



# The influence of field margin characteristics on syrphid abundance

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## Abstract

Field margins have an important ecological role in agroecosystems including hosting beneficial insect such as syrphids. However, little is known of syrphid preferences for different types of field margins. Syrphids were sampled in field margins in an organic agroecosystem to test the hypothesis that syrphid abundance in field margins depends not only on the floral resource abundance but also on field margin component type, field margin complexity, and adjacent land-use type. Floral resource abundance had the greatest influence on the number of syrphids surveyed. Field margin characteristics were deemed to effect syrphid abundance both independently of their effect on floral resources and by altering floral resource abundance. Syrphids were more abundant in field margins adjacent to cropped fields than those adjacent to grazed fields or roads. More syrphids were found in ditch components than in tree or grass strip components. The influence of floral resources on syrphid abundance varied depending on their botanical families, although no significant differences were observed for the effect of botanical family floral resource index on syrphid abundance. These findings demonstrate that field margin characteristics play an important role in facilitating plant–syrphid interactions and offer an insight in agroecosystem management for the promotion of beneficial insects. The influence of field margin characteristics on other beneficial insect groups should also be investigated.

**Keywords** Semi-natural habitat · Ecosystem services · Agroecology · Hoverfly · Beneficial insects · Agrobiodiversity

## Introduction

Intensive agricultural activity is considered to be one of the main factors that contribute to biodiversity loss in agroecosystems (Tschardt et al. 2005). Semi-natural habitats play an important role in biodiversity conservation (Kleijn et al. 2011). In this context, field margins are valuable elements of agroecosystems as they offer many resources to insects such as oviposition sites, floral resources, and preys for predatory organisms (Denys and Tschardt 2002; Bischoff et al. 2016; Burgio et al. 2004; Landis et al. 2000; Sutherland et al. 2001). Field margins can be homogeneous or can be composed of a combination of structural components, for example, ditches, grass strips, tree lines, hedges, banks, and

stonewalls. The composition of margins in terms of component types and their management characterise field margin vegetation composition (Blaix and Moonen 2020). The traits characterising (especially the dominant) plant species determine the services that the vegetation can provide to organisms, for example, nectar and pollen provisioning and overwintering sites (Gardarin et al. 2018).

Some insects, for example, syrphids (Diptera: Syrphidae), provide ecosystem services to farming systems. Their economic importance has been proven by calculating their contribution to crop pollination and to the reduction of crop pest abundance through predation (Smith and Chaney 2007; Stanley et al. 2013; Rader et al. 2016; Dunn et al. 2020; Rodríguez-Gasol et al. 2020). The presence of syrphids as predators in cultivated landscapes is, therefore, important especially in organic and low-input systems that rely on the services provided by functional biodiversity to compensate for the limited use of synthetic pesticides. Syrphids respond strongly and positively to the floral resource present in cultivated landscapes (MacLeod 1999; Branquart and Hempstine 2000; Ramsden et al. 2015). Also, syrphid species composition is strongly correlated to the local vegetation

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composition despite being typically considered as generalist flower visitors (Burgio and Sommaggio 2007; Rotheray and Gilbert, 2011; Burgio et al. 2015). It is, thus, likely that the structural composition of field margins allows us to predict the capacity of field margin types to attract syrphids. Although the effect of field margins on syrphids has been studied (e.g. Barbir et al. 2015; Ramsden et al. 2015), little information is known about the influence of field margin characteristics on the availability of floral resources and the subsequent effect it has on syrphid abundance. Structural elements composing field margins determine abiotic characteristics such as the presence of water, temperature profiles through shading, and the presence of oviposition sites, all factors that are important for syrphid survival (Gilbert 1985; Tenhumberg and Poehling 1995; Moonen and Marshall 2002; Miranda and Rotheray 2018). This may lead to an influence of field margin characteristics on syrphid abundance independent of floral resource availability. Furthermore, if differences between field margin component types in attracting or hosting syrphids can be demonstrated, it will be easier to estimate the suitability of farmland for syrphids on the one hand and provide guidelines for farmers who are interested in implementing biodiversity-friendly practices and ecological intensification of agroecosystems on the other hand. Identification of plant species for such a suitability analysis is often not feasible for farmers and local land managers. If components of field margins can be related to syrphid abundances, this would provide a simple indicator for habitat quality and a straightforward guideline for ecological intensification.

For this reason, we have set up a study aimed at analysing the characteristics of the field margins that influence the overall abundance of syrphids. In order to establish the full expression of syrphid diversity and abundance in relation to the local margin characteristics, the study was located on an organic farm in a natural park. This presupposed the absence of pesticides and the negative effects of pesticides on syrphids, as is often the problem when studying insects in mixed organic and conventional landscapes. By studying the various field margin components and the floral resources they offer, and by applying an innovative analysis based on the comparison of partially mediated structural equation models and fully mediated models, we were able to disentangle the contribution of floral resources (abundance and plant family) and the structure of the field margin components to total syrphid abundance and predatory syrphid abundance.

## Material and methods

The study was conducted in 2016 and 2017 in an organic mixed livestock farm of circa 200 hectares of arable crops, pastures and forage crops in the regional park of Migliarino,

San Rossore and Massaciuccoli in the province of Pisa, Italy. The sampling site is located near the southern border of the park, 5 km west of Pisa (43°41'N, 10°19'E) (SI 1). It is surrounded by natural woodland on the North, West and partly on the East side, and it is bordered by a poplar plantation and the river Arno on the South side. The northern part of the study area is dominated by arable crops and hay meadows, while the southern part is characterised by pastures. Horses were present in the pastures in 2016 and 2017 and a large number of deer were also observed due to the presence of the adjacent natural woodland. The study site had an average daily maximum temperature of 20.45 °C and minimum of 9.62 °C in 2016, and 20.79 °C and 9.03 °C in 2017. The average daily maximum and minimum temperatures during the sampling period were 26.75 °C and 14.86 °C in 2016 and 25.38 °C and 12.49 °C in 2017. The crops grown in 2016 and 2017 in the study site were barley, maize, alfalfa, and faba beans.

## Field margin

Forty field margins were chosen for sampling in 2016 in such a way that they represented a balanced sampling design containing eight replicates for each of the five different field margin components identified in the area: tree lines, shrubs, ditches, grass strips, and vehicle tracks (see SI 2 and SI 3 for definitions and pictures of the field margin component types). During the first year of sampling, vehicles were observed on both the grass strips and tracks which made the distinction between the two arbitrary. For this reason, the two groups were merged in 2017 and are referred to as grass strips. Therefore, in 2017, a total of 32 field margins were sampled to keep a balanced sampling design in relation to the number of component types (see SI 4 for further description of the field margins). The average width of the field margins was 9.48 m while the maximum width was 16 m and the minimum width was 2 m. Field margins containing trees, shrubs, and/or ditches are typical of the Pisa Plain, where banks and stonewalls are mostly absent, while ditches are a frequently occurring element due to the need for drainage in the rainy autumn and spring. These ditches are about 1–2 m wide and 50–100 cm deep, and they mostly dry up in the summer period when rainfall is almost absent. They are reshaped and cleaned annually or biannually.

Three characteristics were used to describe the field margins; the field margin component type which identifies in which component type the sampling was performed, field margin complexity which is the number of component types in the sampled field margin, and adjacent land-use type which describes the land usage next to the field margins. Three different land-use types were identified: cropped fields, grazed fields, and unpaved roads.

## Sampling

Syrphid abundance and floral resource sampling were performed from May to September in 2016 and from March to August in 2017. Timed surveys were conducted which consisted of recording all the syrphids seen in a single 10 m × 1 m transect during a ten-minute interval for each field margin. Surveys were performed during sunny days with low wind speed between 9:00 and 17:00. A total of 12 sampling rounds of surveying were conducted during the two-year period with approximately a month interval between sampling rounds. The sampling focussed on the herbaceous and shrub layer (up to 2 m in height) of the field margins. The sampling points were at least 80 m apart. The average nearest neighbour distance between margins was 196 m while the maximum distance was 336 m. Syrphids were recorded at family level in 2016 and to species or genus level in 2017. Information on syrphid larval-feeding habit was obtained from Syrph the Net and used to classify the syrphids sampled in 2017 as predatory or non-predatory (Speight et al. 2015).

Floral resource sampling consisted of estimating flower frequencies and cover for each flowering species in 10 m × 1 m transects in the herbaceous and shrub layer of the field margin. The sampling procedure and estimation employed by Roy et al. (2003) was used. The frequency was estimated as the number of 1 m<sup>2</sup> quadrats in which a species was in flower in the transect. A value from 1 to 4 for flower cover in each transect was allocated to each species based on the following criteria:

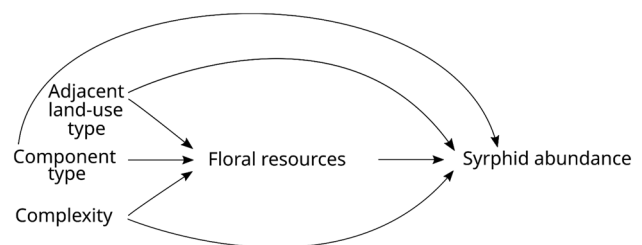
- 1 for species with less than 10 individual blooms and less than 1% cover of blooms;
- 2 for species with 10 individual blooms or more and less than 1% cover of blooms;
- 3 for species with 1–5% cover of blooms; and
- 4 for species with > 5% cover of blooms.

A total of 12 floral resource sampling rounds were performed within 10 days of syrphid surveys. The product of the flower frequency and cover for each plant species was then calculated for each field margin to obtain a floral resource index which was used as an estimation of the abundance of floral resource available (Roy et al. 2003). An index for all species combined was calculated for each field margin as well as indices for each botanical family in each field margin. Flower cover at species level was not considered for data analysis as it would have resulted in flower index variables with many zeros and subsequently, would have created statistical complications.

## Data analysis

An innovative approach based on multi-level structural equation models (ML-SEMs) was employed using a Bayesian

framework to detect the influence of adjacent land-use type, field margin component type, and field margin complexity on total syrphid abundance mediated by floral resource abundance (Fig. 1) (du Toit and du Toit 2008; Bürkner 2017). This technique combines multi-level modelling, which allows for the analysis hierarchically structured of data, and the causal model approach of structural equation modelling (Rappaport et al. 2020). ML-SEMs were also built to analyse the effect of the same variables on predatory syrphid abundances. All models included field margin component types, field margin complexity, adjacent land use, and floral resource index as explanatory variables. All models were tested for multicollinearity among explanatory variables by calculating generalised variance inflation factors (GVIF; Fox and Monette 1992). No correlation between predictor variables is considered to occur if  $(GVIF^{1/(2 \times Df)})^2$ , where Df are the degrees of freedom of the predictor variable, is close to one which was the case for all predictor variables in each model (Fox and Monette 2002). Mixed effect models were fitted with sampling round and sampling location included as group effects (i.e. random effects). Both partially mediated models and fully mediated models were fitted and compared to assess if the effects of the field margin characteristics on syrphid abundance are direct or indirect. Varying intercepts instead of varying slopes were used for the group effects of all models as possible model specification problems were detected by the Pareto smoothed importance sampling (PSIS) diagnostics when varying slopes were used (Vehtari et al. 2017). The partially mediated models were compared with their equivalent fully mediated models using PSIS leave-one-out cross-validation (LOO CV) (Vehtari et al. 2017, 2021). Models differed in performance when the difference in expected log pointwise predictive density was greater than 4 (Sivula et al. 2022). If no differences were detected between the performance of the partially mediated model and the fully mediated model, the partially mediated model was retained for analyses. Contrasts between posterior distributions were used to detect differences between factor levels and slopes of the posterior distributions were observed for continuous variables. Ninety per cent credible intervals



**Fig. 1** Path diagram of the hypothetical relationship tested between field margin characteristics, the abundance of floral resources and syrphid abundance

(CI) were constructed and used to detect the most significant results. By convention, when CIs do not overlap, the factor levels are considered to differ in their effect on the response variables. Similarly, continuous variables were considered to have an important effect on the response variables when the CI measured at their lowest value did not overlap the CI at their highest value.

The contribution of different flower types based on botanical family in explaining variations in syrphid abundances and predatory syrphid abundance was assessed using Bayesian ML-SEMs by including their floral resource index as mediators of the effect of field margin characteristics. Only families for which the dataset contained less than 90% of zeros were included. The models only included sampling round as a group effect to reduce model specification problems. To the same end, statistically problematic botanical families were dropped (Rosaceae and Scrophulariaceae) since we were not able to obtain model convergence with these variables included.

A negative binomial distribution, which is frequently used for count data, was used in all models (ML-SEM and multi-level models) as the syrphid counts from the surveys followed this distribution. Weakly informative priors were used in ML-SEM specifications. The analyses concerning predatory syrphid abundance were done on data collected in 2017 only as syrphids collected in 2016 were not identified to the genera level and, therefore, not classified based on larval-feeding habits. Analyses on overall syrphid abundance were conducted with data collected from surveys performed in 2016 and 2017. All analyses were performed on R software 3.3.1 (R Core Team 2018) using the brms package (Bürkner 2017) which consists of an R interface for Stan, a Bayesian statistical modelling platform (Carpenter et al. 2017). Figures were drawn using the ggplot2 (Wickham 2016) package and the InkScape software v0.91 (<https://inkscape.org>).

## Results

In the first year of sampling, 283 individuals were surveyed while 239 individuals were recorded during the second year. In 2017, when individuals were determined at species level, more predatory syrphids (184, 77% of total syrphids) were sampled than non-predatory syrphids (55, 23%). The most abundant taxa were *Sphaerophoria* and *Paragus* (SI 5). The temporal distributions of syrphid abundances are displayed in SI 6. They are both predatory as larvae and represent 52% of the overall number of syrphids sampled. The most abundant non-predatory syrphid taxon was *Syrirta* who represented 8% of total individuals sampled. No differences were found between partially mediated models and fully mediated models of the effect on syrphids and between models of the effect on predatory syrphids (SI 7). Partially mediated

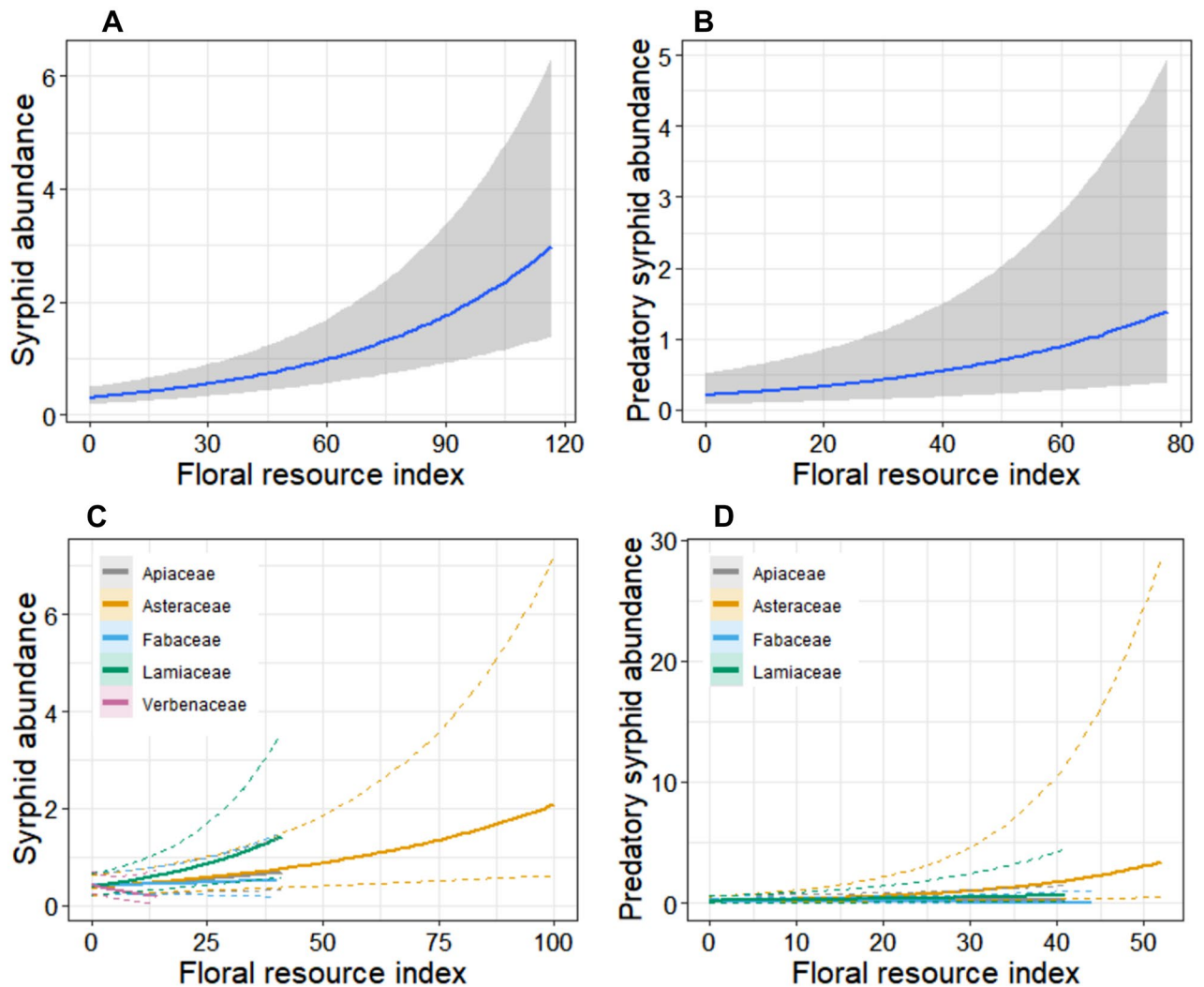
models were retained for analyses to observe potential direct effects of field margin component type, margin complexity, and adjacent land-use on syrphid abundance. Standardised estimates for each model are provided in SI 8 to 11.

## Floral resources

Eighty-nine species of flowering plants were sampled. *Torilis japonica* (Houtt.) DC. of the Apiaceae family was the most frequently occurring in 2016 (67% of margins), while in 2017, it was *Ranunculus sardous* Crantz (66% of margins) of the Ranunculaceae family (SI 12). The temporal distributions of floral resources for the botanical families included in the statistical models are displayed in SI 13. The floral resource index was positively correlated with total syrphid abundance with the posterior predicted abundance (PPA) equal to 0.31 [90% credible interval (CI) (0.19, 0.49)] for the minimum floral resource index and equal to 2.99 [90% CI (1.40, 6.33)] for the maximum floral resource index (Fig. 2A). It also had a weakly positive effect on syrphid predator abundance; however, the CI of the PPA for the minimum floral resource index 0.20, [90% CI (0.07, 0.51)] overlapped the CI for the maximum floral resource index [1.40, 90% CI (0.38, 4.98)] (Fig. 2B). The influence of floral resources on syrphid abundance did not clearly differ depending on the botanical family of the flower with no clear effect of botanical family floral resource index detected on total syrphid abundance, although Asteraceae floral abundance was weakly positively correlated with syrphid abundance with the PPA equal to 0.37 [90% CI (0.21, 0.62)] for the minimum floral resource index and equal to 2.08 [90% CI (0.62, 7.21)] for the maximum floral resource index (Fig. 2C). Predatory syrphid abundance was not correlated with the floral resource index of any of the botanical families (Fig. 2D).

## Adjacent land-use type

Adjacent land-use type had both a direct (independent of the floral resource index) and indirect (by altering the floral resource index) influence on syrphid abundance (Fig. 3). Field margins adjacent to cropped fields contained more syrphids than those adjacent to roads [PPA = 0.86, 90% CI (0.25, 1.57)] while also having a higher floral resource index than margins adjacent to roads [posterior predicted floral resource index (PPFI) = 16.56, 90% CI (7.18, 28.60)] and those adjacent to grazed fields [PPFI = 14.17, 90% CI (5.10, 25.57)] (Fig. 3A and C). Margins adjacent to cropped fields also contained more predatory syrphids than field margins adjacent to grazed fields [PPA = 0.81, 90% CI (0.01, 2.09)] (Fig. 3B). There were no differences between the number of syrphids and the amount of floral resources found in fields' margins adjacent to grazed fields and those adjacent to roads

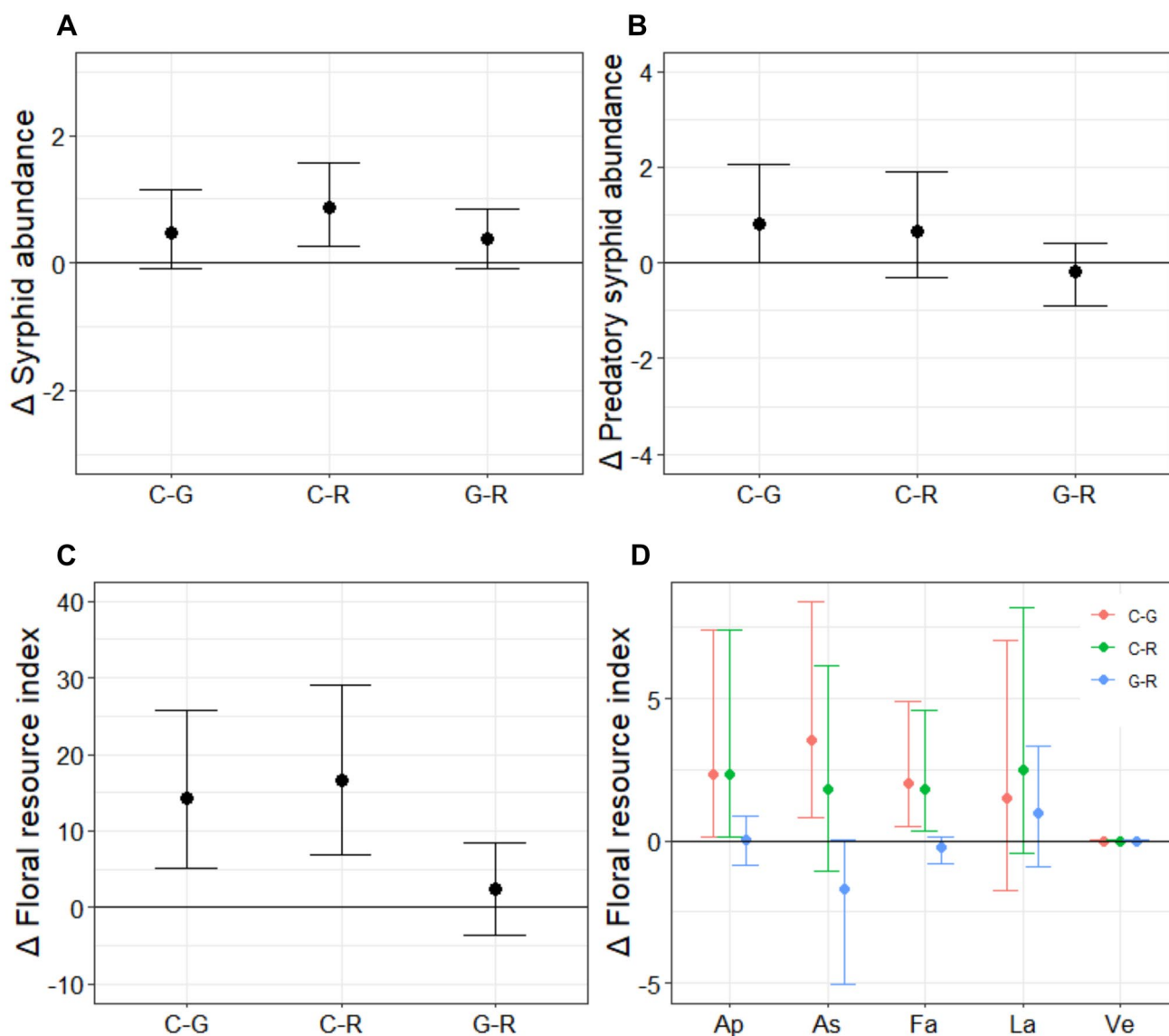


**Fig. 2** Model predictions of the effect of floral resource abundance on syrphid abundance (**A** and **C**) and predatory syrphid abundance (**B** and **D**). The width of the shaded area and the dotted lines represent the credible intervals

(Fig. 3A, B, and C). Field margins adjacent to cropped fields had a higher floral resource index for the Apiaceae family than margins adjacent to grazed fields [PPFI = 2.29, 90% CI (0.15, 7.24)] or roads [PPFI = 2.31, 90% CI (0.12, 7.28)], and also a higher floral resource index for the Fabaceae family than margins adjacent to grazed fields [PPFI = 2.03, 90% CI (0.49, 5.04)] or roads [PPFI = 1.83, 90% CI (0.38, 4.65)] (Fig. 3D). Margins near cropped fields also had more Asteraceae flowers than margins adjacent to grazed fields [PPFI = 3.48, 90% CI (0.82, 8.10)]. The floral resource index of Lamiaceae and Verbenaceae did not change between field margins with different adjacent land-use types (Fig. 3D).

### Field margin component type

A greater syrphid abundance was associated with the ditch component than with the grass strip [PPA = 1.17, 90% CI (0.44, 2.02)] or tree components [PPA = 0.97, 90% CI (0.21, 1.87)] (Fig. 4A). Also, more syrphids were found in the shrub component than in the grass strip component [PPA = 0.59, 90% CI (0.01, 1.29)]. The ditch component was also associated with a greater predatory syrphids abundance than the grass strip [PPA = 1.08, 90% CI (0.16, 2.44)] or tree components [PPA = 1.04, 90% CI (0.12, 2.42)] (Fig. 4B). A greater abundance of flowers was associated with the ditch component than with the tree component [PPFI = 13.47, 90% CI (3.32, 26.44)] (Fig. 4C).



**Fig. 3** Contrasts of model predictions of the effect of adjacent land-use type on syrphid abundance (A), predatory syrphid abundance (B), and on the floral resource index (C and D). C cropped field; G grazed field; R road. ap Apiaceae; as Asteraceae; fa Fabaceae; la Lamiaceae; ve Verbenaceae.  $\Delta$  Syrphid abundance: differences in syrphid abundance between adjacent land-use types;  $\Delta$  Predatory syrphid abundance: differences in predatory syrphid abundance between adjacent land-use types;  $\Delta$  Floral resource index: differences in floral resource abundance between adjacent land-use types. Error bars indicate the credible intervals

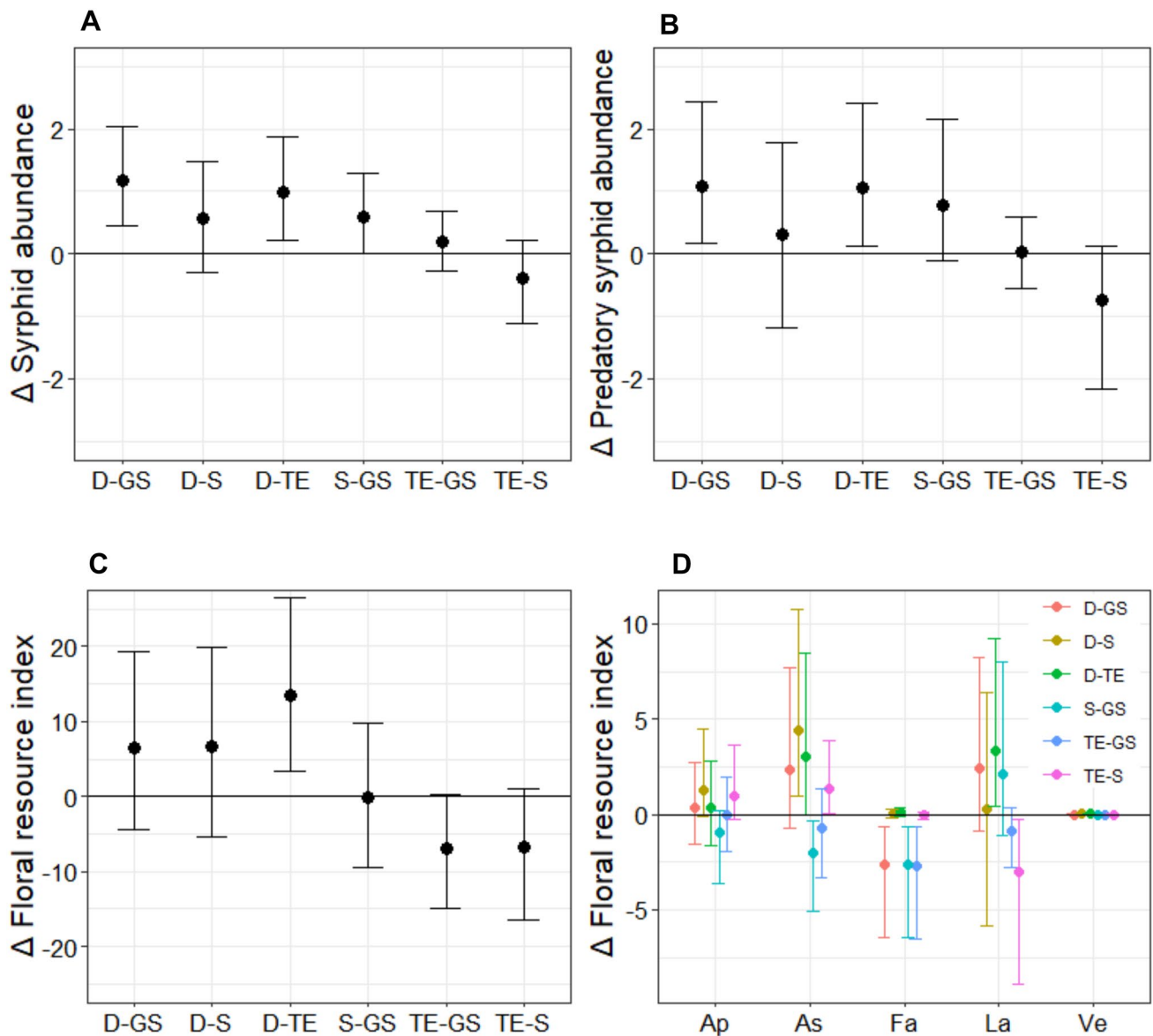
More Asteraceae flowers were found in the ditch component than in the shrub component [PPFI = 4.39, 90% CI (0.96, 10.78)], while the shrub component had a lesser abundance of Asteraceae flowers than the grass strip component [PPFI = -2.05, 90% CI (-5.09, -0.35)] (Fig. 4D). The ditch [PPFI = -2.63, 90% CI (-6.44, -0.66)], shrub [PPFI = -2.67, 90% CI (-6.47, -0.66)], and tree [PPFI = -2.73, 90% CI (-6.57, -0.68)] components all had a lesser amount of Fabaceae flowers than grass strips. The tree component had less Lamiaceae flowers than the shrub component [PPFI = -3.03, 90% CI (-8.90, -0.30)], and the ditch component had a greater amount of Lamiaceae

floral resource than the tree component [PPFI = 3.31, 90% CI (0.41, 9.25)].

Plots of the effect of field margin complexity on syrphids suggest a positive correlation; however, the credible intervals of predicted values at the minimum and maximum complexity values overlap (Fig. 5A and B). Similarly, no clear effect of field margin complexity on the floral resource index is discernible (Fig. 5C and D).

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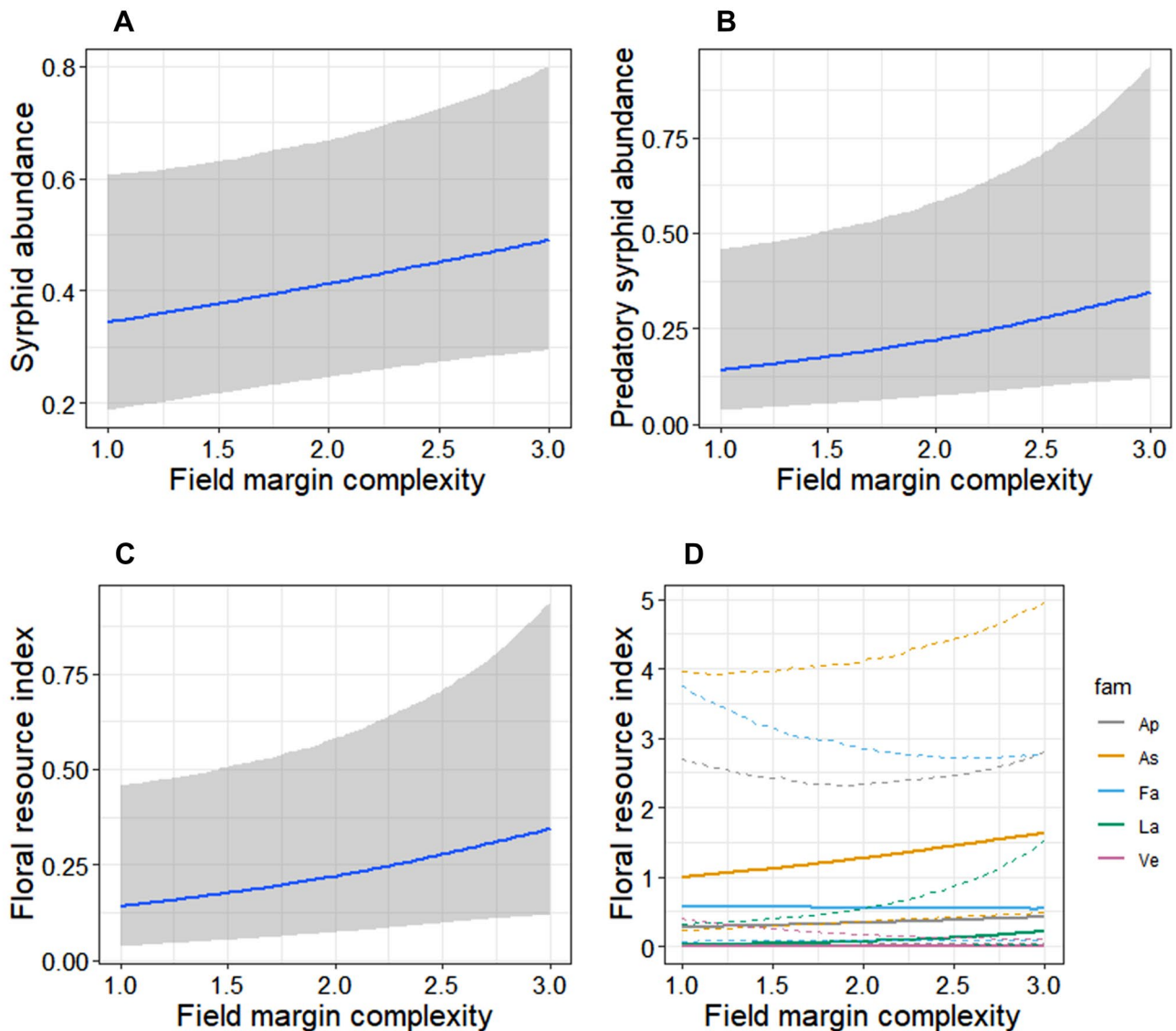
**Fig. 4** Contrasts of model predictions of the effect of field margin component types on syrphid abundance (**A**), predatory syrphid abundance (**B**), and floral resource index (**C** and **D**). *D* ditch; *GS* grass strip; *S* shrub; *TE* tree. *Ap* Apiaceae; *As* Asteraceae; *Fa* Fabaceae; *La* Lamiaceae; *Ve* Verbenaceae.  $\Delta$  Syrphid abundance: differences in

syrphid abundance between adjacent land-use types;  $\Delta$  Predatory syrphid abundance: differences in predatory syrphid abundance between adjacent land-use types;  $\Delta$  Floral resource index: differences in floral resource abundance between adjacent land-use types. Error bars indicate the credible intervals

## Discussion

In this study, we demonstrated that floral resource abundance, field margin component type, and adjacent land-use type had an effect on syrphid abundance either directly or indirectly in organically farmed agricultural systems. Field margin component type played a role in determining syrphid abundance independently of floral resource availability. Similarly, Pfister et al. (2017) found a greater syrphid abundance in hedgerows than in grassy margins in Germany.

This may be due to other resources offered by woody habitats, such as a habitat for overwintering, for ovipositioning, and for shelter, which may be exploited by syrphids (Lewis 1969; Almohamad et al. 2009; Ramsden et al. 2015). Furthermore, microclimatic conditions may differ between hedgerows and grassy margins. For example, temperature may differ between them, and hedgerows may act as a wind-break and provide shade in summer (Marshall and Moonen 2002; Sánchez et al. 2010). The activity of flies in general is dependant on temperature, and they reduce their activity



**Fig. 5** Model predictions of the effect of field margin complexity on syrphid abundance (A), predatory syrphid abundance (B), and floral resource index (C and D). *Ap* Apiaceae; *As* Asteraceae; *Fa* Fabaceae;

*La* Lamiaceae; *Ve* Verbenaceae. The width of the shaded area and the dotted lines represent the credible intervals

when the weather becomes too warm (Inouye et al. 2015). The number of syrphids observed in our study decreases after June which may be due to an increase in temperature which may have led to a narrower daily foraging time span or a local migration of syrphids to the adjacent forest. Syrphids are particularly attracted to humid habitats which could explain why the models constantly estimated a greater abundance of syrphids in the ditch component than in grass strips (Ssymank et al. 2008). Ditches offer water which is an important resource for syrphids in terms of consumption. Pfister et al. (2017) found that the presence of watercourses in the habitat is an important factor in increasing the abundance of predatory flies. Many syrphids of the

Eristalinae sub-family use structures which can hold water as breeding sites (Miranda and Rotheray 2018). More studies need to be conducted to determine how differences in field margin types may impact service provisioning for syrphids other than floral resource provisioning. Differences in syrphid abundance between field margins could also be due to the presence of specific plants since herbaceous vegetation composition in field margins can be influenced by the field margin component type (Blaix and Moonen 2020). Lagerlöf et al. (1992) found that syrphids had a preference for ditches over other herbaceous field margins. They suggested that the presence of flowers from the Apiaceae and Asteraceae families renders the ditch a suitable habitat as syrphids are



particularly attracted to flowers of those families. We show similar results with Apiaceae and Asteraceae flowers found in greater numbers in ditches although we were not able to show a clear correlation between syrphid abundance and the floral resource index of those two botanical families. Although there was little difference in flower abundance between ditches and grass strips, more Asteraceae flowers were found in ditches than trees which may have led to more syrphids being found in ditches than in the tree component.

Adjacent land-use type can be considered as an indication of field margin management. Field margins adjacent to roads were managed intensively with vegetation mowed often, and the trees trimmed and ditches cleaned at least once a year. Field margins adjacent to cropped fields were also often mowed to facilitate the access of agricultural machinery, while field margins adjacent to the grazed fields were less often mowed. In terms of the direct impact of land use, unpaved roads can be considered as a disturbed habitat and the passing of vehicles, at times, created a visible layer of dust on the vegetation, which can have a chemical and physical impact on vegetation and, therefore, may impact the floral resource available for syrphids (Farmer 1993). The cropped fields offered potential oviposition sites for syrphids with the possible presence of pests offering a resource to predatory larvae, especially since the sampled cropped fields were in a low-input managed site with infrequent tillage (Almohamad et al. 2009). The grazed fields contained not only horses but also many deer and boars as, unlike the cropped fields, little effort was put in place in preventing the wild animals from entering the fields. This, in places, led to visible disturbance of the ground and vegetation, with large patches of bare ground, which seemed to have negatively impacted vegetation growth and persistence in the margin and, possibly, the resources the vegetation offered to syrphids. These facts help in interpreting the effect of adjacent land-use type on syrphid abundance. The cropped fields had a more positive effect on syrphid abundance in adjacent field margins than the unpaved roads in both a direct and indirect manner. The direct effect may not be due to the provision of oviposition sites since no differences in predatory syrphid abundance in field margins was detected between those adjacent to cropped fields and those adjacent to a road. Instead, the difference may be due to margins adjacent to the unpaved roads being more disturbed than the ones adjacent to cropped fields, due to the dust raised by vehicles which settles on the vegetation. Adjacent land-use type also indirectly influenced syrphid abundance with field margins adjacent to cropped fields providing more floral resource than field margins near grazed fields or roads. It is possible that the activity of animals, both wild and domesticated, had a greater disturbance on flowering vegetation in field margins than farmer interventions, especially since no or little inputs were used in the fields and tillage was infrequent. Indeed,

the negative effect of livestock density on flower abundance through trampling and grazing has been found elsewhere (Nolte et al. 2013; Tadey 2015). These results may differ in conventionally managed farming systems where the negative effect of farming practices may be greater than the negative effect of animal trampling or grazing.

Field margin complexity, in terms of the number of different types of field margin components present in margins, was found to have little effect on syrphid abundance. It was thought that complex field margins could provide a diversified habitat which would lead to a greater diversity of resources (Cole et al. 2017). It is possible that at the field margin scale, habitat diversity is not as important as at the farm scale. Another explanation can be that the functionality of one field margin component, in this case the ditch, is more important for increasing syrphid abundances than the small-scale diversity that characterises complex field margins, supporting the suggestion that not in all situations does diversity result in a higher ecosystem service expression and sometimes a high bio-functionality is more efficient (Moonen and Bärberi 2008). It is also possible that the effect of complexity is not apparent as it may be partly masked by the other field margin variables. We did not have enough field margin replicates to develop a completely balanced design with all variables entirely independent of the others. Further studies may be needed to determine if field margin complexity can impact floral resources and syrphid abundance.

Floral resource availability has been found to influence insect abundance in other studies, and we observe a similar result in this study (Ramsden et al. 2015; Fowler et al. 2016; Cole et al. 2017). It also has been demonstrated that the abundance of floral resource alone is not sufficient to attract syrphids and that certain floral characteristics such as morphology play a key role (Klecka et al. 2018). Syrphids are considered as generalists although specific floral preferences associated with corolla length, flower shape, and colour have been reported (Branquart and Hemptinne 2000; van Rijn and Wäckers 2016; Klecka et al. 2018). Syrphid preferences for flowers belonging to certain families are likely due to differences in these flower traits. These preferences may not be easily apparent at the family or even at the genus level due to different preferences between syrphid species (Speight et al. 2015). A study on the community structure of syrphids and how it is determined by flower type is needed to elucidate these preferences. This was not possible in this study due to the sampling technique used. Syrphid observational surveys allow for recording of specimens at the genus level but many species need to be captured in order to be identified. The use of malaise traps would be more appropriate for studying syrphid community structure; however, these are costly and their use in the study site was not feasible due to the presence of boars and deer which are known to destroy these traps (Burgio et al. 2013). This was also confirmed by a trial

where we positioned overwintering traps in the field margin components (similar to Raymond et al. 2014), but many of the traps were destroyed by wild boars. When considering all syrphids (predatory and non-predatory), syrphid abundance increased with increasing floral resource abundance with no clear increase when individual botanical families were analysed, which can either be due to syrphids being generalists or the presence of more specialised species in the community with a variety of flower preferences among them. The influence of floral resource index on predatory syrphids was not as strong as its influence on general syrphid abundance. This could be the consequence of higher errors in estimates due to lower counts as a result of the exclusion of observations of non-predatory syrphids. Syrphinae, a sub-family generally considered to be predators as larvae, are thought to prefer actinomorphic flowers such as Asteraceae flowers (Branquart and Hemptinne 2000). However, we did not find predatory syrphids to be correlated with any of the individual botanical family floral resource index. It is possible that we lacked the data to investigate such relationships. Indeed, we only have data for one year, and sampling was spread out from Spring to the end of Summer. Focusing sampling efforts when floral resources are at their highest (June, July, and August in our study site) may help in acquiring enough data to distinguish syrphid preferences. It is possible that flower parameters which are not captured by division of flowers in botanical families could be important for the capacity of flowers to attract syrphids. Fowler et al. (2016) found that nectar quality and quantity produced by flowers were positively correlated with Hymenoptera flower visits. Nectar accessibility has also been found to influence syrphid abundance in field margins, while flower size preferences have been observed for *Episyrphus balteatus* de Geer (Sutherland et al. 1999; van Rijn and Wäckers 2016). This information along with pollen quantity and quality could complement measurement of floral resources in future studies on drivers of syrphid abundance or preferences.

## Conclusion

As expected, floral resource abundance played an important role in increasing the number of syrphids in field margins. This underlines the importance of increasing the abundance of flowers in agroecosystems, whether by including semi-natural habitats in the system or letting spontaneous vegetation grow. Furthermore, field margin characteristics also played an important role in determining syrphid abundance. This provides an opportunity to enhance syrphid populations by manipulating semi-natural habitats and land use in agroecosystems. Field margins that are structurally different to fields can provide more resources than grass strips. Our data show that syrphids have preferences for field margins with a

ditch and margins near less disturbed areas such as low-input cultivated fields. This information can support farmers who are looking for ways to increase the habitat suitability of their farmland for syrphids in organic or low-input farming settings. Further research is needed to identify which non-floral resources important to syrphids, such as overwintering sites, are associated with field margin characteristics.

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## Declarations

**Competing interests** The authors have no competing interests to declare that are relevant to the content of this article.

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