direct-seeded in the field in seven rows spaced 15 cm apart in MA and CT, and at a rate of 28 g of seed per plot in NH (in 2018 and 2019) and phacelia, which was direct-seeded at 30 cm spacing in MA and CT and 5 cm spacing in NH (in 2019).

Observation of Insect Densities on Insectary Plants

To quantify syrphid fly visits to insectary plants, observations were taken during conditions with less than five miles per hour of wind and no rainfall. Since syrphid flies are most active in the morning (Gilbert 1981, Skevington et al. 2019), observations were taken between 1000 and 1200 hr. Plant species were observed whenever all

Table 1. Seeding dates for insectary plant species grown in experiments conducted in NH, MA, and CT in 2017, 2018, and 2019

Insectary plant	CT 2019	MA 2018	MA 2019	NH 2017	NH 2018	NH 2019
Alyssum *Lobularia maritima* L.	20-May	5-June	20-May	20-June	31-May	31-May
Ammi *Ammi majus* L. 'White Dill'	20-May	20-May	20-May	–[a]	–	31-May
Buckwheat *Fagopyrum esculentum* Moench	29 June[b]	13-July	10 June[b]	20 June, 21 July	21 June[b], 4 July[b], 2 Aug.[b]	21 June[b], 22 July[b]
Calendula *Calendula officinalis* L. 'Alpha'	20-May	5-June	20-May	–	7 June, 3 Aug.	21-June
Cilantro *Coriandrum sativum* L. 'Santo'	20-May	22-June	20-June	20 June, 20 July	31 May, 1 July	31 May, 21 June
Dill *Anethum graveolens* L. 'Bouquet'	20-May	22-June	20-May	20 June, 20 July	31 May, 1 July	31 May, 21 June
Phacelia *Phacelia tanacetifolia* Bentham	20 May[b]	13-July	10 June[b]	20-June	–	15 June[b]
Fennel *Foeniculum vulgare* Miller	–	–	–	20-June	–	–

[a]Presence of a '–' indicates that this species was not planted in this site and this year.
[b]Indicates species that were direct-seeded into the field on that day; all other species were seeded in plug trays and then transplanted into the field 3–4 wk after seeding.

four replicates were flowering. Insects observed within the delineated area were counted once, whereas insects that left the area and reentered again were counted as an additional insect observation. Each of the three sites followed slightly different observation protocols as described below.

Connecticut

Insectary plants were observed from July through August over seven dates in 2019. Researchers used one observer and one note taker to perform one-min observations over the entire plot (1.4 m^2). Only insects that landed on flowers were counted.

Massachusetts

Insectary plants were observed from August through October with ten sampling dates in 2017 and 12 dates in 2018. A square cardboard cutout (929 cm^2) was placed over portion of each flowering plot and insect observations were made from within this space. In 2017, three two-min observations were taken per plot, whereas in 2018 only two observations per plot were taken. During the observations, only insects that landed on flowers were counted.

New Hampshire

Insectary plants were observed for insect densities from July through October in 2017, 2018, and 2019. There were eight sample dates in 2017, 11 dates in 2018, and 13 dates in 2019. To measure insect densities, a plastic ring (0.2 m^2) was placed over a portion of each flowering plot insect observations were made from within this space. In all years, researchers observed insects within the plastic ring for two min with the naked eye before moving to another part of the same plot for a second two-min observation. Insects were counted even if they did not land or feed.

Survey of Syrphid Species Collected from Insectary Plants

In MA and NH, insect specimens were collected for identification using a standardized protocol (Tonkyn 1980). Two passes were made with a 38.1 cm diameter insect sweep net, lightly grazing the top few inches of the insectary flowers and vegetation. Each sweep covered approximately a 180° arc across the length of each plot in each direction. In MA, syrphids were collected from August through mid-October, with 15 sample dates in 2018 and July through September, with 16 dates in 2019. In NH, syrphid specimens were collected from June through October, with 10 sample dates in 2018 and 15 dates in 2019. Syrphids were placed in ethyl acetate (MA) or ethanol (NH) until they expired and then stored in 70% ethanol.

Specimens were organized by species and samples were sent to the Canadian National Collection of Insects in Ottawa, Ontario for identification by Michelle Locke. When it was not possible to identify the specimen to species, we reported some groups to the genus only. Specimens from the NH site were archived and can be accessed in the Department of Biological Sciences Insect Collection at the University of New Hampshire, Durham, NH, USA.

Statistical Analysis

All statistical analyses were performed using (JMP PRO15, SAS Institute 1989–2021). To estimate the cumulative ability of an insectary plant species to support adult syrphids, we used Area Under the Insect Population Curve (AUIPC), calculated identically to Area Under the Disease (or Infestation) Progress Curve (AUDPC, AUIPC) (Madden et al. 2007, Ouédraogo et al. 2018). This single metric accounts for the combination of syrphid density at each observation time *and* the duration of bloom time. AUIPC was calculated for each planting of insectary plant throughout its' bloom period as follows:

$$AUIPC = \sum_{i=1}^{n-1} \frac{y_i + y_{i+1}}{2} \times (t_{i+1} - t_i)$$

where y_i is the syrphid abundance at the ith observation, t_i is time in d at the ith observation, and n is the total number of observations for the specific insectary plant block. Then, to compare syrphid fly abundance on any given insectary plant species to that measured for alyssum during the same time period, we created a single measurement, the relative AUIPC.

$$Relative\ AUIPC = \frac{AUIPC_{species\ x}}{AUIPC_{alyssum}}$$

Relative AUIPC was calculated independently for each block of each insectary plant; means and standard errors were calculated for each experiment. A species with as many syrphid flies as alyssum equals a relative AUIPC of 1. Alyssum was used as a comparator species because 1) it was included in all experiments, 2) it was in bloom when all other species were in bloom, and 3) it has been tested and is established as an effective insectary plant in various cropping systems (Smith and Cheney 2007, Brennan 2016).

To determine whether some syrphid flies might be more prevalent on some insectary species than others, chi-square tests of goodness of fit compared observed proportions with overall proportions. Tests were performed for each syrphid species that had at least 10 individuals collected throughout the experiment. The observed number of any of these species that were collected from each insectary plant was compared with the predicted numbers, given the overall proportion of syrphids found on each insectary plant.

Results

Syrphid Fly Abundance Relative to Alyssum

The syrphid abundance on several insectary plant species compared with alyssum consistently showed that fewer syrphids were observed on phacelia, calendula, and ammi than on alyssum, with relative AUIPC values always less than 1 (Fig. 1, Supp Tables 1–6 [online only]). In three out of seven experiments in which they were included, cilantro and dill had relative AUIPC values near 1, suggesting that they sometimes hosted as many syrphid flies as alyssum. Buckwheat, however, stood out as occasionally having relative AUIPC values much higher than 1. For example, in 2017 in both MA and NH, buckwheat hosted over three times the number of syrphid flies as alyssum with AUIPC values of 3.9 and 4.6. However, this pattern was not consistent across year and site; in 2018 in MA and NH and in 2019 in CT, buckwheat hosted approximately half as many syrphids than alyssum, with AUIPC values of less than 0.6 in both sites.

Bloom Period of Insectary Plants

The measured duration of bloom period for each insectary plant species varied between year and between plantings within a year (Fig. 2). Alyssum had the longest bloom period, with a mean of 87.3 ± 23.0 d. Ammi, calendula, and phacelia all had bloom periods with means greater than 50 d, and in all cases, they bloomed until terminated by frost. In contrast, buckwheat had the shortest bloom period of 27.3 ± 16.3 d, while cilantro (35.4 ± 17.8 d) and dill (39.8 ± 17.8 d) had intermediate bloom durations compared to other species.

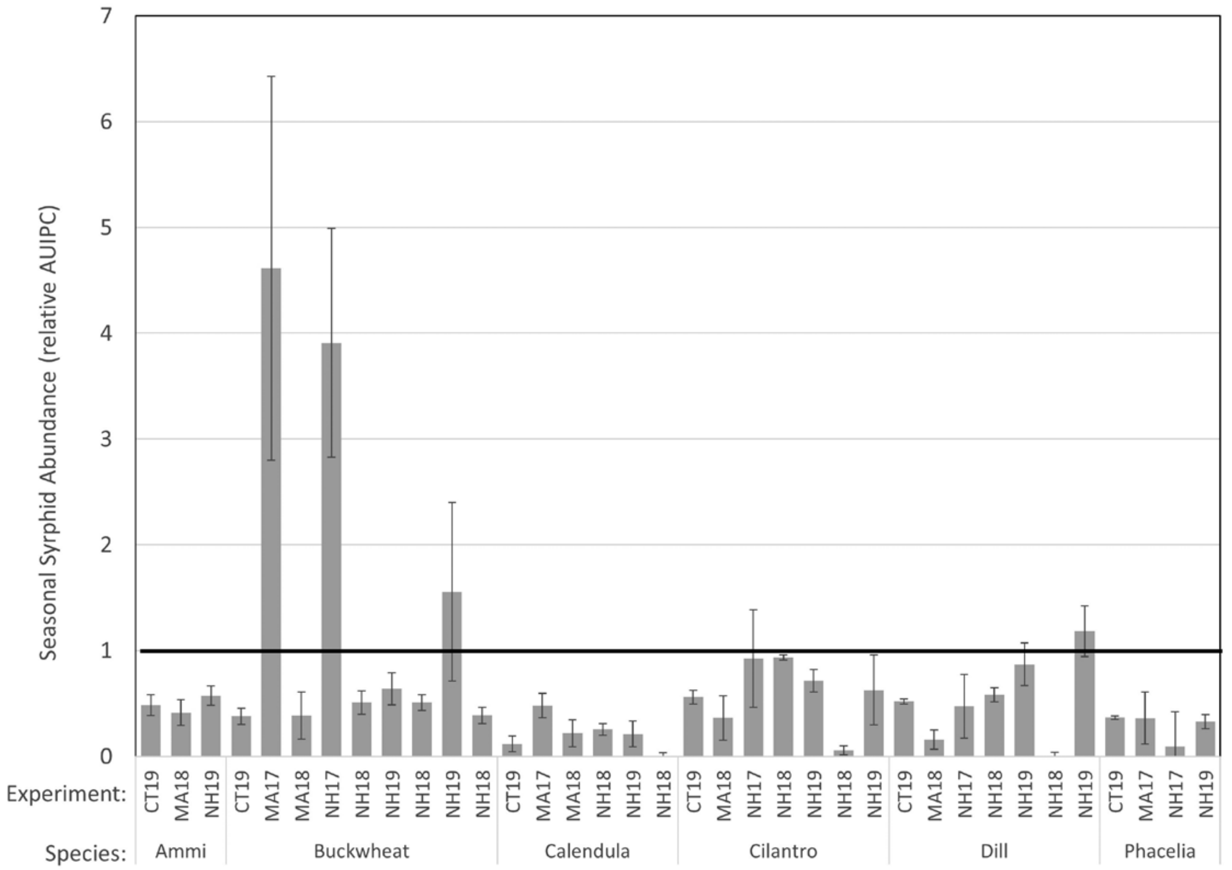

Fig. 1. Syrphid fly abundance on several insectary plant species compared with alyssum, as measured by relative AUIPC (Area Under the Insect Population Curve) (±2SEM) for data collected in six experiments (CT19 signifies CT in 2019; NH17, NH18, NH19 signifies NH in 2017, 2018, and 2019; MA18 signifies MA in 2018). Relative AUIPC signifies the AUIPC of a species, divided by the AUIPC observed for alyssum during the same bloom period. A species with as many syrphid flies as alyssum would have a relative AUIPC of 1.

Of the species tested, alyssum, ammi, calendula, and phacelia exhibited indeterminate flowering, which resulted in long, continuous bloom periods, even without removing senescing flower heads. In contrast, buckwheat, cilantro, and dill were determinate-flowering, which resulted in relatively short bloom periods. Alyssum was the shortest plant in stature, due to its creeping growth habit. All other species grew to heights of 1 m or greater, and lodging was observed at some sites following heavy rain or windy conditions.

Syrphid Fly Species Identification

Overall, during 2018 and 2019 in both MA and NH, 1,447 syrphid fly specimens were collected and comprised 21 species (Table 2). The three most prevalent species collected in both sites in both years were *Toxomerus marginatus* (Say) (Diptera: Syrphidae) (70.1% of samples), *T. geminatus* (Say) (Diptera: Syrphidae) (8.8% of samples), and *Syritta pipiens* (L.) (Diptera: Syrphidae) (13.1% of samples). *Toxomerus marginatus* was the single most abundant syrphid collected and was found throughout observation periods in both years and sites. In addition to nine species collected in both MA and NH, there were three species collected only in MA (*Eristalinus aeneus* (Scopoli) (Diptera: Syrphidae), *Eumerus strigatus* (Fallén) (Diptera: Syrphidae), *Eupeodes latifasciatus* (Macquart) (Diptera: Syrphidae)) and six species collected only in NH (*Eristalis arbustorum* (L.) (Diptera: Syrphidae), *Eristalis transversus* (Wiedemann) (Diptera: Syrphidae), *Eupeodes americanus* (Wiedemann) (Diptera: Syrphidae), *Helophilus fasciatus* (Walker) (Diptera: Syrphidae), *Syrphus rectus* (Osten Sacken) (Diptera: Syrphidae), and *Syrphus vitripennis (*Meigen) (Diptera: Syrphidae)).

Adult syrphids were collected from all insectary plants, and the relative number of specimens collected from each plant species mirrors the observational data presented earlier (Table 2). The most syrphid flies were collected from alyssum; the fewest were collected from phacelia and calendula, while other species had intermediate numbers. Compared to the relative proportion of all syrphid flies present on each insectary plant species, nearly all of the most abundant syrphids showed a different pattern (as evidenced by statistically significant chi-square goodness of fit tests). For example, compared to the total number of syrphid fly specimen collected, the number of *T. germinatus* specimens were more prevalent on buckwheat, *Allograpta obliqua* (Harris) (Diptera: Syrphidae) were more prevalent on dill, and *Sphaerophoria philantha* (Meigen) (Diptera: Syrphidae) were more prevalent on phacelia than expected, based on overall proportions. A higher proportion of *T. marginatus*, the most abundant syrphid species, was collected from alyssum and a lower proportion was collected from buckwheat and cilantro than were expected based on overall proportions.

Discussion

Synchronicity in the arrival of crop pests and their natural enemies is key to pest suppression (Langoya and van Rijn 2008). Therefore, our focus in these experiments was to have flowers in bloom before early

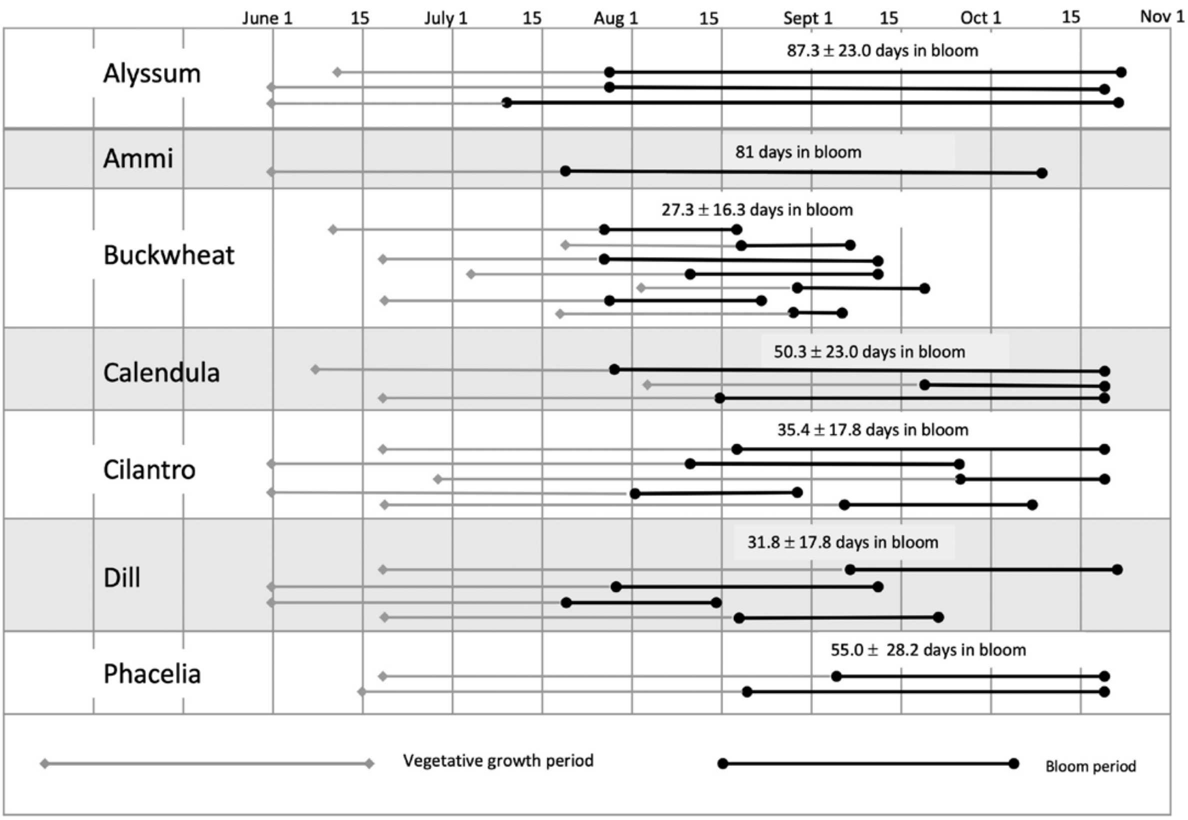

Fig. 2. Duration of vegetative and bloom period for all insectary plant species evaluated in NH in 2017, 2018, and 2019. In some cases, multiple plantings were made in a given year in an attempt to increase the potential bloom period. The mean (±2SEM) d in bloom are presented for each species; these values were calculated including all plantings from all year. SE values are not presented for ammi, which was included in only one yr.

July, when cabbage aphid, *Brevicoryne brassicae* (L.) (Hemiptera: Aphididae) is estimated to arrive in main season brassica, *Brassica* (L.) (Brassicales: Brassicaceae) crops. The estimated flight times of syrphid flies in northeast North America can begin as early as March (Skevington et al. 2019), so our observations do not reflect the abundance of syrphid flies across their full flight times in the study region. Indeed, in NH in 2019, we observed very high numbers of syrphid flies throughout June on an early planting of alyssum that was not part of this experiment (A.H.C., unpublished data), showing that they were already present at the NH site before the start of the trial.

Here we used alyssum as a comparator species because of its long bloom time and because it has been established as an effective insectary plant in several crops including our study system, brassica (Smith and Cheney 2007, Brennan 2016, Hogg et al. 2011a). An insectary plant species with as many syrphid flies as alyssum equals a relative AUIPC of 1. Therefore, we assumed that insectary plant species with AUIPC < 1 were less suitable for the syrphid species at our farm sites. Naturally, this assessment does not imply these resources are without value and a diversity of floral resources supports a diversity of beneficial insects. Some of the differences in syrphid flower preference between experiments may be explained by syrphid selectiveness based on floral resources available (both within and outside the experiment) at a given time, the presence of different species of syrphids in different locations, the physical structure of the flowers and accessibility of nectar or pollen, or the number of open flowers present on any given observation day.

We consistently observed fewer syrphids on phacelia, calendula, and ammi than on alyssum (Fig. 1) and these findings are largely consistent with other reports. Phacelia is an attractive option for insectary plantings because it is relatively inexpensive, easy to grow, relatively frost resistant, and has been reported to contribute to biological control in other systems (Hickman and Wratten 1996). Nonetheless, several investigators observed fewer syrphids visiting phacelia compared to other study plant species, perhaps due to the physical structure of phacelia flowers that makes accessing nectaries more challenging for syrphid species (Laurenz and Meyhöfer 2016, van Rijn and Wäckers 2016). Calendula is a visually attractive insectary planting, which is sometimes grown as a cash crop for its herbal or medicinal properties. However, calendula is consistently reported as relatively under-visited compared to other insectary species (Colley and Luna 2000, Laubertie 2007, Koptka et al. 2012). Ammi, on the other hand, is often cited as an important resource for a wild range of beneficial insects, including syrphids, and has a floral structure that facilitates nectar availability for this group (Gilbert 1981, Bugg et al. 2008, Laurenz and Meyhöfer 2016). While our experiment found these species to be of intermediate importance for supporting syrphids, each brings potential value to filling out a season-long insectary planting.

Cilantro and dill sometimes hosted as many syrphids as alyssum (Fig. 1) and these culinary herbs also make attractive insectary plants for growers due to their potential as a cash crop. Moreover, these crops may have underperformed at our study sites, compared to syrphid visitation observed in other geographic regions. Several studies reported cilantro to have the greatest syrphid visitation rates compared with other early blooming species tested, but there are few indications that alyssum and cilantro were not comparable resources (MacLeod 1992, Colley and Luna 2000, Ambrosino et al. 2006).

Table 2. Cumulative number and percentage of syrphid fly species from sweep net collection in Durham, NH and South Deerfield, MA throughout the 2018 and 2019 seasons overall, and grouped by insectary plant species on which they were found across both sites and year

	No. of syrphid flies collected per site per year					No. of syrphid flies per insectary plant[a]								
Syrphid Species	MA 2018	MA 2019	NH 2018	NH 2019	% of total	Aly	Amm	Bkw	Cal	Cil	Dil	Pha	χ^2	$P(\chi^2)$[b]
Allograpta obliqua	6	5	0	13	1.7%	8	3	1	0	2	10	0	11.1	0.085
Eristalinus aeneus	3	5	0	0	0.6%	6	0	0	1	1	0	0	*np*	*np*
Eristalis arbustorum	0	0	0	1	0.1%	1	0	0	0	0	0	0	*np*	*np*
Eristalis tenax	2	0	2	5	0.6%	4	0	0	4	0	1	0	*np*	*np*
Eristalis transversa	0	0	1	0	0.1%	0	0	0	1	0	0	0	*np*	*np*
Eristalis spp.	0	0	0	1	0.1%	1	0	0	0	0	0	0	*np*	*np*
Eumerus strigatus	3	0	0	0	0.2%	2	0	0	0	0	1	0	*np*	*np*
Eupeodes americanus	0	0	3	1	0.3%	1	0	0	0	2	1	0	*np*	*np*
Eupeodes latifasciatus	2	0	0	0	0.1%	1	1	0	0	0	0	0	*np*	*np*
Helophilus fasciatus	0	0	0	2	0.1%	2	0	0	0	0	0	0	*np*	*np*
Melanostoma mellinum	5	0	1	1	0.5%	3	1	0	0	2	1	0	*np*	*np*
Neoascia spp.	0	0	0	1	0.1%	1	0	0	0	0	0	0	*np*	*np*
Orthonevra nitida	0	2	0	3	0.4%	3	1	1	0	0	0	0	*np*	*np*
Paragus spp.	1	0	0	0	0.1%	0	1	0	0	0	0	0	*np*	*np*
Sphaerophoria contigua	1	0	1	1	0.2%	1	1	1	0	0	0	0	*np*	*np*
Sphaerophoria philanthus	1	0	2	0	0.2%	1	0	1	1	0	0	0	*np*	*np*
Sphaerophoria spp.	6	2	2	4	1.0%	7	0	0	1	1	1	4	144.3	<0.001
Syritta pipiens	45	55	8	78	13.1%	70	26	25	1	35	29	0	45.6	<0.001
Syphus rectus	0	0	0	1	0.1%	1	0	0	0	0	0	0	*np*	*np*
Syrphus ribesii	0	0	2	0	0.1%	1	0	0	1	0	0	0	*np*	*np*
Syrphus vitripennis	0	0	4	0	0.3%	2	0	0	2	0	0	0	*np*	*np*
Toxomerus geminatus	16	35	1	73	8.8%	56	8	18	1	15	27	0	16.5	0.011
Toxomerus marginatus	103	108	187	602	70.3%	583	78	48	22	83	176	10	16.2	0.013
Toxomerus politus	0	6	8	1	1.1%	3	0	2	2	4	4	0	16.7	0.010
Total	196	218	222	787		759	120	98	37	145	253	11		

[a]Aly = Alyssum (*Lobularia maritima*), Amm = *Ammi majus*, Bkw = buckwheat (*Fagopyrum esculentum*), Cal = *Calendula officinalis*, Cil = cilantro (*Coriandrum sativum*), Dil = dill (*Anethum graveolens*), Pha = *Phacelia tanacetifolia*.

[b]To explore whether some syrphid flies might be more prevalent on some insectary species than others, chi-square tests of goodness of fit compared observed proportions with the overall proportions. Tests were performed for each syrphid species that had at least 10 individuals collected throughout the experiment. '*np*' = test not performed. Chi-squared and P-values are presented for all tests performed (df = 6).

Buckwheat occasionally hosted more adult syrphids than alyssum at our study sites (Fig. 1). This burst of floral resources is typical of buckwheat, which produces many small flowers that support a broad range of beneficial insects, but has a shorter bloom period than other species in our study (Fig. 2; Ambrosino et al. 2006, Campbell et al. 2016). Buckwheat is compatible in a broad range of systems. It is generally easier to establish from seed than the other species in our study and plantings can be cut or mowed periodically to encourage multiple flushes of flowers in one season. Buckwheat is not as cold tolerant as other insectary plant species and its tendency to reseed can be problematic in some systems (Bowie et al. 1996, Tavares et al. 2015). Buckwheat is also a commonly used cover crop, which is planted to improve soil nutrition, soil health, and reduce soil erosion (Creamer and Baldwin 2000). Therefore, seeds are often readily available.

In all of our study sites and years, alyssum consistently hosted among the highest syrphid densities observed. Colley and Luna (2000) concluded that alyssum was 'a significant provider of floral resources for hoverflies', and Hogg et al. (2011b) showed that providing alyssum to syrphid flies enhanced syrphid egg production. Alyssum has been successfully used for conservation biological control of aphids in agricultural fields (Bugg et al. 2008, Brennan 2013). These observations, coupled with favorable horticultural characteristics (a low-growing habit and a long bloom duration), suggests that alyssum may offer the greatest potential for practical conservation biocontrol in agricultural settings, compared to the other species we evaluated.

One drawback of using alyssum for biological control of pests of brassica crops is that this species can also host or support pests of brassica crops. In 2017 in NH and in all years in MA, we observed cabbage flea beetle, *Phyllotreta cruciferae* (Goeze) (Coleoptera: Chrysomelidae) feeding on young alyssum plants. Adult *P. rapae* butterflies were observed on alyssum in 2018 in NH and on calendula in 2019 in CT (unpublished data). Ambrosino et al. (2006) also occasionally observed *P. rapae* adults on insectary plants near a brassica crop in one site but observed this pest more frequently on phacelia than on alyssum, buckwheat, or cilantro. Potential attractiveness to pests of cash crops remains an important consideration when choosing insectary plants and may warrant further study.

Using insectary plants with shorter bloom durations as insectary plants (e.g., buckwheat, cilantro, dill) may complicate management because regular, sequenced planting is required to maintain a continuous bloom period. However, shorter-duration crops may fit well in certain cropping systems, and suitability for direct-sowing rather than transplanting could provide advantages in some cases, as direct-sowing requires less labor and resources than transplanting. While we focused on annual flowering plants, early flowering native perennial flowering plants may be important in supporting syrphid populations, since most syrphid fly species collected (including *T. marginatus*) are native and have coevolved along with the bloom period and flower architecture of native plants. Such species may support syrphid population peaks early in the season before annual flowering species in bloom, and before pest populations become established or increase during the cropping season.

Of the total 21 species of syrphid flies collected in MA and NH, 19 were considered abundant, common, or fairly common by Skevington et al. (2019), and the remaining two were considered uncommon (*Paragus angustifrons* (Loew) (Diptera: Syrphidae) and *Toxomerus politus* (Say) (Diptera: Syrphidae)). Several of the syrphid genera collected are known to have aphidophagous larvae, such as *Allograpta* (Osten Sacken), *Eupeodes* (Osten Sacken), *Melanostoma* (Schiner), *Sphaerophoria* (Lepeletier & Serville), *Syrphus* (F.), and *Toxomerus* (Macquart) (Skevington et al. 2019). One known exception to the mostly predatory *Toxomerus* genus is *T. politus,* which has larvae that feed on pollen from sorghum (*Sorghum* spp. Moench, Poaceae) and corn (Nunes-Silva et al. 2010) and is the only known phytophage within the genus (Reemer and Rotheray 2009). Larvae of *S. pipiens*, adults of which were among the most frequently collected, are detritivores and feed on decaying matter (Bugg et al. 2008).

Sweep net collections in MA and NH confirmed that the largest proportion of the syrphids collected from insectary plant species were *T. marginatus*, and collections with the peak number of this species was often aligned with peaks in total syrphid populations. *Toxomerus marginatus* is the most prevalent syrphid species found in vegetable crops in California (Bugg et al. 2008, Smith and Cheney 2007) and is the most abundant syrphid in northeastern North America (Skevington et al. 2019). Larvae feed on soft-bodied insects, including aphids, thrips, mealybugs (Skevington et al. 2019) and the caterpillar stage of the imported cabbageworm, *Pieris rapae* (L.) (Lepidoptera: Pieridae) (Ashby and Pottinger 1974). Tooker et al. (2006) also reported *T. marginatus* and *Sphaerophoria contigua* (Macquart) to be the top two prevalent aphid-eating species in central Illinois over 33 yr of data collection.

While limitations to our study included that we did not assess flower abundance over time, prevalence of other arthropod species, and other factors that might have influenced syrphid abundance, this work does represent a snapshot of several site-years on typical diversified farm landscapes in the northeastern U.S. The prevalence of aphid-eating syrphid species associated with insectary plants in our experiments, and the long bloom period of some insectary plant species, suggest that conservational biological control approaches may be viable in the northeastern U.S. Additional research is needed to test the efficacy and economic feasibility of using this approach to manage specific pest complexes on specific crop families and to confirm the direct effects of syrphid predation on pest species in this system.

Acknowledgments

Special thanks to Alan Eaton, Istvan Miko, Don Chandler, and Michelle Locke for entomological expertise, Iago Hale for experimental design advice, and Sabrina Beck, Evan Ford, Leah Ford, Madie Hassett, Luke Hydock, Talia Levy, Michele Meder, Ainsley McStay, Maggie Ng, Kyle Quigley, Kaelin Smith, and Kiernan Sellars for technical assistance, and to two anonymous reviewers, whose feedback lead to significant improvements in our manuscript. Thank you to Michelle Locke at the Canadian National Collection of Insects in Ottawa, Ontario for assistance with insect identification. Partial funding was provided by the New Hampshire Agricultural Experiment Station. This is Scientific Contribution Number 2965. This work was supported by the USDA National Institute of Food and Agriculture Hatch Project NH00685 and by Northeast SARE Project No. LNE 18-365.

Authors Contributions

Alina Harris-Cypher (Conceptualization-Equal, Data curation-Equal, Formal analysis-Equal, Investigation-Equal, Methodology-Equal, Project administration-Equal, Writing – original draft-Equal), Caterina Roman (Writing – original draft-Equal), Genevieve Higgins (Conceptualization-Equal, Investigation-Equal, Methodology-Equal, Project administration-Equal, Writing – original draft-Equal, Writing

– review & editing-Equal), Susan Scheufele (Conceptualization-Equal, Investigation-Equal, Methodology-Equal, Project administration-Equal, Writing – original draft-Equal), Ana Legrand (Conceptualization-Equal, Investigation-Equal, Methodology-Equal, Writing – original draft-Equal, Writing – review & editing-Equal), Anna Wallingford (Writing – original draft-Equal, Writing – review & editing-Equal), Rebecca Sideman (Conceptualization-Equal, Data curation-Equal, Formal analysis-Equal, Funding acquisition-Equal, Investigation-Equal, Methodology-Equal, Supervision-Equal, Writing – original draft-Equal, Writing – review & editing-Equal)

Supplementary Data

Supplementary data are available at *Environmental Entomology* online.

References Cited

Ambrosino, M. D., J. M. Luna, P. C. Jepson, and S. D. Wratten. 2006. Relative frequencies of visits to selected insectary plants by predatory hoverflies (Diptera: Syrphidae), other beneficial insects, and herbivores. *Environ. Entomol*. 35: 394–400.

Amorós-Jiménez, R., A. Pineda, A. Fereres, and M. A. Marcos-García. 2014. Feeding preferences of the aphidophagous hoverfly *Sphaerophoria rueppellii* affect the performance of its offspring. *BioControl*. 59: 427–435.

Ashby, J. W., and R. P. Pottinger. 1974. Natural regulation of *Pieris rapae* Linnaeus (Lepidoptera: Pieridae) in Canterbury, New Zealand. *N. Z. J. Agric. Res*. 17: 229–239.

Bowie, M. H., S. D. Wratten, and A. J. White. 1996. Agronomic and phenology of 'companion plants' of potential for enhancement of insect biological control. *N. Z. J. Crop Hort. Sci*. 23: 423–427.

Brennan, E. B. 2013. Agronomic aspects of strip intercropping lettuce with alyssum for biological control of aphids. *Biol. Control*. 65: 302–311.

Brennan, E. B. 2016. Agronomy of strip intercropping broccoli with alyssum for biological control of aphids. *Biol. Control*. 97: 109–119.

Bugg, R. L., R. G. Colfer, W. E. Chaney, H. A. Smith, and J. Cannon. 2008. Flower flies (Syrphidae) and other biological control agents for aphids in vegetable crops. ANR Publication 8285.

Campbell, J. W., A. Irvin, H. Irvin, C. Stanley-Stahr, and J. D. Ellis. 2016. Insect visitors to flowering buckwheat, *Fagopyrum esculentum* (Polygonales; Polygonaceae), in north central Florida. *Fla. Entomol*. 99: 264–268.

Colley, M. R., and J. M. Luna. 2000. Relative attractiveness of potential beneficial insectary plants to aphidophagous hoverflies (Diptera: Syrphidae). *Environ. Entomol*. 29: 1054–1059.

Cowgill, S. E., N. W. Sotherton, and S. D. Wratten. 1993. The selective use of floral resources by the hoverfly *Episyrphus balteatus* (Diptera: Syrphidae) on farmland. *Ann. Appl. Biol*. 122: 223–231.

Creamer, N. G., and K. R. Baldwin. 2000. An evaluation of summer cover crops for use in vegetable production systems in North Carolina. *HortScience*. 35: 600–603.

Gilbert, F. S. 1981. Foraging ecology of hoverflies: morphology of the mouthparts in relation to feeding on nectar and pollen in some common urban species. *Ecol. Entomol*. 6: 245–262.

Haenke, S., B. Scheid, M. Schaefer, T. Tscharntke, and C. Thies. 2009. Increasing syrphid fly diversity and density in sown flower strips within simple vs. complex landscapes. *J. Appl. Ecol*. 46: 1106–1114.

Hickman, J. M., G. L. Lövei, and S. D. Wratten. 1995. Pollen feeding by adults of the hoverfly *Melanostoma fasciatum* (Diptera: Syrphidae). *N. Z. J. Zool*. 22: 387–392.

Hickman, J. M., and S. D. Wratten. 1996. Use of *Phacelia tanacetifolia* strips to enhance biological control of aphids by hoverfly larvae in cereal fields. *J. Econ. Entomol*. 89: 832–840.

Hogg, B. N., R. L. Bugg, and K. M. Daane. 2011a. Attractiveness of common insectary and harvestable floral resources to beneficial insects. *Biol. Control*. 56: 76–84.

Hogg, B. N., E. H. Nelson, N. J. Mills, and K. M. Daane. 2011b. Floral resources enhance aphid supression by a hoverfly. *Entomol. Exp. Appl*. 141: 138–144.

Kopta, T., R. Pokluda, and V. Psota. 2012. Attractiveness of flowering plants for natural enemies. *HortScience*. 39: 89–96.

Langoya, L. A., and P. C. J. van Rijn. 2008. The significance of floral resources for natural control of aphids. *Proc. Neth. Entomol. Soc. Meet*. 19: 67–74.

Laubertie, E. 2007. The role of resource subsidies in enhancing biological control of aphids by hoverflies (Diptera: Syrphidae). *PhD Dissertation*. Lincoln University, Lincoln, New Zealand.

Laurenz, S., and R. Meyhöfer. 2016. Phenology and flower visitors of selected plant species with special respect to predators of the cabbage whitefly. *IOBC/WPRS Bull*. 118: 22–29.

MacLeod, A. 1992. Alternative crops as floral resources for beneficial hoverflies (Diptera: Syrphidae). *In* 1992 Brighton Crop Protection Conference - Pests and Diseases:997-1002. British Crop Protection Council, Brighton.

Madden, L.V., G. Hughes, and F. van den Bosch. 2007. *The study of plant disease epidemics*. The American Phytopathological Society, APS Press, St. Paul, Minnesota.

Nunes-Silva, P., G. D. Cordeira, D. Obregon, J. F. L. Neto, F. C. Thompson, B. F. Viana, B. M. Freitas, and P. G. Kevan. 2010. Pollenivory in larval and adult flower flies: pollen availability and visitation rate by *Toxomerus politus* Say (Diptera: Syrphidae) on sorghum *Sorgum bicolor* (L.) Moench (Poaceae). *Stud. Dipterol*. 17: 177–185.

Ouédraogo, A. P., B. J. Batieno, F. Traore, J. -B. Tignegre, B. -L. Huynh, P. A. Roberts, T. Close, and J. T. Ouédraogo. 2018. Screening of cowpea (*Vigna unguiculata* (L.) Walp.) lines for resistance to three Aphids (*Aphis craccivora* Koch) strains in Burkina Faso. *Afr J. Agric. Res*. 13: 1487–1495.

Pineda, A., and M. A. Marcos-García. 2008. Use of selected flowering plants in greenhouses to enhance aphidophagous hoverfly populations (Diptera: Syrphidae). *Ann. Soc. Entomol. Fr*. 44: 487–492.

Reemer, M., and G. E. Rotheray. 2009. Pollen feeding larvae in the presumed predatory syrphine genus *Toxomerus* Macquart (Diptera, Syrphidae). *J. Nat. Hist*. 43: 939–949.

Schwartz-Lazaro, L. M., and J. T. Copes. 2019. A review of the soil seedbank from a weed scientists perspective. *Agronomy*. 9: 369.

Skevington, J., M. Locke, A. Young, K. Moran, W. Crins, and S. Marshall. 2019. General Introduction, pp. 12–33. *In Field guide to the flower flies of Northeastern North America*. Princeton University Press.

Smith, H. A., and W. E. Cheney. 2007. A survey of syrphid predators of *Nasonovia ribis-nigri* in organic lettuce on the coast of California. *J. Econ. Entomol*. 100: 39–48.

Tavares, J., K. -H. Wang, and C. R. R. Hooks. 2015. An evaluation of insectary plants for management of insect pests in a hydroponic cropping system. *Biol. Control*. 91: 1–9.

Tonkyn, D. W. 1980. The formula for the volume sampled by a sweep net. *Ann. Entomol. Soc. Am*. 73: 452–454.

Tooker, J. F., M. Hauser, and L. M. Hanks. 2006. Floral host plants of Syrphidae and Tachinidae (Diptera) of central Illinois. *Ann. Entomol. Soc. Am*. 99: 96–112.

Van Rijn, P. C. J., and F. L. Wäckers. 2016. Nectar accessibility determines fitness, flower choice, and abundance of hoverflies that provide natural pest control. *J. Appl. Ecol*. 53: 925–933.

White, A., S. Wratten, N. Berry, and U. Weigmann. 1995. Habitat manipulation to enhance biological-control of brassica pests by hover flies (Diptera, Syrphidae). *J. Econ. Entomol*. 88: 1171–1176.