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Perspective

Enhancing natural enemies in sugar beet fields: The impact of flower strip types and landscape elements

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HIGHLIGHTS

- Flower strip types differ in flower-volume and -composition early in the season.
- Most aphid predators were found in autumn-sown annual and perennial flower strips.
- Hoverfly communities differ between autumn-sown annual and perennial flower strips.
- Nearby forests help support aphid antagonists in otherwise open landscapes.

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ABSTRACT

Flower strips (FS) enhance predators that can help regulate aphids. In sugar beet crops, early-season aphid populations can spread viruses, so timely FS resources are key to attract aphid predators to reduce virus transmission. This study aims to identify the optimal FS type(s) for supporting aphid antagonists in early spring, track their abundances in the different FS types, and analyze the landscape factors influencing antagonist presence.

We selected three different seed mixtures, each sown on 10 sugar beet fields managed without insecticides. FS types were compared to sugar beet strips in fields without insecticides, and conventionally managed fields, both served as controls. We assessed the strips by counting flowers and collecting insects with a sweep net in mid-April, early May, and early June.

Autumn-sown annual and second-year perennial FS produced greater and earlier flower volumes than other treatments. Over time, the flower compositions of these two FS types also became increasingly distinct from each other. Aphid antagonists were more abundant in these FS types compared to spring-sown annual FS and controls. Hoverfly communities differed between autumn-sown and perennial FS. Braconidae were positively linked to forest cover within 500 m, while hoverflies showed a negative association with forest at the 2000 m scale.

Overall, autumn-sown annual and perennial FS are better suited for conservation biocontrol of aphids in sugar beet systems than spring-sown annual FS. Hoverfly composition differences may lead to variation in aphid suppression. From a landscape perspective, forested areas near fields within otherwise open landscapes are important in supporting beneficial insects.

1. Introduction

Conservation biological control aims to enhance natural enemy populations to regulate pest species and reduce the need for pesticides. One approach is to provide resources for beneficial insects in the vicinity of the target crop. Flower strips (FS) have been studied in various settings and their ability to support beneficial insects with floral resources has been demonstrated (Albrecht et al., 2020; Tschumi et al., 2016). Research has either compared different plant mixtures for their attractiveness to arthropods without focusing on a specific crop (Blümel et al., 2024; Gardarin, 2023; Scheper et al., 2021) or examined the effect of one FS type within a particular crop (Tschumi et al., 2016; Twardowski et al., 2005). However, studies that compare different FS types with a focus on arthropods relevant to a specific crop system are rare. Research

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exploring FS in sugar beet systems is particularly scarce (Twardowski et al., 2005), despite the significant challenge posed by *Myzus persicae* (Sulzer). This aphid species is a primary vector of several viruses responsible for Virus Yellows, a major threat to sugar beet production (Kershaw, 1965; Watson et al., 1951). In addition to *M. persicae*, *Aphis fabae* (Scopoli), the most abundant aphid on sugar beets, also transmits the viruses, though less efficiently (Limburg et al., 1997). The presence of FS have been shown to reduce *A. fabae* populations (Twardowski et al., 2005). Since *M. persicae* appears early in the season (end of April; Landis & Van Der Werf, 1997; Mahillon et al., 2022), FS must include early-flowering species to ensure aphid predators like ladybirds, hoverflies, parasitic wasps, and lacewings are present when aphids colonize the fields (Campbell et al., 2016; Haaland et al., 2011). These natural enemies rely on FS for pollen and nectar (e.g., Dunn et al., 2020; Kopta et al., 2012). But spontaneous flowering species (within the FS or the sugar beets) may also play a role, as many bloom early in the season and contribute to resource provision (Dib et al., 2012; Laffon et al., 2024). While adults of beneficial insects benefit from various resources, juveniles mainly feed on aphids (Alcalá Herrera et al., 2022; Dunn et al., 2020; Ferran & Dixon, 1993). Parasitic wasps, especially Braconidae and Aphelinidae, lay eggs in aphids, and the larvae consume the host (Acheampong et al., 2012; Singh & Singh, 2016). Despite their importance, the diversity of parasitic wasps remains poorly understood (Acheampong et al., 2012; Petrović, 2022). The attractiveness of FS to beneficial insects depends on both their composition and timing of their establishment (Albrecht et al., 2020). The surrounding landscape also plays a key role by providing source populations of beneficial insects (Shaw, 2006). Heterogeneous landscapes generally support more beneficial insects than simplified ones (Schirmel et al., 2018; Zhao & Reddy, 2019), though the needs of beneficial insects vary by taxa. Parasitic wasps appear to benefit from forest cover (Haro-Barchin et al., 2018) and semi-natural habitats (SNH; Zhao & Reddy, 2019), but landscape effects on Braconidae are less clear. Hoverflies, lacewings and ladybirds generally respond positively to SNH (Ouin et al., 2006; Schirmel et al., 2018; Serée et al., 2020; Taranto et al., 2022; Woltz & Landis, 2014). But some studies report higher hoverfly numbers in arable-dominated landscapes (Haenke et al., 2009; Jönsson et al., 2015). For ladybirds, the opposite was found: they were less common in landscapes dominated by annual crops (Woltz & Landis, 2014).

This study examined three FS types in the sugar beet systems. These types differ in plant species composition, duration, and sowing time; two are commercially available in Switzerland. Due to the different FS types and sowing periods, we anticipate seasonal variations in flower composition and volume (**H1**). In FS sown during the same season as the sugar beets, most plant species are expected to flower later because of their delayed development. An exception is *Fagopyrum esculentum*, a key food plant for beneficial insects (Kopta et al., 2012). It flowers early but lacks winter hardiness, making it ideal for the spring-sown annual FS in our design. Additionally, we hypothesize that differences in mixture composition will influence the composition of aphidophagous insect communities (**H2.1**, Haaland et al., 2011; Hatt et al., 2017; Scheper et al., 2021). The composition of beneficial insects may be relevant for aphid control, as some groups or species are more effective than others (Almohamad et al., 2007; Lillo et al., 2021). Although broad insect groups may not show significant differences in response to FS composition, a more detailed species-level analysis is expected to reveal distinct patterns (**H2.2**, Levin, 1992). Hoverflies (*Syrphidae*) are particularly relevant in this context, as they act as key early-season predators of aphids (Dib et al., 2010). However, the abundance of beneficial insects is influenced not only by the characteristics of the FS, but also by the surrounding landscape. Fields embedded in a greater proportion of natural habitats are generally expected to support a higher abundance of beneficial insects (**H3.1**). However, when examining overall beneficial insect communities at a broad taxonomic level, we do not anticipate strong effects due to diverse ecological needs by different species (**H3.2**, Hadly et al., 2009). A finer-scale analysis is likely to reveal landscape effects. Here, alongside other beneficials, it is particularly important to focus on parasitic wasps, specifically the Braconidae family. They are often overlooked in FS studies despite their crucial role in biological control. Understanding which landscape factors promote their abundance is essential.

Based on these hypotheses (H1- H3.2), the following aspects will be addressed: (1) identifying suitable sown FS types in terms of flower composition and early flower resources availability for aphid antagonists (see H1), (2) quantifying the abundance and composition of aphid antagonists in the different FS types and controls, with a particular focus on hoverfly species composition (see H2.1 and H2.2), and (3) examining the relationship between landscape parameters and the presence of aphid antagonists, with a special emphasis on Braconidae (see H3.1 and H3.2).

2. Materials and Methods

2.1. Field selection and establishment of flower strips

This experiment investigated five treatments: (1) autumn-sown annual FS, (2) perennial FS, (3) spring-sown annual FS, (4) sugar beet control strips, all four on sugar beet fields managed according to IP-Suisse standards, which – among other regulations – prohibit the use of insecticides or fungicides (throughout this paper, we refer to this control as control IP, IP-SUISSE, 2024), and (5) sugar beet control strips on conventionally managed fields (in three fields, insecticides were applied before the last sampling took place). Including control strips on both management types allowed the assessment of whether insecticide- and fungicide-free fields support more beneficials, as claimed by the program (IP-SUISSE, 2024).

Fields were selected in the central Swiss plateau (cantons Zurich, Aargau, Schaffhausen, Thurgau). The Central Swiss Plateau represents the typical agricultural landscape of the Swiss Lowlands, represented by small-scale crop fields, meadows, and forest fragments (Tschumi et al., 2015).

The 6 m wide FS were established as follows:

- Autumn-sown annual FS; sown between 24. August 2022 and 7. September 2022; mixture conventionally available (BLW, 2025), aiming to promote beneficial insects in winter crops
- Spring-sown annual FS; sown between 9. April 2023 and 20. May 2023; mixture conventionally available (BLW, 2025), aiming to promote beneficial insects in summer crops
- Perennial FS; sown between 19. April 2022 and 20. May 2022; mixture newly established, aiming to attract both natural enemies and pollinators

The farmers carried out the seedbed preparation and sowing. The exact species composition and densities are detailed in Table S1. In total, 14 fields were sown with perennial FS, 12 with the autumn-sown annual FS, and 13 with the spring-sown annual FS. For control treatments, a 6 m wide sugar beet strip was selected either at the field edge or in the center, reflecting the distribution of FS to ensure a comparable proportion of edge and center placements for FS and control treatments. Out of the pool of fields, 10 fields for each FS type were selected for the study based on the emergence of sown species (a selection of species depending on the FS type, with each species occurring at least once within every 10 square meters) and a cover of less than 70 % spontaneous species shortly before the sampling started. For all treatments, fields were selected to ensure the absence of other flowering elements within a 200 m radius (see 'Landscape characterization and parameter decision' for definition). However, flowering elements that emerged during the 2023 season could not be controlled.

Field sizes ranged from 0.41 ha to 5.85 ha (mean: 2.26 ha, SE: 0.19 ha), spanning elevations between 366 m and 708 m above sea level (mean: 471 masl, SE: 10 masl). The FS sizes varied from 600 m^2 to 2′500

m^2 (autumn-sown annual FS mean: 1′150 m^2, SE: 80 m^2, spring-sown annual FS mean: 1′420 m^2 SE: 150 m^2, and perennial FS mean: 1′300 m^2, SE: 110 m^2), and the minimal distances between fields were 425 m to 10′983 m (mean: 2′594 m, SE: 347 m).

2.2. *Aphid antagonists in flower strips*

In each treatment (n = 10), insect sampling was conducted at three time points – mid-April 2023, early May 2023, and early June 2023 – using a 40 cm diameter sweep net (net bag, similar to Gemplers 15″ Sailcloth Insect Sweep Net with Birch Handle, No: R20701, https://www.gemplers.com). Sweep netting is a widely accepted and adequate method for many insect groups (Noyes, 1982; Quicke, 2015). For future studies, a finer net as described by Noyes (1982) is recommended, as very small insects are likely to have blown out during collection. Sampling was repeated between early (seedling stage of sugar beet) to mid-season (12-leaf stage of sugar beet). Sweep netting was conducted over three consecutive days under cloudy or sunny conditions without rain, with a minimum temperature of 10 °C. Within each strip (control strips and FS), 60 sweeps were performed. The collected insects were transferred to a plastic bag (PolyZip bag, 300x400 mm). The insects were stored in a cool box until they were permanently stored at −20 °C. All plant material was removed before further processing. The following groups were identified, and the respective individuals counted: Hoverflies (Syrphidae), ladybirds (adults and larvae, Coccinellidae), lacewings (adults and larvae, Chrysopidae), and parasitic wasps. The family Braconidae was extracted from the parasitic wasps for analysis.

The ladybird and lacewing species collected in our study are known to be aphid predators. The other insect groups required closer examination. Parasitic wasps were identified at the family level and hoverflies at the species level to distinguish between aphid predators or parasitoids of aphids, and species feeding on other prey. Parasitic wasps were identified using Baur & Klopfstein (2007) and Baur & Neumann (2024) and hoverflies using Bot & Van de Meutter (2023), Speight (2018) and van Veen (2014).

2.3. *Flowers in the strips*

The flowers in the FS and the control strips were assessed at the same time as the insects. To achieve this, the number of flowers was recorded across four representative 1 m^2 plots within a 100 m section. The number of flowers per species was noted (for Asteraceae the capitulum including petals was counted). Flower measurements were taken using a ruler to assess either the length, width, and height for tubular flowers or the diameter and depth for spherical flowers of each single flower (except for Asteraceae where the capitulum including petals was measured). These measurements were later used to calculate flower volume (see e.g., Ammann et al., 2022).

2.4. *Landscape characterization and parameter decision*

The environment around the fields was examined within different-sized circles. Buffers with radii of 500 m, 1000 m, 1500 m, and 2000 m were created around the fields using QGIS (QGIS Development Team, 2024). These buffers were then filled with available land-use data (LGL, 2023; Swiss Federal Office of Topography, Berne, 2023).

In some cases polygons of different layers were slightly overlapping on the digital maps. To enable calculation, we prioritized the semi-natural habitats as essential resources for biodiversity, then the agricultural patches, followed by the forests.

For subsequent statistical models, the percentage of the landscape covered by flowering elements and forest was calculated separately within the different buffer zones. Flowering elements were defined as the combined area of rotational fallows, wildflower fallows, field margins on arable land, and FS on open arable land. The mean and SE of forest and flowering elements for each treatment can be found in Table S2.

Forest as well as flowering elements have been shown to be drivers for parasitic wasps (Bennett & Gratton, 2012; Haro-Barchin et al., 2018; Zhao & Reddy, 2019), Coccinellidae (Taranto et al., 2022; Woltz & Landis, 2014) and hoverflies (Haenke et al., 2009; Jönsson et al., 2015; Ouin et al., 2006; Schirmel et al., 2018).

2.5. *Data analysis*

All statistical analyses were conducted using R (R Core Team, 2024). Data visualization was done using the ggplot2 package (Wickham, 2016). Generalized linear mixed models were constructed with glmmTMB (Brooks et al., 2017), and model fit was assessed using DHARMa (Hartig, 2022). If a post hoc analysis was required, the emmeans package was used (Lenth, 2024).

'Treatment' (FS types and controls) and 'sampling rounds' (time points) were included as fixed factors to model the flower volumes of sown and spontaneous species, with the 'field' as a random factor. The nbinom1 family was used, and pairwise comparisons were conducted for 'treatment' and 'sampling rounds'.

The Aphelinidae were not included in the analyses since only one individual was collected. Overall aphid antagonists – composed of Braconidae, aphidophagous hoverflies, ladybirds adults and larvae, and lacewings adults and larvae – as well as hoverflies and Braconidae specifically, were modeled similarly. Ladybirds and lacewings were not modeled separately due to insufficient sample sizes. The models included the variables 'treatment' and 'sampling round', along with the covariates 'proportion of forest' and 'proportion of flowering areas' in the surrounding landscape, including their two-way interactions with 'treatment'. The 'proportion of forest' and 'proportion of flowering areas' were scaled. The natural logarithm (log + 1) transformation was applied to the 'proportion of flowering areas' before its inclusion in the model. We applied this transformation to address convergence issues because the variable values, especially those within a 500 m radius buffer, were close to zero. The 'proportion of flowering areas' and 'proportion of forest' were tested for each buffer with radius of 500 m, 1000 m, 1500 m, and 2000 m separately. For each buffer, a full model was built, and covariates were selected using the drop1 function. The best models from each distance were then compared using ANOVA. We assessed model diagnostics using the DHARMa package (Hartig, 2022). Additional checks for overdispersion, zero inflation, and multicollinearity revealed no significant issues, suggesting the model assumptions were adequately met.

The full models were specified as follows:

- Overall aphid antagonists ~'treatment' * scale('proportion of forest') + 'treatment' * scale(log('proportion of flowering areas' + 1)) + 'sampling round' + (1|'field'), family = nbinom1
- Braconidae ~'treatment' * scale('proportion of forest') + 'treatment' * scale(log('proportion of flowering areas' + 1)) + 'sampling round' + (1|'field'), family = nbinom2
- Hoverflies ~'treatment' * scale('proportion of forest') + scale(log('proportion of flowering areas' + 1)) + 'sampling round' + (1|'field'), family = nbinom1

For overall aphid antagonists and Braconidae, the sample size was 150 (5 treatments × 10 replicates × 3 sampling rounds). The hoverfly model initially included all treatments but encountered convergence issues. Since most hoverflies were recorded in the autumn-sown annual and perennial FS, we restricted the analysis to these two treatments to ensure model stability, resulting in a final sample size of 60 (2 treatments × 10 replicates × 3 sampling rounds). The interaction between 'treatment' and 'proportion of flowering areas' was omitted since we found a confounding effect in the interaction with autumn-sown annual and perennial FS; see the supplement for the rationale.

To assess differences in the composition of flowers, aphid antagonists, and hoverflies across ‘sampling rounds’ and ‘treatments’, we performed a series of pairwise PERMANOVA analyses using the *pairwise. adonis* function from the *vegan* package (Oksanen et al., 2022). The Bray-Curtis distance matrix was used, with the combination of ‘treatment’ and ‘sampling round’ (e.g., perennial FS mid-April, hereafter referred to as analyzed-groups) as the explanatory variable. Sites with no recorded plants or insects in a given sampling round were excluded from the PERMANOVA analysis, as the Bray-Curtis dissimilarity metric cannot compute meaningful distances for all-zero rows (joint absences are disregarded, as they do not necessarily indicate ecological similarity). In addition, analyzed-groups that showed less than 3 replicates were excluded due to insufficient sample size, which violates basic statistical assumptions required for meaningful analysis. Detailed number of replicates per analyzed-group for the PERMANOVA analysis is given in Table S3. To visualize variation in flower community composition, we conducted non-metric multidimensional scaling (NMDS) based on the same distance matrices used in the PERMANOVA. The analysis was performed using the metaMDS function (vegan package; Oksanen et al., 2022), with ordination fit assessed via stress values using stressplot.

To assess whether the matrices – each with a sample size of 150 (5 treatments × 10 replicates × 3 sampling rounds) – of aphid antagonists and hoverflies align with the matrix of flower volumes, we performed a Procrustes analysis using the vegan package (Oksanen et al., 2022). Procrustean rotation analysis is a robust and powerful method for evaluating concordance (Peres-Neto & Jackson, 2001). As a first step, we conducted an ordination using the rda() function without explanatory variables on the aphid predator matrix, the hoverfly matrix, and the flower volume matrix after applying a Hellinger transformation (Legendre & Gallagher, 2001). The resulting ordinations were then analyzed using the Procrustes rotation (procrustes()) and the PROTEST permutation test (protest()) to statistically assess the concordance between the two matrices. The sample size consisted of five treatments, each with 10 replicates, across three sampling rounds. Results of Procrustes analysis for each sampling rounds separately showed similar results with, however, slightly higher correlation values (see supplement). This is due to the fact that communities within a sampling round better concord than between the sampling rounds.

3. Results

3.1. Autumn-sown annual and perennial flower strips differ in flower composition and volume

The patterns visualized in the NMDS ordination (Fig. 1) reveal clear temporal and treatment-specific shifts in flowering species composition. Overlaps between treatments and sampling rounds, such as autumn-sown annual FS (mid-April), perennial FS (mid-April), spring-sown

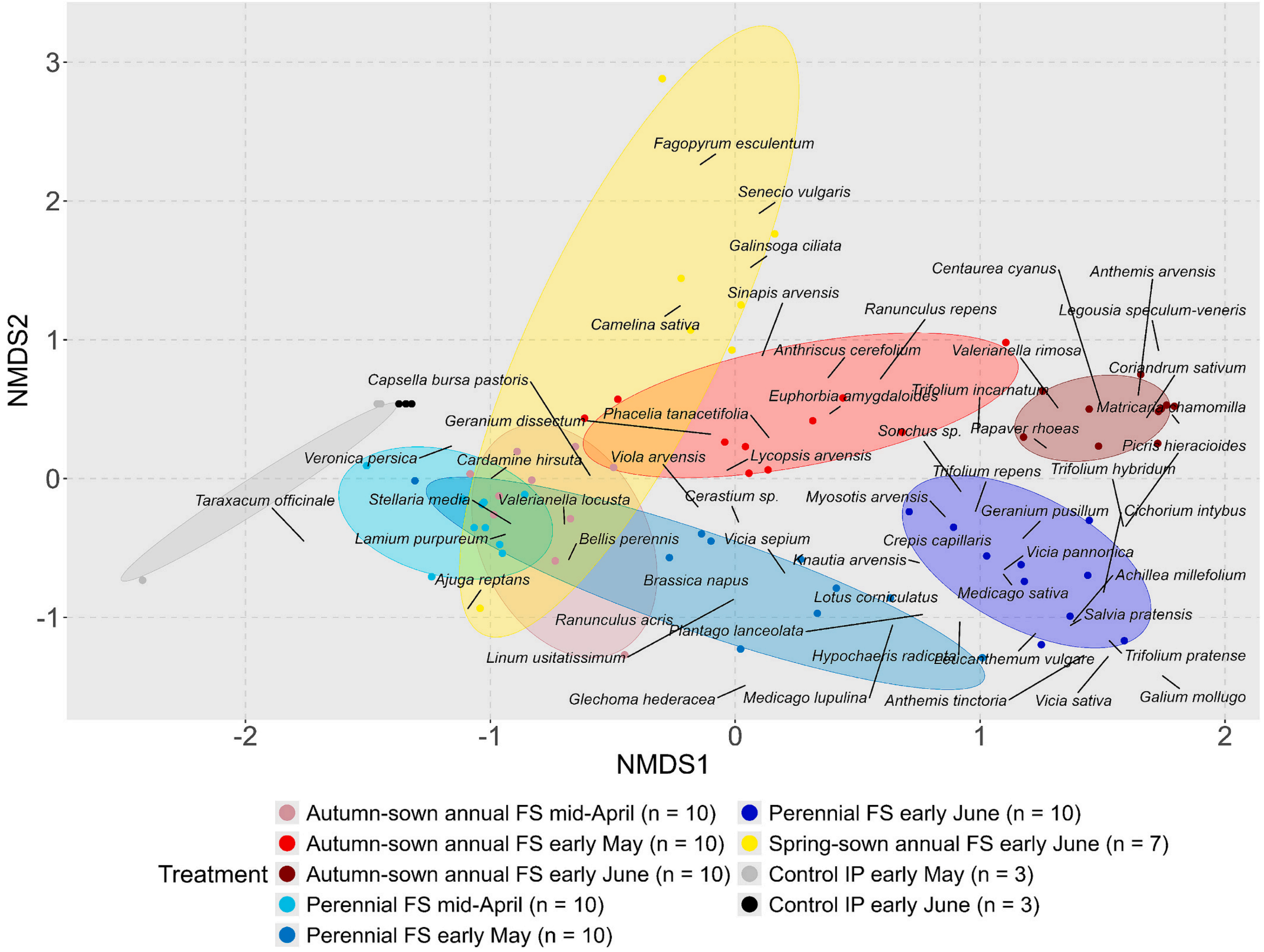

Fig. 1. NMDS plot showing flower composition across treatments and sampling rounds: Autumn-sown annual FS (reddish), perennial FS (blueish), spring-sown annual FS (yellowish), control IP (greyish), and control conventional (greenish). Points represent fields, with ellipses indicating 95 % confidence intervals. No ellipses are drawn for control conventional because only one data point was included. Fields with no flowering plants were excluded.

annual FS (early June), and the control treatments, are primarily due to spontaneous species. A significant temporal gradient emerges toward the right side of the plot for autumn-sown annual and perennial FS (except for perennial FS mid-April to early May, p-values are listed in Table S5). In early May, the clusters representing these treatments are more dispersed, indicating higher variability in flowering species composition within each strip type. As the season progresses, sown species become dominant on the right side of the plot, with more of them blooming later in the season. For instance, in early May, *Plantago lanceolata* and *Leucanthemum vulgare* were prevalent in perennial FS, while *Anthriscus cerefolium* was frequently observed in autumn-sown annual FS. By the final sampling round in early June, the clusters representing autumn-sown annual and perennial FS became more compact, reflecting a reduction in species composition variability. During this period, *Leucanthemum vulgare* dominated in perennial FS, while *Centaurea cyanus* was characteristic of autumn-sown annual FS. Notably, these clusters no longer overlap with earlier ones, highlighting a distinct shift in floral communities as the season advances (p-values are listed in Table S5). A detailed species list and their flower volume percentages can be found in Table S7.

The flower volumes varied across sampling rounds and treatments, as shown in Fig. 2 (see Table S9). Overall, significantly higher flower volumes of both sown and spontaneous species were observed in autumn-sown annual FS and perennial FS compared to spring-sown annual FS and control treatments (p-values are listed in Table S9). In the spring-sown annual FS, no flowers were present until the beginning of June. The flower volume of sown species consistently increased across sampling rounds (mid-April to early May; $\beta = 3.66 \pm 0.75$ SE, $z = 4.92$, $p < 0.001$ and early May to mid-June; $\beta = 6.60 \pm 0.77$ SE, $z = 8.54$, $p < 0.001$). In contrast, the flower volume of spontaneous species remained relatively constant over all sampling rounds (see Table S8).

3.2. Effects of strip type and temporality on aphid antagonists

Significantly higher abundances of aphid antagonists were found in perennial and autumn-sown annual FS than in spring-sown annual FS and control treatments (Fig. 2, p-values are listed in Table S9). This difference reflects the general pattern of flower provision. Across all sampling rounds, 60 ladybirds, 141 ladybird larvae, nine lacewings, 57 lacewing larvae, 179 aphidophagous hoverflies, and 958 parasitic wasps were recorded. Ladybird larvae dominated the control treatments in early June (see Fig. 2). The 958 parasitic wasps spanned 21 families (see Fig. S2). 151 individuals belonged to Braconidae and 1 to Aphelinidae, both important aphid parasitoid families. Most Braconidae specimens (109) appeared in early June, with fewer in mid-April (22) and early May (20). Braconidae were significantly more abundant in the autumn-sown annual FS than in the control treatments, and the spring-sown annual FS (Fig. 2, p-values are listed in Table S9). The perennial FS showed more Braconidae than the conventional control ($\beta = 2.26 \pm 0.58$ SE, $z = 3.89$, $p < 0.001$). Overall, hoverfly abundance was lower in

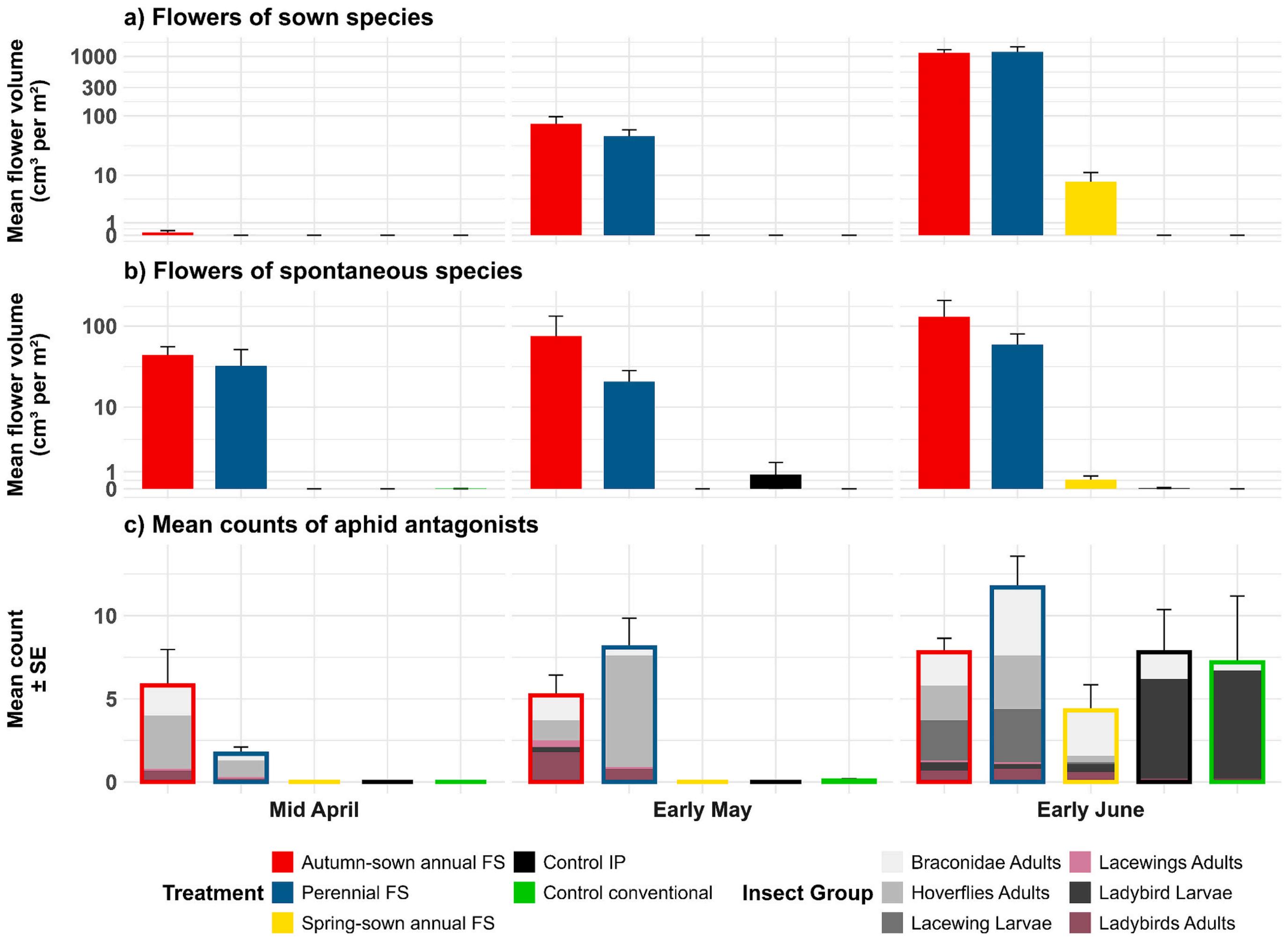

Fig. 2. Mean flower volume (cm^3/m^2) of sown (a) and spontaneous (b) species, and mean count of aphid antagonists (c) across treatments ($n = 10$) and sampling rounds. In panels a) and b), colors indicate treatments, with standard errors. In panel c), the outlines of the bars indicate the treatments, while the fillings correspond to insect groups.

autumn-sown annual FS than in perennial FS, though the difference was not statistically significant (β = -0.42 ± 0.28 SE, z = -1.52, p = 0.13; see Fig. 2, Table S9).

The aphid antagonist community in control treatments was characterized by a high number of ladybird larvae by early June. This contrasted significantly with communities of all sampling rounds of perennial FS and the first and third sampling rounds of autumn-sown annual FS (pairwise PERMANOVA, for p-values and other comparisons see Table S4). The aphid antagonist community in early May of autumn-sown annual FS differed not significantly from the controls. The aphid antagonist composition of spring-sown annual FS early June (the earlier samplings were removed) was significantly different compared to the perennial FS early May (p-values are listed in Table S4).

The Procrustes analysis revealed a weak but significant correlation between the aphid antagonists and the flower volume composition (Procrustes correlation: r = 0.34, p = 0.01, m^2 = 0.89; Fig. 3a).

3.3. *Flower strip type shapes hoverfly community*

Of the 189 hoverflies belonging to 15 species, we excluded 10 individuals that were not identifiable to species level. Hoverfly communities significantly differed between the analyzed-groups: ‘Autumn-sown annual FS mid-April‘ versus ‘perennial FS early May‘, ‘autumn-sown annual FS early June‘ versus ‘perennial FS early May‘, and ‘perennial FS early May‘ versus ‘perennial FS early June‘ (pairwise PERMANOVA, for p-values and other comparisons see Table S6). Hoverfly communities in perennial FS in early May often significantly differed from other communities, apparently due to the abundance of *Platycheirus clypeatus* and the high numbers of *Melanostoma mellinum* (Fig. 4). A significant but low correlation was detected between hoverfly community and flower volume composition (Procrustes correlation: r = 0.28, p = 0.001, m^2: 0.92; Fig. 3b).

3.4. *Contrasting landscape responses of aphid antagonists, hoverflies, and braconids*

Forest and flowering elements had no effect on overall aphid antagonist abundance. However, we found a positive effect on braconids of forests within a 500 m radius around the fields (β = 0.29 ± 0.13 SE, z = 2.24, p = 0.03; see Fig. 5b, Table S8). For hoverflies, forests within a 2000 m radius had a negative effect on their presence (β = -0.29 ± 0.15 SE, z = -1.98, p = 0.05; see Fig. 5a, Table S8).

4. Discussion

The investigated FS types differed in terms of flower volume and flower composition. Autumn-sown annual and perennial FS supported more beneficial insects with distinct communities compared to controls, with species-specific responses linked to flower composition. While no overall landscape effect was detected, braconids increased with nearby forest cover, whereas hoverflies declined with forest cover at broader scales.

4.1. *Flower strip type affects flower volume and composition*

Our findings confirm that the FS type influences flowering capacity and composition over time. Perennial and autumn-sown annual FS produced greater flower volume throughout the observation period than spring-sown annual FS and control treatments. Most of these blooms came from sown species.

Early-season flowers, which are crucial for sugar beet systems (Landis & Van Der Werf, 1997) were present in perennial and autumn-sown annual FS but absent in spring-sown annual FS. During the first sampling round, flower volume in the former primarily consisted of spontaneous species, such as *Taraxacum officinale* (Asteraceae), an important food source for hoverflies (Branquart & Hemptinne, 2000) or *Veronica persica*, which has been shown to be important for parasitic wasps (Dib et al., 2012). Since the emergence of spontaneous vegetation depends on the soil seed bank (Menalled et al., 2001), which is quite site dependent, Laffon et al. (2024) suggest including *Veronica persicae* in seed mixtures because of its early flowering.

In contrast to autumn-sown annual and perennial FS the flower volume in spring-sown annual FS was low. This was likely due to delayed soil cultivation caused by wet spring conditions in 2023, followed by drought, hindering seedling establishment. Weather conditions during the study year may have delayed flowering in spring-sown annual FS compared to other years. These challenges are consistent with findings from other studies on FS and may reflect broader climate change trends (Raderschall et al., 2022). Consequently, FS sown in the season preceding the target crop offer a more reliable option for farmers, as management interventions such as cleaning cuts can be implemented ahead of the main growing season. The low flower volume in the control

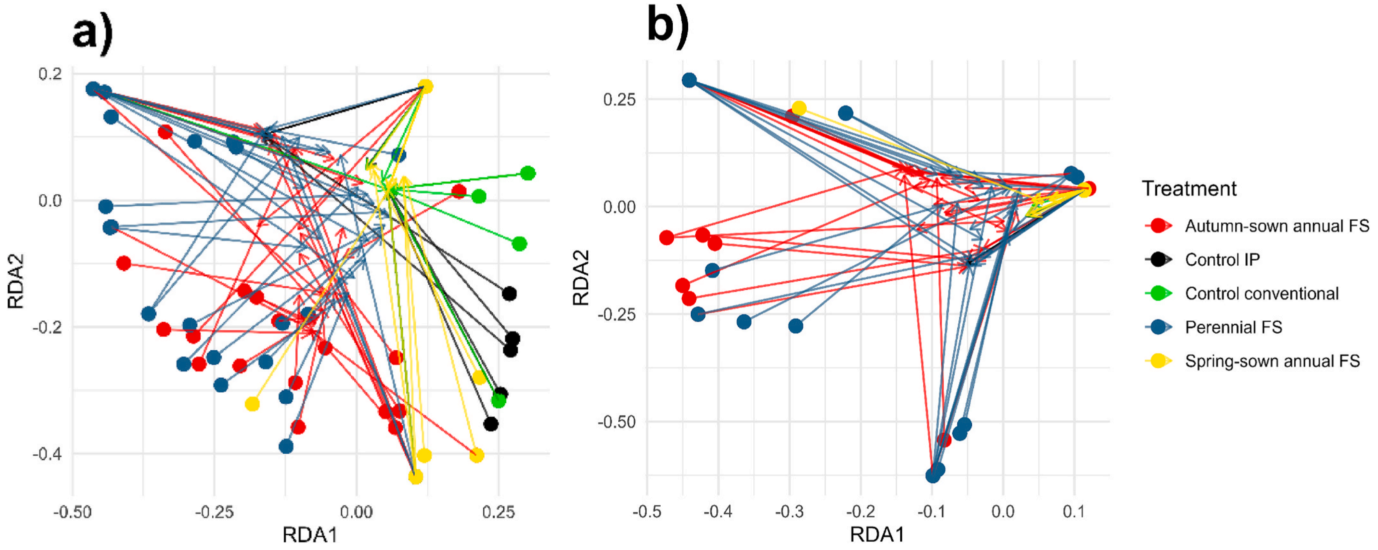

Fig. 3. Procrustes plots showing the correlation between flower volume composition and aphid antagonist (a) and hoverfly (b) communities across treatments. Line length indicates similarity — shorter lines mean stronger correlation. Both panels are based on the same sample size, i.e., 5 treatments × 10 replicates × 3 sampling rounds. In (b), many points overlap due to identical patterns in both datasets.

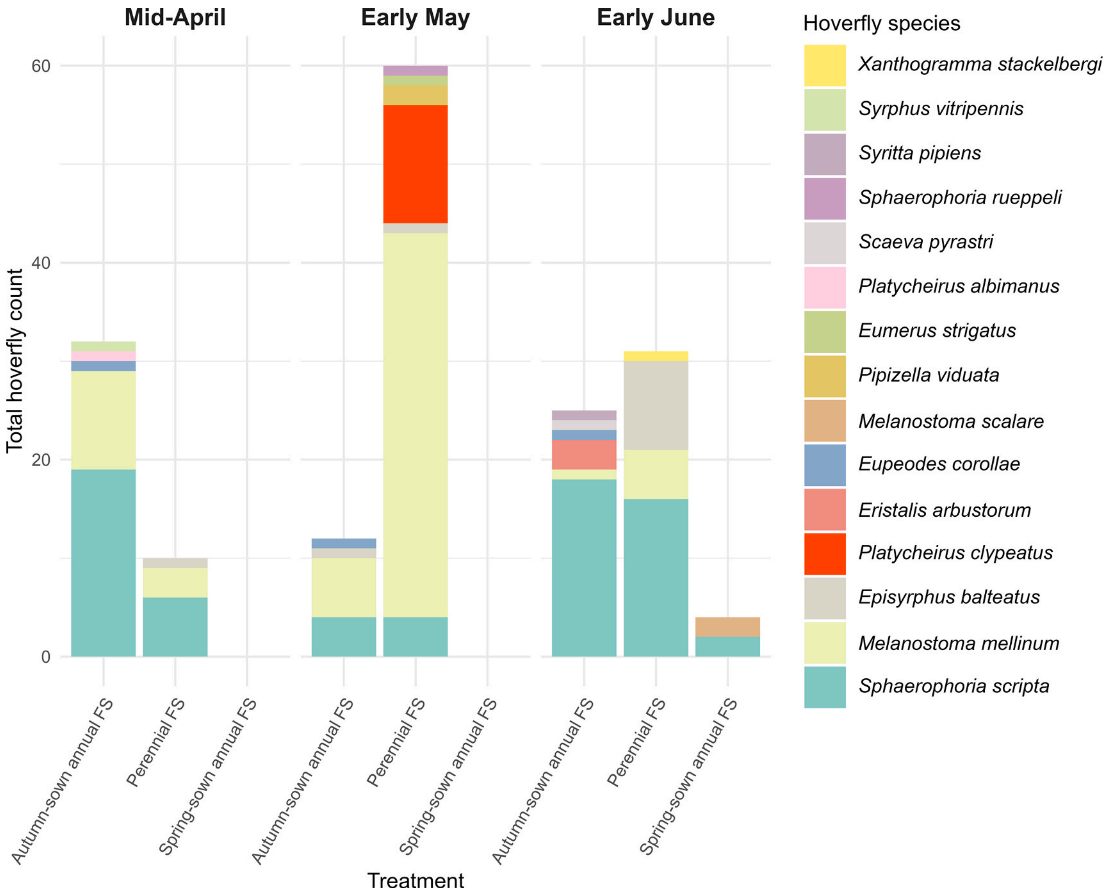

Fig. 4. Total count of hoverfly species observed across different treatments and sampling rounds (mid-April, early May, and early June). The y-axis represents the sum of hoverfly species found in 10 replicates per treatment.

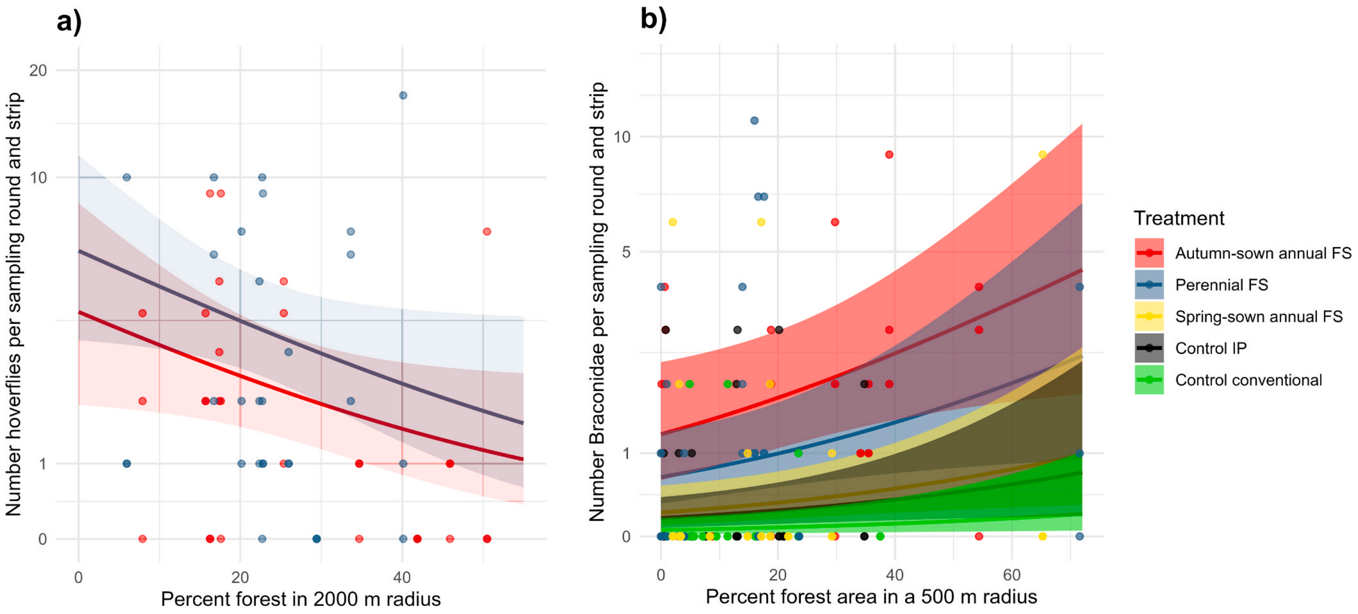

Fig. 5. Relationship between hoverfly (a) and braconid (b) abundance and the percentage of forest within a sector of 2000 m and 500 m radius around the fields, respectively. Points show data color-coded by treatments. Lines with 95 % confidence intervals represent model predictions. The Y-axis is log-scaled. Only autumn-sown annual FS and perennial FS were included in the hoverfly model.

treatments could be explained by herbicide application at the start of the sampling period and later by shading from the sugar beet canopy.

4.2. Autumn-sown annual and perennial flower strips support early-season aphid predators

From a pest control perspective, autumn-sown annual and perennial FS appear to be beneficial early in the season. We found no significant difference in total aphid antagonist abundance between these two FS types, both supported higher numbers than other treatments. This shows the link between flower availability and predator presence.

The diversity and temporal variation in the availability of floral resources in autumn-sown annual and perennial FS attracted aphid antagonists and provided them with food at a critical point in time (Pontin et al., 2006). Several sown plant species proved particularly promising for early-season food support (Elias et al., 2025; Kuppler et al., 2023). For example, *Leucanthemum vulgare*, *Plantago lanceolate*, *Salvia pratensis*, *Hypochaeris radicata*, *Lotus corniculatus*, *Centaurea cyanus*, *Sinapis arvensis* and *Anthriscus cerefolium* began flowering as early as May. Notably, members of the Apiaceae (*Anthriscus cerefolium*) and Brassicaceae (*Sinapis arvensis*) families have been shown to increase the longevity of parasitic wasps (Russell, 2015). In addition, extrafloral nectaries in *Centaurea cyanus* may provide further benefits to aphid predators (Géneau et al., 2013). These two FS types achieved a strong alignment between floral resource availability and the activity periods of beneficial insects. The early establishment before the sugar beet season may also provide overwintering habitats, further supporting predator and parasitoid populations (Ganser et al., 2019; Gillespie et al., 2015).

Having addressed the autumn-sown annual and perennial FS, we next assess the overall beneficial insect dynamics observed in spring-sown annual FS and control strips. In early June, high numbers of ladybird larvae and Braconidae were observed in control treatments. This is likely due to their primary reliance on aphids, either as prey or hosts for egg-laying (Albittar et al., 2016; Ferran & Dixon, 1993). Braconidae numbers in FS were similar to or even higher than in controls in early June, likely due to their foraging for pollen, nectar, or suitable hosts. The presence of aphids in the FS raises a potential concern: FS may unintentionally support pest populations by providing alternative food sources. However, most of the aphids present in sweep net samples from FS belonged to *Uroleucon jaceae*, a species restricted to *Centaurea* and harmless to sugar beet (Börner, 1952). These aphids may attract beneficial insects that later move into sugar beet fields, potentially enhancing pest control.

It should be noted that the sweep net method used in this study has limitations. Due to the fabric construction of the net, very small insects could have been blown out during sampling. As a result, groups such as Aphelinidae may not have been reliably captured, and their abundance is likely underrepresented in the dataset. Future studies could explore the responses of this parasitic wasp family in more detail.

4.3. Hoverfly communities differ between autumn-sown annual and perennial flower strips

Although overall antagonist composition did not differ significantly between autumn-sown annual and perennial FS, the hoverfly communities showed distinct differences at the species level. These variations, observed at specific sampling points, could influence aphid control in adjacent sugar beet fields (Almohamad et al., 2007; Lillo et al., 2021). These community differences are most likely driven by the distinct plant species offered by the FS types. For example, *Platycheirus clypeatus* was detected exclusively in perennial FS in early May. According to Van Der Goot and Grabandt (1970), this species is associated with early-flowering *Plantago lanceolata*, which accounted for 17 % of the flower volume of sown species in these FS type at that time. These results support our hypothesis that no effect would be found at higher taxonomic levels and underscore the value of analyzing species composition at a finer taxonomic resolution, rather than relying solely on broader groupings, total abundance, or biodiversity indices (Lyashevska & Farnsworth, 2012).

4.4. Insect-group- and scale-dependent forest responses

The influence of the surrounding landscape varied depending on the insect group considered. No significant landscape effect was found on overall aphid antagonist abundance, most likely due to the groups diverse composition and varying habitat requirements (Hadly et al., 2009). Braconidae abundance increased with higher forest cover within a 500 m radius, possibly due to greater food availability or favorable microclimates at forest edges (Gillespie et al., 2015). The 500 m radius aligns with the limited mobility of parasitic wasps (Gillespie et al., 2015). The more mobile hoverflies were best explained at the 2000 m scale. Contrary to previous studies, we found a negative effect of forest cover on hoverfly abundance (Toikkanen et al., 2022). This may reflect differences in general landscape configuration within a country and habitat preferences. Power (2016) showed hoverflies associated with open farmland to respond positively to grasslands, suggesting that landscape factors differ when forest-dwelling species are excluded (Ouin et al., 2006). No effect of flowering elements on hoverflies was observed, likely because the sampling design excluded areas within 200 m of such elements, minimizing their influence. Additionally, generalist hoverflies may have relied on floral resources from other crops in the landscape.

5. Conclusions

Our research demonstrates that carefully designed FS can support beneficial insects by offering a succession of flowers through strategic plant selection. A key factor for early-season impact was establishing FS in the season prior to sugar beet cultivation, allowing the plants more time to develop. Interestingly, while the most effective FS types supported similar total numbers of aphid antagonists, they attracted different communities of hoverflies, suggesting that each approach might contribute uniquely to natural pest control. Beyond local FS type, the surrounding landscape also played a role: we found that wooded areas near FS in otherwise open agricultural landscapes enhances their contribution for biological control. This finding merits further study to optimize FS designs and to better understand how landscape structures affect specific groups of beneficial insects.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT in order to improve the clarity of the writing and assists with code writing. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

CRediT authorship contribution statement

Angela Studer: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Linda Näpflin:** Writing – review & editing, Investigation, Data curation. **Philippe Jeanneret:** Writing – review & editing, Validation, Supervision, Methodology, Formal analysis, Conceptualization. **Katja Jacot:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The datasets supporting this article will be uploaded to Dryad Digital Repository following manuscript acceptance.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocontrol.2025.105879.

References

Acheampong, S., Gillespie, D.R., Quiring, D.J.M., 2012. Survey of parasitoids and hyperparasitoids (Hymenoptera) of the green peach aphid, *Myzus persicae* and the foxglove aphid, *Aulacorthum solani* (Hemiptera: Aphididae) in British Columbia. J. Entomol. Soc. Br. Columbia 109 (December), 12–22.

Albittar, L., Ismail, M., Bragard, C., Hance, T., 2016. Host plants and aphid hosts influence the selection behaviour of three aphid parasitoids (Hymenoptera: Braconidae: Aphidiinae). Eur. J. Entomol. 113, 516–522.

Albrecht, M., Kleijn, D., Williams, N.M., Tschumi, M., Blaauw, B.R., Bommarco, R., Campbell, A.J., Dainese, M., Drummond, F.A., Entling, M.H., Ganser, D., Arjen de Groot, G., Goulson, D., Grab, H., Hamilton, H., Herzog, F., Isaacs, R., Jacot, K., Jeanneret, P., Sutter, L., 2020. The effectiveness of flower strips and hedgerows on pest control, pollination services and crop yield: A quantitative synthesis. Ecol. Lett. 23 (10), 1488–1498. https://doi.org/10.1111/ele.13576.

Alcalá Herrera, R., Cotes, B., Agustí, N., Tasin, M., Porcel, M., 2022. Using flower strips to promote green lacewings to control cabbage insect pests. J. Pest. Sci. 95 (2), 669–683. https://doi.org/10.1007/s10340-021-01419-7.

Almohamad, R., Verheggen, F.J., Francis, F., Haubruge, E., 2007. Predatory hoverflies select their oviposition site according to aphid host plant and aphid species. Entomol. Exp. Appl. 125, 13–21.

Ammann, L., Bosem-Baillod, A., Eckerter, P.W., Entling, M.H., Albrecht, M., Herzog, F., 2022. Comparing floral resource maps and land cover maps to predict predators and aphid suppression on field bean. Landsc. Ecol. 37 (2), 431–441. https://doi.org/10.1007/s10980-021-01361-0.

Baur, H., Klopfstein, S., 2007. In: Schlupfwespen der Schweiz: Systematik. https://doi.org/10.5281/zenodo.13356261.

Baur, H., Neumann, M., 2024. Interactive key to Central European parasitic wasps (Hymenoptera: Parasitica). Zenodo. https://doi.org/10.5281/zenodo.13362996.

Bennett, A.B., Gratton, C., 2012. Local and landscape scale variables impact parasitoid assemblages across an urbanization gradient. Landsc. Urban Plan. 104, 26–33.

Blümel, S., Beule, L., Bissantz, N., Kirchner, W.H., Haberlah-Korr, V., 2024. Taxon-specific response of natural enemies to different flower strip mixtures. J. Appl. Ecol. 61, 2405–2417.

BLW (Hrsg.). (2025). Saatmischungen für Produktionssystembeiträge nach Direktzahlungsverordnung (DZV. https://www.blw.admin.ch/de/produktionssystembeitraege.

Börner, C. (1952). *Europae centralis aphides: Die Blattläuse Mitteleuropas*. Knabe.

Bot, S., Van de Meutter, F., 2023. Hoverflies of Britain and North-west Europe: A photographic guide. Bloomsbury Publishing.

Branquart, E., Hemptinne, J., 2000. Selectivity in the exploitation of floral resources by hoverflies (Diptera: Syrphinae). Ecography 23, 732–742.

Brooks, M.E., Kirstensen, K., van Benthem, K., Magnusson, A., Berg, C.W., Nielsen, A., Skaug, H.J., Maechler, M., Bolker, B., 2017. glmmTMB: Balances Speed and Flexibility Among Packages for Zero-inflated Generalized Linear Mixed Modeling. The R Journal 9 (2), 378–400.

Campbell, J., Irvin, A., Irvin, H., Stanley-Stahr, C., Ellis, J.D., 2016. Insect visitors to flowering buckwheat, *Fagopyrum esculentum* (Polygonales: Polygonaceae), in north–central Florida. Fla. Entomol. 99 (2), 264–268.

Dib, H., Libourel, G., Warlop, F., 2012. Entomological and functional role of floral strips in an organic apple orchard: Hymenopteran parasitoids as a case study. J. Insect Conserv. 16, 315–318.

Dib, H., Simon, S., Sauphanor, B., Capowiez, Y., 2010. The role of natural enemies on the population dynamics of the rosy apple aphid, *Dysaphis plantaginea* Passerini (Hemiptera: Aphididae) in organic apple orchards in south-eastern France. Biol. Control 55, 97–109.

Dunn, L., Lequerica, M., Reid, C.R., Latty, T., 2020. Dual ecosystem services of syrphid flies (Diptera: Syrphidae): Pollinators and biological control agents. Pest Manag. Sci. 76 (6), 1973–1979.

Elias, D., Schäfer, J., Sieg, L.F., Tischew, S., Kirmer, A., 2025. Wildflower sowings as alternative for conventional inter-row greening in German vineyards. Basic Appl. Ecol. 87, 153–161.

Ferran, A., Dixon, A.F.G., 1993. Foraging behaviour of ladybird larvae (Coleoptera: Coccinellidae). Eur. J. Entomol. 90 (4), 383–402.

Ganser, D., Knop, E., & Albrecht, M. (2019). Sown wildflower strips as overwintering habitat for arthropods: Effective measure or ecological trap? Agriculture, Ecosystems and Environment, 275(November 2018), 123–131. doi: 10.1016/j.agee.2019.02.010.

Gardarin, A., 2023. Aphid biological control in arable crops via flower strips: The predominant role of food resources over diversity effects. J. Appl. Ecol. 60, 2118–2131.

Géneau, C.E., Wäckers, F.L., Luka, H., Balmer, O., 2013. Effects of extrafloral and floral nectar of *Centaurea cyanus* on the parasitoid wasp *Microplitis mediator*: Olfactory attractiveness and parasitization rates. Biol. Control 66, 16–20.

Gillespie, M.A.K., Gurr, G.M., Wratten, S.D., 2015. Beyond nectar provision: The other resource requirements of parasitoid biological control agents. Entomol. Exp. Appl. 159, 207–221.

Haaland, C., Naisbit, R.E., Bersier, L.-F., 2011. Sown wildflower strips for insect conservation: A review. Insect Conserv. Diversity 2011 (4), 60–80.

Hadly, E. A., Spaeth, P. A., & Li, C. (2009). Niche conservatism above the species level. pNAS, 106, 19707–19714.

Haenke, S., Scheid, B., Schaefer, M., Tscharntke, T., Thies, C., 2009. Increasing syrphid fly diversity and density in sown flower strips within simple vs. Complex landscapes. J. Appl. Ecol. 46 (5), 1106–1114.

Haro-Barchin, E., Scheper, J., Ganuza, C., de Groot, G.A., Colombari, F., van Kats, R., Kleijn, D., 2018. Landscape-scale forest cover increases the abundance of *Drosophila suzukii* and parasitoid wasps. Basic Appl. Ecol. 31, 33–43.

Hartig, F. (2022). DHARMa: Residual Diagnostics for Hierarchical (Multi-Level / Mixed) Regression Models [Software].

Hatt, S., Uyttenbroeck, R., Lopes, T., Mouchon, P., Chen, J., Piqueray, J., Monty, A., Francis, F., 2017. Do flower mixtures with high functional diversity enhance aphid predators in wildflower strips? Eur. J. Entomol. 114, 66–76.

IP-SUISSE (Hrsg.). (2024). Richtlinien Pflanzenbau. https://www.ipsuisse.ch/richtlinien-pflanzenbau/.

Jönsson, A., Ekroos, J., Dänhardt, J., Anderson, G.K.S., Olsson, O., Smith, H.G., 2015. Sown flower strips in southern Sweden increase abundances of wild bees and hoverflies in the wider landscape. Biol. Conserv. 184, 51–58.

Kershaw, W.J.S., 1965. The spread of yellows viruses in sugar beet. Ann. Appl. Biol. 56 (2), 231–241.

Kopta, T., Pokluda, R., Psota, V., 2012. Attractiveness of flowering plants for natural enemies. Hortic. Sci. 39 (2), 89–96.

Kuppler, J., Neumüller, U., Mayr, A.V., Hopfenmüller, S., Weiss, K., Prosi, R., Schanowski, A., Schwenninger, H., Ayasse, M., Burger, H., 2023. Favourite plants of wild bees. Agric. Ecosyst. Environ. 342, 108266.

Laffon, L., Bischoff, A., Blaya, R., Lescourret, F., Franck, P., 2024. Spontaneous flowering vegetation favours hoverflies and parasitoid wasps in apple orchards but has low cascading effects on biological pest control. Agr Ecosyst Environ 359, 108766.

Landis, D.A., Van Der Werf, W., 1997. Early-season predation impacts the establishment of aphids and spread of beet yellows virus in sugar beet. Entomophaga 42 (4), 499–516.

Legendre, P., Gallagher, E.D., 2001. Ecologically meaningful transformations for ordination of species data. Oecologia 129, 271–280.

Lenth, R. V. (2024). emmeans: Estimated Marginal Means, aka Least-Squares Means [Software]. https://cran.r-project.org/package=emmeans.

Levin, S., 1992. The Problem of Pattern and Scale in Ecology: The Robert H. MacArthur Award Lecture. Ecology 73 (6), 1943–1967.

LGL. (2023). Open GeoData Portal. www.lgl-bw.de.

Lillo, I., Perez-Bañón, C., Rojo, S., 2021. Life cycle, population parameters, and predation rate of the hover fly *Eupeodes corollae* fed on the aphid *Myzus persicae*. Entomol. Exp. Appl. 169, 1027–1038.

Limburg, D.D., Mauk, P.A., Godfrey, L.D., 1997. Characteristics of beet yellows closterovirus transmission to sugar beets by *Aphis fabae*. Phytopathology 87 (7), 766–771.

Lyashevska, O., Farnsworth, K.D., 2012. How many dimensions of biodiversity do we need? Ecol. Ind. 18, 485–492.

Mahillon, M., Groux, R., Bussereau, F., Brodard, J., Debonneville, C., Demal, S., Kellenberger, I., Peter, M., Steinger, T., Schumpp, O., 2022. Virus Yellows and Syndrome "Basses Richesses" in Western Switzerland: A Dramatic 2020 Season Calls for Urgent Control Measures. Pathogens 11, 885.

Menalled, F.N.D., Gross, K.L., Hammond, M., 2001. Weed aboveground and seedbank community esponses to agricultural management systems. Ecol. Appl. 11 (6).

Noyes, J.S., 1982. Collecting and preserving chalcid wasps (Hymenoptera: Chalcidoidea). J. Nat. Hist. 16 (3), 315–334.

Oksanen, J., Simpson, G. L., Blanchet, G. F., Kindt, R., Legendre, P., Minchin, P. R., O'Hara, R. B., Solymos, P., Stevens, M. H. H., Szoecs, E., Wagner, H., Barbour, M., Bedward, M., Bolker, B., Borcard, D., Carvalho, G., Chirico, M., De Caceres, M., Durand, S., … Weedon, J. (2022). vegan: Community Ecology Package [Software]. https://CRAN.R-project.org/package=vegan.

Ouin, A., Sarthou, J.-P., Bouyjou, B., Deconchat, M., Lacombe, J.-P., Monteil, C., 2006. The species-area relationship in the hoverfly (Diptera, Syrphidae) communities of forest fragments in southern France. Ecography 29, 183–190.

Peres-Neto, P.R., Jackson, D.A., 2001. How well do multivariate data sets match? The advantages of a Procrustean superimposition approach over the Mantel test. Oecologia 129, 169–178.

Petrović, A., 2022. Sizing the Knowledge Gap in Taxonomy: The Last Dozen Years of Aphidiinae Research. Insects 13 (170), 1–18.

Pontin, D.R., Wade, M.R., Kehrli, P., Wratten, S.D., 2006. Attractiveness of single and multiple species flower patches to beneficial insects in agroecosystems. Ann. Appl. Biol. 148, 39–47.

Power, E.F., Jackson, Z., Stout, J.C., 2016. Organic farming and landscape factors affect abundance and richness of hoverflies (Diptera, Syrphidae) in grasslands. Insect Conserv. Diversity 9, 244–253.

QGIS Development Team. (2024). QGIS Geographic Information System. [Software]. Open Source Geospatial Foundation Project. http://qgis.osgeo.org.

Quicke, D. L. J. (2015). The Braconid and Ichneumonid parasitoid wasps. JohnWiley & Sons, Ltd,.

R Core Team. (2024). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. (Version 4.4.1) [Software]. https://www.r-project.org/.

Raderschall, C.A., Lundin, O., Lindstrom, S.A.M., Bommarco, R., 2022. Annual flower strips and honeybee hive supplementation differently affect arthropod guilds and ecosystem services in a mass-flowering crop. Agr Ecosyst Environ 326, 107754.

Russell, M., 2015. A meta-analysis of physiological and behavioral responses of parasitoid wasps to flowers of individual plant species. Biol. Control 82, 96–103.

Scheper, J., Bukovinszky, T., Huigens, M., Kleijn, D., 2021. Attractiveness of sown wildflower strips to flower-visiting insects depends on seed mixture and establishment success. Basic Appl. Ecol. 56 (2021), 401–415.

Schirmel, J., Albrecht, M., Bauer, P., Sutter, L., Pfister, S.C., Entling, M.H., 2018. Landscape complexity promotes hoverflies across different types of semi-natural habitats in farmland. J. Appl. Ecol. 55, 1747–1758.

Serée, L., Rouzes, R., Thiéry, D., Rusch, A., 2020. Temporal variation of the effects of landscape composition on lacewings (Chrysopidae: Neuroptera) in vineyards. Agric. For. Entomol. 22 (3), 274–283. https://doi.org/10.1111/afe.12380.

Shaw, M., 2006. Habitat considerations for parasitic wasps (Hymenoptera). J. Insect Conserv. 10, 117–127.

Singh, R., Singh, G., 2016. Ecofriendly Pest Management for Food Security. Elsevier.

Speight, M. C. D. (2018). StN key for the identification of the genera of European Syrphidae (Diptera). (S. 45 pp.). Syrph the Net, the database of European Syrphidae (Diptera).

Swiss Federal Office of Topography, Berne. (2023). Swisstopo (2023) Topographic landscape model TLM3D. .

Taranto, L., Rodrigues, I., Santos, S.A.P., Villa, M., Pereira, J.A., 2022. Response of the Coccinellidae Community within Sustainable Vineyards to the Surrounding Landscape. Agronomy 12, 2140.

Toikkanen, J., Halme, P., Kahanpää, J., Toivonen, M., 2022. Effects of landscape composition on hoverflies (Diptera: Syrphidae) in mass-flowering crop fields within forest-dominated landscapes. J. Insect Conserv. 26, 907–918.

Tschumi, M., Albrecht, M., Collatz, J., Dubsky, V., Entling, M.H., Najar-Rodriguez, A.J., Jacot, K., 2016. Tailored flower strips promote natural enemy biodiversity and pest control in potato crops. J. Appl. Ecol. 53, 1169–1176.

Tschumi, M., Albrecht, M., Entling, M.H., Jacot, K., 2015. High effectiveness of tailored flower strips in reducing pests and crop plant damage. Proc. R. Soc. B Biol. Sci. 282, 20151369.

Twardowski, J.P., Hurej, M., Klukowski, Z., 2005. The effect of the strip-management on reduction of *Aphis fabae* (Homoptera: Aphididae) populations by predators on sugar beet crop. J. Plant Prot. Res. 45 (3), 213–219.

Van Der Goot, V.S., Grabandt, R.A.J., 1970. Some species of the genera *Melanostoma*, *Platycheirus* and *Pyrophaena* (Diptera, Syrphidae) and their relation to flowers. Entomologische Berichten 30, 135–143.

van Veen, M. P. (2014). Hoverflies of Northwest Europe. KNNV Publishing.

Watson, M.A., Hull, R., Blencowe, J.W., Hamlyn, B.M., 1951. The spread of beet yellows and beet mosaic viruses in the sugar beet. Ann. Appl. Biol. 4 (38), 741–929.

Wickham, H., 2016. ggplot2: Elegant Graphics for Data Analysis [Software]. Springer-Verlag, New York https://ggplot2.tidyverse.org.

Woltz, J.M., Landis, D.A., 2014. Coccinellid response to landscape composition and configuration. Agric. For. Entomol. 16, 341–369.

Zhao, Z., Reddy, G.V.P., 2019. Semi-natural habitats mediate influence of inter-annual landscape variation on cereal aphid-parasitic wasp system in an agricultural landscape. Biol. Control 128, 17–23.