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Flowering fields, organic farming and edge habitats promote diversity of plants and arthropods on arable land

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Abstract

1. Increased farming intensity led to massive declines across multiple farmland taxa. In Europe, measures introduced to counteract these losses include those considered agronomically productive, such as organic farming, as well as those that support no direct production of crops, such as non-crop flowering fields in conventional farming systems.
2. We studied biodiversity effects of non-productive flowering fields managed under conventional farming compared to both an organically managed cereal mono-crop (organic winter spelt fields) and a flowering mixed-crop (organic lentil mixed-crop fields) as well as conventionally managed winter wheat fields, which served as control crop. These four crop-use types were studied on six sites over 3 years (17 sites in total) to assess their impact on the activity density (cover for plants), species richness and community composition of wild plants, carabids, spiders, butterflies and wild bees.
3. Species richness of wild plants was highest under organic farming and at field edges when compared to the interior. In the case of carabids and spiders, species richness was highest at the field edges, but there was no difference between the four crop-use types. In contrast, activity density and species richness of butterflies and wild bees responded only to flowering crop-use types, showing no edge effects. Arable land cover in 500 m buffer area also affected community composition of all taxa, with the exception of spiders, but had only minor effects on activity densities and species richness.
4. *Synthesis and applications*. Our findings underline that there is no single best measure to promote biodiversity on arable land. Instead a mosaic of non-productive and productive measures such as conventional flowering fields, organic crops and field edge habitats might be more appropriate to support the regional species pool in arable-dominated landscapes. To support a range of complementary biodiversity-promoting farming practices, agricultural policy should foster the co-ordination and collaboration between multiple farmers within the same region by covering additional costs for coordination and prioritizing collaborative schemes.

KEYWORDS
agri-environment schemes, butterfly, carabid beetle, edge effect, farmland biodiversity, landscape structure, spider, wild bee

1 | INTRODUCTION

Globally as well as in Europe, increased farming intensity has led to massive declines across multiple taxa in terms of their biomass, abundance and species richness (Sánchez-Bayo & Wyckhuys, 2019; Stoate et al., 2009). To counteract this loss, the European Union (EU) established agri-environmental schemes (AESs) to financially compensate farmers for environment-friendly practices. Although AESs are the highest biodiversity conservation-related expenditure in the EU, broad debates about their cost efficiency have been launched (Kleijn et al., 2011) as farmland biodiversity continues to decline (Batáry et al., 2015; Pe'er et al., 2014). It remains a key policy challenge for the future to establish AESs with higher biodiversity gain. While redesigning the AES concept remains problematic, it is likely that relatively minor changes in current implementation policy that foster increased biodiversity conservation quality at the field level and higher complementarity at the landscape level could potentially provide huge benefits for farmland biodiversity.

To enhance biodiversity on arable land, non-productive measures exist, such as annual flowering fields (fallow arable land planted with flowering forbs), which remove whole fields from crop production. In contrast, there are also productive approaches, combining continued crop use and biodiversity upgrades on the same area, for example, organically farmed arable crops. Flowering fields are applied in a number of countries in Central Europe as part of their AES programs (e.g. England, Germany, Switzerland; Dietzel et al., 2019; Haaland et al., 2011). Annual establishment of flowering field is often preferred by farmers, as it allows better weed and pest control and greater flexibility for farm management. Several studies have reported positive effects on flower-visiting and other arthropod groups (Dietzel et al., 2019; Haaland et al., 2011). In contrast, organic farming, which is supported by almost all countries in Central and Western Europe in their AESs (Batáry et al., 2015), can also benefit biodiversity through reduced farming intensity (Bengtsson et al., 2005; Tuck et al., 2014). To date, direct comparisons of biodiversity effects between non-productive flowering fields and production-integrated measures, such as organically farmed crops, are rare (but see Mader et al., 2017).

Furthermore, there might be differences between different taxonomic and functional species groups in response to the implementation of annual flowering fields (Dietzel et al., 2019; Haaland et al., 2011) or crops under organic management (Batáry et al., 2012; Tuck et al., 2014). Annual flowering fields create mass-flowering habitats, which are likely to be beneficial to highly mobile flower-visiting arthropods such as bees, butterflies and hoverflies, which are able to exploit this resource rapidly. Less mobile species, such as ground-dwelling carabids and spiders could also benefit from flowering fields compared to conventional mono-crops due to reduced farming intensity, increased vegetation heterogeneity and wild plant resources for their prey. But long-term applications of less intensive farming practices such as organic farming might affect less mobile taxa more strongly than short-term conversion of conventional crops into annual flowering fields, as these taxa may take significantly longer to colonize such annual habitats compared with bees and butterflies that are able to forage over many kilometres (Westphal et al., 2006; Woodcock et al., 2012). Organic farming in the EU includes a permanent conversion to less intensive farming practices (The EU Commission, 2008; The EU Council, 2007), such as permanent ban of chemical pesticides and mineral fertilizers and reduced crop plant density (Fischer et al., 2018). Long-term effects of organic farming were seen to promote carabid species diversity (Irmler, 2018; Schröter & Irmler, 2013) and spider abundance (Birkhofer et al., 2008).

In addition to local farming practice effects within crop fields, the composition of the surrounding landscape may be expected to affect large and mobile taxa more strongly than small and less mobile species groups (Concepción et al., 2012; Tscharntke et al., 2012). Indeed, such differences in mobility may also impact arthropod diversity at the scale of individual fields, with field edges having more diverse invertebrate populations than the interior in response to reduced management (Batáry et al., 2012), immigration from neighbouring habitats (Woodcock et al., 2016) and increased habitat heterogeneity (Bianchi et al., 2006). Without simultaneous assessments of the responses of different taxa and functional groups to flowering fields and organic crops, it is not possible to assess if these have different effects on arable field biodiversity.

In this study we compared the effects of an AES that established flowers at a field scale under conventional management (annual flowering field: seed mixture of flowering forbs sown on fallow land) to both an organically managed cereal mono-crop (organic winter spelt) as well as an organic lentil mixed-crop for the promotion of biodiversity on arable land. These were compared to a control crop of conventionally managed winter wheat. For these four crop-use types, we measured biodiversity responses by the activity density (cover for plants), species richness and community composition of five functionally different taxa, which were wild plants (primary producers), carabids and spiders (ground-dwelling predators), and butterflies and wild bees (flower-visiting arthropods). We hypothesized that (a) flower-visiting arthropods would be the most abundant and species rich in conventional flowering fields as they are expected to provide the highest amount of flower resources. (b) We expect that plants and ground-dwelling arthropods benefit more strongly from organically managed mono-crops and lentil mixed-crops in response to long-term applications of less intensive farming practices. (c) In organic farming systems, lentil mixed-crops would promote both the activity density and species richness of flower-visiting arthropods to a greater extent than mono-crops due to the increased flower resources. (d) Field edges would support higher activity densities and species richness for all taxa probably caused by spill-over effects from neighbouring habitats, and (e) species richness of all taxa would be negatively related to increased arable land cover in the surrounding landscape independent of crop-use type due to reduced compositional heterogeneity at the landscape level.

2 | MATERIALS AND METHODS

2.1 | Study area and design

Study sites were located in the UNESCO Biosphere Reserve Swabian Alb in southwest Germany. Terrain elevation of the Swabian Alb ranges between 460 and 860 m a.s.l. with a mean annual temperature of 6–7°C and a mean annual precipitation of 700–1,000 mm (Fischer et al., 2010). Soils are shallow, stony and poor luvisols or cambisols on a bedrock of White Jurassic limestone (soil type according to IUSS Working Group WRB, 2015).

We selected arable fields farmed under four crop-use types: (a) conventional winter wheat *Triticum aestivum* (L.) representing a control; (b) conventional flowering field (sown seed mixture of 15–18 species including *Centaurea cyanus* L., *Helianthus annuus* L. and *Phacelia tanacetifolia* Benth.: see Appendix S1 in Supporting Information); (c) organic winter spelt (*T. aestivum* subsp. *spelta* L.) representing an organic cereal control; (d) and organic lentil (*Lens culinaris* Medic.) intercropped with a supporting crop (cereal or camelina *Camelina sativa* (L.)). We sampled each crop-use type on six study sites per study year ($n = 6$) and repeated the sampling over 3 years from 2016 to 2018 (4 crop-use types × 6 sites (5 sites in the last year) × 3 years). Each study site comprised four crop-use types within the communal district of a village. Two study sites were selected in 3 years, two study sites in 2 years and seven sites within 1 year resulting in 11 unique study sites. If a study site was selected for more than 1 year, we did not use the same study fields again but selected another field within that study site due to crop rotation (except one flowering field sampled over 2 years). The mean field size was 2.3 ± 0.2 ha (ha; mean ± *SEM*) with similar field sizes between crop-use types (winter wheat: 2.5 ± 0.4 ha; flowering field: 2.4 ± 0.4 ha; winter spelt: 2.1 ± 0.2 ha; lentil mixed-crop: 2.1 ± 0.4 ha) and varied between study sites from 1.4 ± 0.3 to 3.9 ± 1.1 ha. The mean minimum distance between study fields within a study site was much smaller (0.7 ± 0.1 km) than the mean minimum distance between study sites (4.6 ± 0.7 km), which is in accordance with the spatially nested study design.

To standardize landscape context, soil and climate conditions, we blocked the four crop-use types in close spatial proximity, that is, spatially nesting of the four crop-use types per study site (Appendix Figure S1 depicts the study design). Crop-use types within each study sites were further nested in pairs, because there were two farmers per study site, each of them managing two crop-use types (conventional farmer: winter wheat and flowering field; organic farmer: winter spelt and lentil mixed-crop). The four crop-use types per study site were also nested per crop type (flowering crop (flowering field, lentil mixed-crop) versus cereal crop (winter wheat, winter spelt)). Nesting of crop-use types was crossed over both nesting factors (farmer, crop type) as each farmer managed one flowering and one cereal crop. The result was a cross-nested study design.

2.2 | Farming practices

The four crop-use types differed in management (conventional vs. organic farming), crop type (cereal vs. flowering plant) and sowing time (autumn vs. spring sown crop; Table 1; Appendix S2). Details

TABLE 1 Farming practice characteristics, achieved yield and subsidy amount of studied crop-use types sampled in 2016, 2017 and 2018 (mean ± *SE*; $n = 68$). Results (*F*-value of ANOVA table) of linear mixed-effects models are given to test for significant differences between crop-use types. Bold values indicate significant effect at $p < 0.05$

			Sowing date (calendar week)	Crops in rotation (number)	Fertilizer (kg N/ha)[b]	Pesticide application (number)	Mechanical weeding[c] (number)	Yield (dt/ha)	Subsidy by AES[d] (€/ha)
Conventional	Winter wheat ($n = 17$)		40.3 ± 0.3 (early October)	3.9 ± 0.2	184.8 ± 10.6	2.1 ± 0.3	0.1 ± 0.1	70.3 ± 2.7	None
	Flowering field ($n = 17$)		18.2 ± 0.2 (early May)	3.9 ± 0.2	1.4 ± 1.4	None	None	None	710
Organic	Winter spelt ($n = 17$)		40.9 ± 0.2 (early October)	5.9 ± 0.2	61.9 ± 16.0	None	1.7 ± 0.2	31.5 ± 1.4	230
	Lentil-mixed-crop ($n = 17$)		14.7 ± 0.3 (mid of April)	5.9 ± 0.2	7.0 ± 4.1	None	0.2 ± 0.1	11.8 ± 1.9	230
Model[a]	*F*-value	Year	1.0	**13.6**	0.5	0.3	0.5	3.1	
		Crop	**2,458.9**	**15.8**	**65.8**	**57.7**	**23.4**	**365.2**	

[a]All models were fitted with normal distribution.

[b]Square root transformed values used for model calculation.

[c]Only weeding between sowing and harvest counted.

[d]Fixed amount according to the agri-environmental scheme (AES) of the federal state Baden-Württemberg between 2015–2020.

about flowering fields and lentil mixed-crops can be found in the Supporting Information Appendix A1 and are also described in Gayer et al. (2019). Cereal crops (winter wheat and winter spelt) were sown in the previous autumn, whereas flowering crops (flowering field, lentil mixed-crop) were spring sown. Only winter wheat was treated with herbicides, fungicides, insecticides or mineral fertilizers. Mechanical weed control was only substantially applied in organic winter spelt. Organically managed crop-use types had a more diverse crop rotation and more perennial crops in rotation (mainly clover-mixtures; Table 1; Appendix S2). Tillage practice consisted of inversion tillage, but in some cases minimum tillage practices were applied (32% of all study fields). This latter management was more frequently in winter spelt (53%). For further details about farming practices and vegetation characteristics, see Supporting Information Appendix A1 and Appendix S3. To assess field-specific management, we carried out personal interviews with farmers using a standardized questionnaire (n = 35; for details about the questionnaire, see Supporting Information Appendix A1).

2.3 | Sampling of organisms

All taxa were sampled at the edge and interior within each study field (sampling design see Appendix Figure S3). We sampled wild plants and ground beetles (Carabidae) over a 3-year period from 2016 to 2018 (n = 17 per crop-use type) and spiders (Araneae), butterflies (diurnal Lepidoptera) and wild bees (Hymenoptera, Apidae, Apiformes) during 2 years (2017–2018, n = 11).

We surveyed plants in five plots (5 × 1 m in size and 5-m distance between them) per transect (edge vs. interior transect = 10 plots per study field; Appendix Figure S3). For each plot, we estimated cover per wild plant species (including sown species in flowering fields) according to the extended Braun–Blanquet scale. In 2016, we surveyed each plot once between 25 June and 4 August, while in 2017 and 2018 we surveyed each plot three times (in mid-June, early July and late July).

We sampled carabids and ground active spiders using pitfall traps with a diameter of 7.2 cm and filled with 30% ethylene glycol as trapping fluid. We placed five traps along each transect (one edge one interior transect per study field) in a distance of 10 m between traps (2 × 5 traps per study field, Supporting Information Appendix A2, Appendix Figure S3). Traps were opened for 10 consecutive days and kept closed for the following 10 days. We conducted three sampling rounds between 15 June and 3 August 2016, two sampling rounds between 15 June and 16 July 2017 and two sampling rounds between 17 June and 19 July 2018, which amounts to a total number of 70 trapping days.

We surveyed butterflies by walking four transect lines (75 × 4 m per transect). Two transects were located along field borders and two along the diagonal in the field interior (see Appendix Figure S3). Each transect was walked at a uniform speed within a standardized duration of 5 min between 09:00 a.m. and 05:00 p.m. on sunny days with limited cloud cover (temperatures >15°C). Wind speed during counts was <20 km/hr. In 2017, we conducted five survey rounds (late May, early June, mid-June, late June and early July) and in 2018 three survey rounds (mid-June, mid-July and late July).

We surveyed bees along two transects of 50 m per study field. Timing of sampling and weather conditions were the same as for the butterflies. One transect was designated along the field border, the other 15–20 m parallel to it starting at the field border and running 50 m in the interior of the study field (Appendix Figure S3). We conducted five point count stops of 5 min along each transect with 10-m distance between point count locations. Per point count we surveyed all bees in a radius of 2 m. In 2017, we conducted three survey rounds (late May, mid-June and mid-July) and in 2018 four survey rounds (mid-June, early July, mid-July and late July). Wild bees and butterflies were sampled on different sampling transects but within a distance of 50 m to the pitfall trap transects (except three cases with less than 100-m distance). For landscape analysis (see Section 2.4), a common set of land cover data (surrounding landscapes) was used for all species groups. For further details about the species survey, see Supporting Information Appendix A2. Lists of all sampled species and their respective number of individuals can be found in Appendix S4–S8.

2.4 | Landscape analysis

We analysed land cover types using the Geographical Information System ArcGIS 10.2.2 (1999–2014 ESRI Inc.) and data from an area-wide classification of habitat complexes of the Biosphere Reserve Swabian Alb (see Schlager et al., 2013). There was one study site outside the borders of the Biosphere Reserve Swabian Alb. Here we used aerial photographs, official digital thematic maps (ATKIS DTK 50) and official biotope mapping data of Baden-Württemberg (URL: http://udo.lubw.baden-wuerttemberg.de/public/, accessed 08.02.2019). We measured land cover types in a radius of 500 m around the midpoint of each interior transect used for pitfall trapping (one landscape measure per study field), therefore a common set of land cover data was used for all species groups. We used 500-m radius following comparative studies (Toivonen et al., 2015), because distances between study fields were small (0.7 ± 0.1 km) due to the spatially nested study design.

We used arable land cover as explanatory landscape variable as it was the most abundant land cover type in the study area with 56.5 ± 1.9% of total cover and a distinct gradient between study fields ranging from 15.7% to 83.0%. We calculated Shannon index as a habitat diversity measure from the percentage cover of arable land, intensively managed grassland, extensive grassland, copses, forest, wetland and urban elements. Arable land cover was negatively correlated with habitat diversity (Shannon index; $r_{142} = -0.83$, $p < 0.001$).

2.5 | Statistical analyses

First, for describing differences in farming- and vegetation characteristics among crop-use types and study years (Table 1), we performed a linear mixed-effects models (LMM) using the LME4 package

(Bates et al., 2014) of the R 3.4.2. software (R Development Core Team, 2017). We included 'crop-use type' and 'year' as fixed factors and 'site', 'farmer' and 'crop type' (cereal vs. flowering crop) as nested random factors into the model by using the following R-syntax:

"lmer(y ~ 'Crop-use type' + 'Year' + (1|'Site'/'Farmer') + (1|'Site'/'Crop type')".

Second, in this and all subsequent LMMs we checked if their prerequisites are given by testing for normal distribution of model residuals by investigating normal quantile–quantile plots and plotting model residuals against fitted values to visualize error distribution and check for heteroscedasticity. For testing independence of 'arable land cover' from 'crop-use type' and 'transect' (field edge vs. interior), we also used the above R-syntax with 'arable land cover' as response variable and 'crop-use type' and 'transect' as single and interacting fixed effects.

Third, for testing effects on abundance and species richness for all taxa, we pooled data of all traps and survey periods per study transect for all taxa separately ($N = 136$ for carabids, plants; $N = 88$ for spiders, butterflies, wild bees). Data for plant cover, activity density and species richness of all taxa were ranged between 0 and 1 to get comparable effect sizes between taxa. Plant cover data were logit transformed. LMMs were calculated for analysing effects of 'arable land cover', 'crop-use type', 'transect' and their interactions on the activity density (=number of individuals for arthropods, cover for plants) and species richness (=number of species; excluding plant species of the sown seed mixture for flowering fields). Separate models were run for each taxon and response variable. The predictors 'year', 'farmer', 'site' and 'crop type' were included as nested random effects in the model. The predictors 'arable land cover', 'crop-use type' and 'Transect' were included as single and interacting fixed effects in the model (indicated by "^3") according to the R-syntax:

"lmer(y ~ ('Arable land cover' + 'Crop-use type' + 'Transect')^3 + (1|'Year'/'Site'/'Farmer') + (1|'Year'/'Site'/'Crop type')".

For the above described LMMs, we used model selection and averaging, based on the multi-model approach of Burnham and Anderson (2002), by calculating all models nested in the global model (i.e. 19 models) using the dredge function of the MuMIn package (Barton, 2017) and compared candidate models according to Akaike's information criteria, corrected for small sample sizes (AICc). The models with <2 ΔAICc of the best model were used for model selection applying the command model.avg of the MuMIn package, as such models are considered to be as good as the best model (Symonds & Moussalli, 2011). We applied the natural average method to avoid shrinkage towards zero (Grueber et al., 2011).

To study effects on community composition, we used multivariate ordination analyses by performing a redundancy analysis (RDA) which uses a canonical probability distribution and assumes linear relationships between variables. We calculated RDAs using the species-abundance matrix with 'arable land cover', 'crop-use type' and 'transect' as constraining factors and 'year', 'Site' and 'farmer' as conditional factors to account for the nested study design. We transformed species-abundance data with the Hellinger transformation prior to the RDA (Legendre & Gallagher, 2001). We calculated permutation tests based on 999 permutations to test for significant effects on community composition. We used the vegan package in R for RDA (Oksanen et al., 2015). We also tested for similarity of species composition between 'crop-use type' using a nonparametric permutational multivariate analysis of variance (PERMANOVA), as well as a multivariate dispersion test (for details about similarity analysis see Supporting Information Appendix A3).

3 | RESULTS

3.1 | Crop-use type effects

Wild plant cover and richness was lower in conventional winter wheat compared to all other crop-use types (Table 2; Figures 1a and 2a). Wild plant richness was higher in both the organic (winter spelt, lentil mixed-crop) compared to conventional (winter wheat, flowering field) managed crop-use types. Further, lentil mixed-crop had higher wild plant cover than flowering fields and winter spelt due to higher cover in the field interior. Carabid activity density was lower in conventional winter wheat than all other crop-use types, although effects of lentil mixed-crop on carabid activity density were less pronounced (Table 2; Figures 1b and 2b). Crop-use type had minor effects on spider activity density and species richness of spiders and carabids (Figures 1c and 2b,c). Both flowering crop types (flowering fields, lentil mixed-crops) had higher butterfly activity densities and species richness compared to both cereal crop types (winter wheat, winter spelt; Figures 1d and 2d). There also was higher butterfly activity density in organic winter spelt compared to conventional winter wheat. Flowering fields had much higher wild bee activity densities and species richness compared to all other crop-use types (Figures 1e and 2e). Lentil mixed-crops had higher wild bee species richness than winter wheat and winter spelt.

Crop-use type had significant effects on species composition for all taxa and explained the highest amount of variation among the three explanatory variables for all taxa (Table 3). Community composition was significantly different between crop-use types for all studied taxa (Appendix S9). The variability of species composition (multivariate dispersion) did also significantly differ between crop-use types, except for carabids and spiders (Appendix S9). The similarity of species communities was highest for carabid as well as spider assemblages, and to a lesser extend for wild plant, butterfly and bee communities (Figure 3). Butterfly, as well as wild bee communities, differed more strongly between crops of different crop types (flowering vs. cereals crops) than between crops of the same crop type (Figure 3d,e).

3.2 | Edge and landscape effects

Wild plant cover was higher at the edge than in the interior of crop fields (Table 2), but these differences were more pronounced in both

TABLE 2 Effects of arable land cover (% in 500 m), crop-use type (winter wheat (WW) versus flowering field (FF) versus winter spelt (WS) versus lentil mixed-crop (LMC)) and transect (edge (E) versus centre (C)) on activity density and species richness of five taxa. Results were calculated by multi-model averaging of linear mixed-effects models. Pairwise comparisons between crop-use types were derived by refitting the model with different baseline levels. Importance of predictor variables, parameter estimates with standard error (*SE*) and *t*/*z*-values. Only models with <2 ΔAICc of the best model are shown. Bold values indicate effect at $p < 0.05$

Response	Taxa[a]	Explanatory[b]	Relative importance [%]	Multi-model estimate[c]	±*SE*	*t*/*z*-value[d]
Cover[e]	Wild plants[f] (0.31/0.73;2)	Crop-use type (FF/WW)	100	0.111	0.0178	**6.200**
		Crop-use type (WS/WW)		0.099	0.019	**5.229**
		Crop-use type (LMC/WW)		0.167	0.02	**8.494**
		Crop-use type (WS/FF)		−0.012	0.02	0.626
		Crop-use type (LMC/FF)		0.056	0.019	**2.927**
		Crop-use type (WS/LMC)		−0.068	0.018	**3.791**
		Transect (E/C)	52	0.037	0.012	**3.142**
Activity density	Carabids (0.13/0.59;1)	Crop-use type (FF/WW)	30.7	0.107	0.046	**2.319**
		Crop-use type (WS/WW)		0.182	0.047	**3.853**
		Crop-use type (LMC/WW)		0.102	0.056	1.806
		Crop-use type (WS/FF)		0.075	0.056	1.334
		Crop-use type (LMC/FF)		−0.005	0.047	0.107
		Crop-use type (WS/LMC)		0.080	0.045	1.758
	Spiders (0.17/0.54;1)	Transect (E/C)	16.3	−0.082	0.044	−1.848
	Butterflies (0.52/0.77;2)	Crop-use type (FF/WW)	99	0.357	0.048	**7.396**
		Crop-use type (WS/WW)		0.112	0.053	**2.096**
		Crop-use type (LMC/WW)		0.406	0.059	**6.823**
		Crop-use type (WS/FF)		−0.252	0.06	**−4.043**
		Crop-use type (LMC/FF)		0.049	0.052	0.919
		Crop-use type (WS/LMC)		−0.294	0.047	**6.164**
		Arable land cover	33	−0.228	0.123	1.826
	Wild bees (0.66/0.89;1)	Crop-use type (FF/WW)	100	0.432	0.033	**13.136**
		Crop-use type (WS/WW)		−0.013	0.041	−0.323
	Wild bees	Crop-use type (LMC/WW)		0.042	0.047	0.896
		Crop-use type (WS/FF)		−0.445	0.047	**−9.533**
		Crop-use type (LMC/FF)		−0.390	0.041	**−9.565**
		Crop-use type (WS/LMC)		−0.055	0.032	−1.709
Species richness	Wild plants (0.54/0.89;1)	Crop-use type (FF/WW)	100	11.11	1.811	**6.134**
		Crop-use type (WS/WW)		18.546	1.82	**10.188**
		Crop-use type (LMC/WW)		22.811	2.245	**10.160**
		Crop-use type (WS/FF)		7.436	2.245	**3.312**
		Crop-use type (LMC/FF)		11.701	1.82	**6.428**
		Crop-use type (WS/LMC)		−4.265	1.794	−2.377
		Transect (E/C)	100	10.485	0.864	**12.137**
	Carabids (0.28/0.52;1)	Transect (E/C)	100	0.178	0.028	**6.410**
	Spiders (0.34/0.53;1)	Transect (E/C)	100	0.203	0.030	**6.751**
	Butterflies (0.58/0.77;1)	Crop-use type (FF/WW)	100	0.319	0.037	**8.618**
		Crop-use type (WS/WW)		0.114	0.046	2.518
		Crop-use type (LMC/WW)		0.430	0.047	**9.063**
		Crop-use type (WS/FF)		−0.204	0.047	**−4.306**

(Continues)

TABLE 2 (Continued)

Response	Taxa[a]	Explanatory[b]	Relative importance [%]	Multi-model estimate[c]	±*SE*	*t*/*z*-value[d]
		Crop-use type (LMC/FF)		0.111	0.046	2.446
		Crop-use type (WS/LMC)		−0.316	0.036	**−8.696**
	Wild bees (0.72/0.82;1)	Crop-use type (FF/WW)	100	0.622	0.042	**14.848**
		Crop-use type (WS/WW)		0.056	0.042	1.336
		Crop-use type (LMC/WW)		0.251	0.046	**5.501**
		Crop-use type (WS/FF)		−0.567	0.046	**−12.4**
		Crop-use type (LMC/FF)		−0.371	0.042	**−8.873**
		Crop-use type (WS/LMC)		−0.196	0.042	**−4.700**

[a]All models were fitted with normal distribution (marginal/conditional R^2 value of full model; number of candidate models, Δ AIC < 2).

[b]Pairwise comparisons between crop-use types were derived by refitting the model with different baseline levels. The baseline level is indicated in parenthesis after the dash (e.g. '(FF/WW)': WW is used as baseline level for the model).

[c]Positive estimates indicate higher number, for example, higher wild plant cover in flowering fields (FF) versus winter wheat (WW).

[d]*T*-value when calculating linear mixed-effects models without model selection and averaging. This was necessary if only one model was left after model selection.

[e]For wild plants, mean plant cover data were used, for all other taxa the number of individuals were used.

[f]Logit transformed values were used for model calculation.

conventional managed crop-use types (winter wheat and flowering field) and absent in lentil mixed-crop (Figure 1a). Activity densities of carabids, spiders, butterflies and wild bees did not considerably differ between the field edge and interior (Figure 1b–e). Species richness of wild plants, carabids and spiders, but not of butterflies and wild bees, was higher at the edge than the interior of fields independent of crop-use type.

Transect position affected community composition of wild plants, carabids and spiders, but not of butterflies or wild bees (Table 3). Transect position explained high amount of variation (10.9%) for the community composition of spiders, but low amount for wild plants and carabids. Percentage of arable land cover did not affect the activity density or species richness of any taxa. It impacted the community composition of all taxa except spiders, but with a low share of explained variation.

4 | DISCUSSION

We found taxon-specific responses to a non-productive crop-use type (flowering field) and two productive crop-use types (mono- and lentil mixed-crop under organic management). Plants were best promoted by productive measures (both organic farmed crops), in particular from lentil mixed-crops, but also by field edges. Ground-dwelling arthropods most strongly benefited from field edges with little differences between non-productive and productive crop-use types, whereas flower-visiting arthropods mainly benefited from crop types offering enhanced flower resources, that is, flowering fields and lentil mixed-crops. Hence, annual abandonment of crop production in flowering fields did benefit specific taxa, but did not result in enhanced biodiversity compared to productive crops under organic management.

4.1 | Crop-use type effects

Responses to crop-use types were only partly in line with hypothesis (1) stating that flower-visiting arthropods are best promoted by flowering fields. Although flowering fields most strongly promoted wild bees, butterflies equally benefited from flowering fields and lentil mixed-crops. In contrast to hypothesis (2), ground-dwelling arthropods did not benefit from organic farming, whereas wild plants did benefit from it. Flowering fields had the highest flower cover (Appendix S3), including many mass-flowering forb species like phacelia *P. tanacetifolia* or borage *Borago officinalis* (L.), offering attractive pollen- and nectar sources for bees and butterflies (Haaland et al., 2011; Pywell et al., 2004; Warzecha et al., 2018). This might explain the observed positive effects on wild bees and butterflies.

Possibly, lentil mixed-crops had higher flower cover compared to both cereal crops (but only assessed in 2017, Appendix S3), which might have led to more wild bee species and butterfly species and individuals. This result confirmed hypothesis (3) that in organic farming systems flower-visiting arthropods can be promoted by cropping lentil mixed-crops. Positive effects of lentil mixed-crops were clearly more pronounced for butterflies than wild bees (Appendix S3). This may have been caused by stronger preferences of butterflies for native plants, in particular *Cirsium* spp. *Cirsium* spp. are among the most frequently visited flowers by butterflies, in particular for the most abundant species of this study such as *Pieris brassicae* L., *Pieris napi* L., *Pieris rapae* L. and *Maniola jurtina* L. (Appendix S7; Clausen et al., 2001; Dover, 1989; Lebeau et al., 2017), whereas short-tongued bee species are not well-adapted to the deep corollas of *Cirsium* spp. (Warzecha et al., 2018). Lentil mixed-crops had highest presence of thistles, especially *Cirsium arvense* Scop. (Appendix S4), making it a more attractive feeding habitat for butterflies than wild bees.

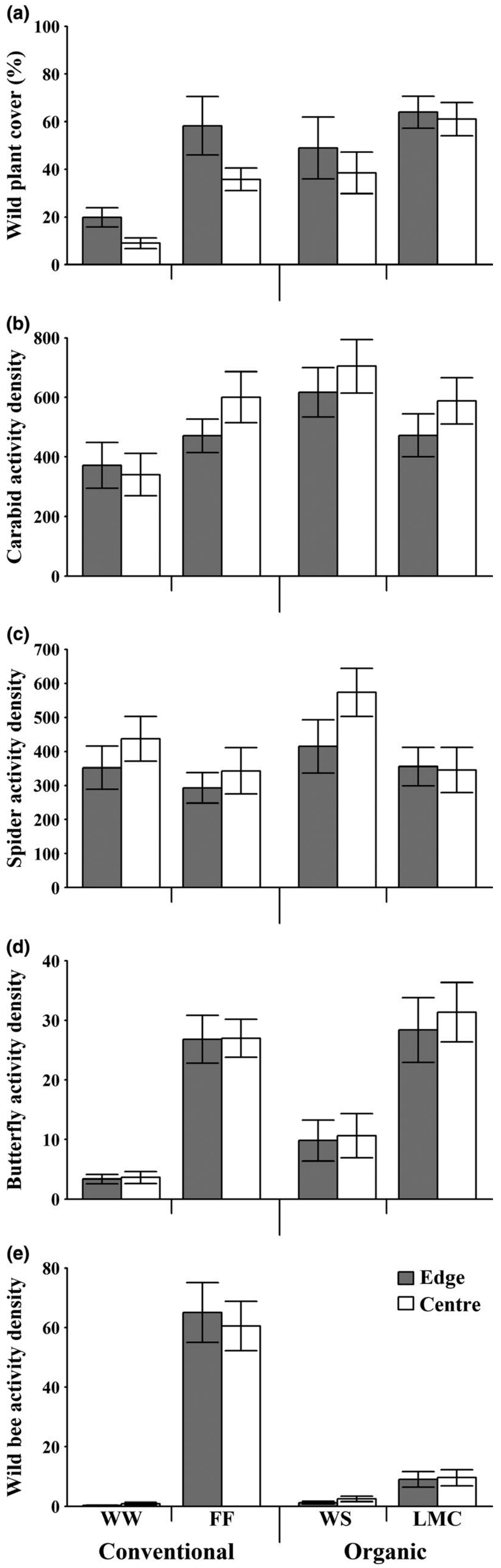

FIGURE 1 Effect of crop-use type (winter wheat [WW], flowering field [FF], winter spelt [WS], lentil mixed-crop [LMC]) and transect position (edge, centre) on wild plant cover (a) and activity density (number of individuals) of carabid beetles (b), spiders (c), butterflies (d) and wild bees (e). Bars are means ± *SE*

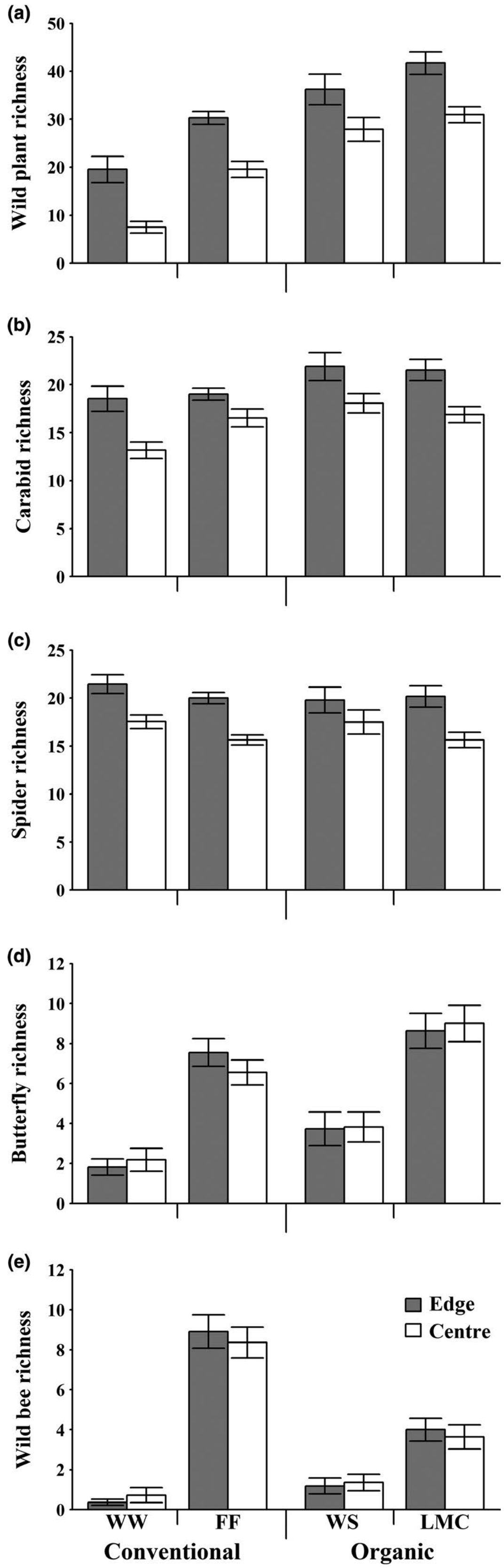

FIGURE 2 Effect of crop-use type (winter wheat [WW], flowering field [FF], winter spelt [WS], lentil mixed-crop [LMC]) and transect position (edge, centre) on species richness (number of species) of wild plants (a), carabid beetles (b), spiders (c), butterflies (d) and wild bees (e). Bars are means ± *SE*

TABLE 3 Results of an RDA to analyse the effects of arable land cover (% in 500 m), crop-use type (winter wheat, flowering field, winter spelt, lentil mixed-crop) and transect position (edge, centre) on community composition of five taxa. Percentage of explained variation, *F*- and *p*-values (bold if $p < 0.05$) are given

Taxa	Explanatory	Variation [%]	*F*	*p*
Wild plants	Arable land cover	1.794	2.887	**0.001**
	Crop-use type	11.87	6.369	**0.001**
	Transect	1.480	2.383	**0.002**
Carabids	Arable land cover	1.943	3.062	**0.002**
	Crop-use type	6.744	3.542	**0.001**
	Transect	3.983	6.277	**0.001**
Spiders	Arable land cover	1.839	2.114	0.054
	Crop-use type	11.068	4.241	**0.001**
	Transect	10.882	12.508	**0.001**
Butterflies	Arable land cover	2.671	2.759	**0.003**
	Crop-use type	7.367	2.537	**0.001**
	Transect	0.5119	0.529	0.937
Wild bees	Arable land cover	2.033	2.349	**0.018**
	Crop-use type	23.52	9.059	**0.001**
	Transect	0.440	0.509	0.898

Despite large differences in farming practice, crop-use type effects on carabids and spiders were small. In arable fields, spiders and carabid communities are dominated by agrobiont, mainly carnivorous and omnivorous species, which are adapted to regular disturbances and crop management (Gallé et al., 2018). Hence, these taxa might be less sensitive to differences in crop use. Additionally, the dominance of agrobiont species in the species community might have led to the observed low impact of crop-use type on species composition of those taxa.

Some other studies also did not find effects of organic farming on spider species richness (Mader et al., 2017) or carabid diversity (Fuller et al., 2005). Birkhofer et al. (2014) even stated that such predatory arthropods are losers under organic farming. Nevertheless, several studies found positive effects of organic versus conventional crops (Bengtsson et al., 2005; Tuck et al., 2014). For flowering areas, studies showed increased activity densities and species richness of carabids and spiders (Dietzel et al., 2019; Haaland et al., 2011), but Frank et al. (2012) showed that positive effects might depend on habitat age with increased beetle diversity and evenness in older flowering fields. Hence, positive effects of conventional flowering fields on carabids and spiders might have been more pronounced, if we had studied perennial instead of annual flowering fields.

4.2 | Edge and landscape effects

In contrast to hypothesis (4) expecting higher activity density and species richness at field edges, only plant cover and species richness of plants, carabids and spiders was higher at the field edge, whereas species richness of butterflies or wild bees, as well as the activity density of all taxa did not remarkably differ between the transects. The reasons may lie in the higher mobility of butterflies and wild bees and the similar flower cover between the field edge and interior (Appendix S3). But it may be also affected by different survey methods between those taxa, because survey transects for flower-visiting insects did start from the field edge and run into the field interior, whereas transects for plants and ground-dwelling arthropods were completely separated between the field edge and interior (Appendix Figure S3). Higher species richness of plants and ground-dwelling arthropod taxa at the field edge was also reported by other studies, for example, Batáry et al. (2012), due to the reduced pest and weed management (Marshall & Moonen, 2002), higher microhabitat heterogeneity and closer proximity of adjacent semi-natural habitats (Schirmel et al., 2016).

Last, our results did not confirm hypothesis (5) expecting a negative relation between species richness and increased arable land cover, because arable land cover had no effects on the activity densities or species richness of any of the studied taxa, although it had some minor effects on community composition with the exception of spiders. Other studies found landscape-moderated biodiversity effects within crop fields, but effects may differ between simple and complex landscapes with larger effects in intensively farmed agricultural landscapes (Batáry et al., 2011; Birkhofer et al., 2018). Our study area consisted of a small-scale agricultural landscape with small field sizes (about 2.3 ha) and a high cover of semi-natural habitats. Therefore, the amount of uncropped land as suitable source habitat might not be a limiting factor in the study area, which in turn might have neutralized differences in the amount of arable land in the surrounding landscape.

5 | CONCLUSIONS

Our results revealed that non-productive flowering fields, two productive crop-use types under organic management (winter spelt and lentil mixed-crops) as well as field edge habitats differently affect the various taxa within arable fields. Flowering fields were the most successful measure for promoting flower-visiting bees and butterflies, organic crops most strongly enhanced wild plants and field edge conditions were the most important factor to enhance carabids and spiders. These findings emphasize that a combination of non-productive and productive measures within arable-dominated landscapes holds greater potential to support the regional species pool than focusing on a single best measure. Future agricultural policy should therefore foster the coordination and collaboration between multiple farmers to ensure that complementary measures are applied within an agricultural landscape. To achieve that, schemes should cover additional costs required for coordination between farmers, more strongly support existing farmer collaboratives and should allow higher flexibility in scheme design. Schemes targeting single environmental management agreements of multiple farmers

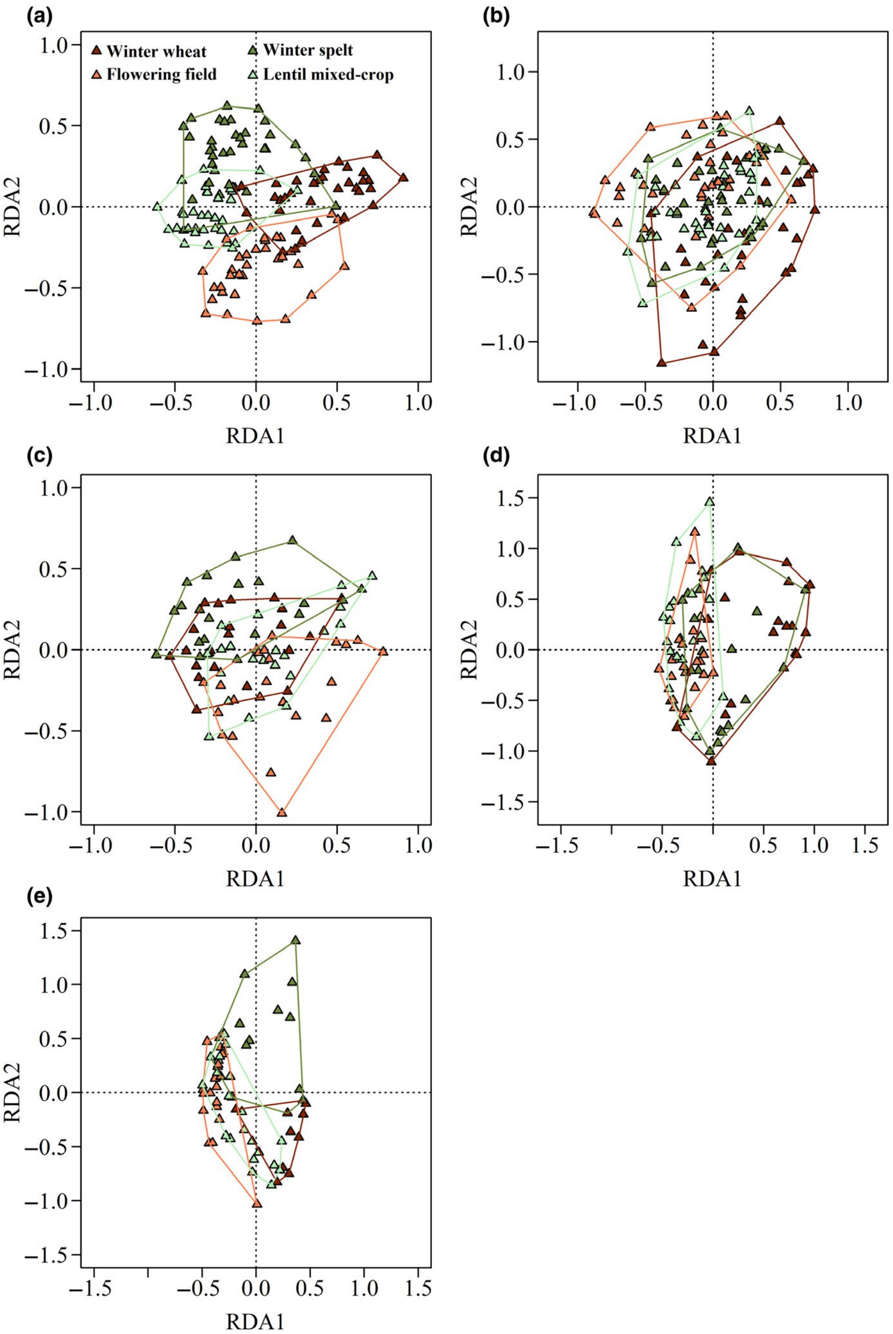

FIGURE 3 Redundancy analysis ordination (RDA) plots of survey transects (triangles) for wild plants (a), carabid beetles (b), spiders (c), butterflies (d) and wild bees (e). Minimum convex polygons of the four crop-use types are shown

should be prioritized in contrast to the current strict focus on individual farm holdings.

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AUTHORS' CONTRIBUTIONS

C.G., M.D., K.R. and P.B. developed the conception and design; C.G. and M.D. organized data collection; J.B. collected and identified wild bees and butterflies; R.W. surveyed plants in 2018; C.G. analysed and interpreted data with substantial input of P.B., R.G. and B.A.W.; C.G. wrote the paper. All the authors contributed critically to the draft and gave final approval for publication.

DATA AVAILABILITY STATEMENT

Data available via the Zenodo Digital Repository http://doi.org/10.5281/zenodo.4437511 (Gayer et al., 2021).

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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