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The potential of weeds in arable fields to support pollinator assemblages

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Abstract

To what extent are weeds on arable land useful to pollinators in an arable-dominated landscape? We sampled the weed flora in fields under conventional or organic farming in SE Sweden. More specifically, we noted the frequency of flowering among weeds that scored high on a pollinator index, henceforth 'pollinator-friendly weeds'. Furthermore, we sampled pollinating insects within cereal crops using transect walks and colour pan traps. As expected, weeds were ubiquitous and occurred in most sampling plots (0.25 m^2). In the pan traps, more than 100 species of pollinators were caught, including 26 Syrphidae, 19 social bees, 37 solitary bees and 22 other Hymenoptera. In the transects walks, the probability of encountering bees increased with flowering of pollinator-friendly weeds, and there was a similar but weaker pattern among hoverflies. Organically grown fields differed from conventional ones by having more pollinator-friendly weeds, more flowering of such weeds, and more bees. There was also a tendency for hoverflies and other Hymenoptera to be more abundant in organic fields. Three conclusions emerged. First, pollinator-friendly weeds made up one third to almost half of the weed occurrences recorded. Second, substantial numbers of pollinators searched for flowers within arable fields, and some increased with the abundance of flowering of pollinator-friendly weeds. Third, flowering pollinator-friendly weeds and some pollinators were more abundant in organic fields than in conventional ones. Overall, we showed that weeds on arable land are a potential and sought after resource among pollinators, and that even conventionally grown crops should be considered a potential habitat for bees.

KEYWORDS
bees, bumblebees, Hymenoptera, summer annual, Sweden, Syrphidae, vegetation, weed, winter annual

1 | INTRODUCTION

Weeds make up an important part of biodiversity on arable land, but since the introduction of widespread modern control methods during the 1950s, their amounts have been modest (Andreasen et al., 2018; Meyer et al., 2013; Richner et al., 2015; Robinson & Sutherland, 2002; Stoate et al., 2001). Chemical control of weeds is one dimenion of agricultural intensification that has caused lower insect and field bird numbers (Biesmeijer et al., 2006; Chiverton, 1999; Chiverton & Sotherton, 1991; Le Feon et al., 2010; Potts et al., 2010; Shrubb, 2003).

Numerous studies have been conducted on factors considered important for pollinators in agricultural landscapes, and then specifically on the floral resources (Nicholls & Altieri, 2013; Raderschall et al., 2021; Senapathi et al., 2017). In these landscape-wise studies, arable fields are often ignored, or only considered if containing a mass-flowering crop (e.g., Ammann et al., 2024). Very few studies specifically consider weeds in arable land as food for pollinators (Holzschuh et al., 2007; Requier et al., 2015; Rollin et al., 2016), although a number of recent publications points to an ongoing reassessment of the role of weeds in general as well as for pollinators (e.g., Balfour & Ratnieks, 2022; Bretagnolle & Gaba, 2015; Carvalheiro et al., 2011; Chandrasena, 2022; Crochard et al., 2022; Esposito et al., 2023).

On balance, it remains unclear how important weeds on arable land are for pollinating insects like bees and hoverflies in arable landscapes. On the one hand, weeds today most often occur in low abundance, but on the other hand, the large acreage of arable land might still mean a fair amount of food for pollinators. It is noteworthy that weeds flower during most of the summer (Milberg et al., 2024).

In the current study, we sampled weeds and pollinators (flower-visiting insects) in fields in an intensively used agricultural area of southern Sweden. We classified some weeds as 'pollinator-friendly', that is, based on how much nectar and/or pollen a species produces (Tyler et al., 2021). To ensure a gradient in weed occurrences, we sampled both conventionally and organically grown fields.

We assessed three assumptions: (i) many pollinator species search for food in arable fields. Although many pollinators have been documented in fields or field margins (Aviron et al., 2023; Gibson et al., 2006; Lagerlöf et al., 1992), the information on species identity of pollinators in arable fields is scant. (ii) Pollinators encountered in transect walks increase with increasing flowering of pollinator-friendly weeds, that is, with more floral resources, there would be more pollinators searching for food. (iii) Organic fields have more flowering of pollinator-friendly weeds and more pollinators than conventional ones. The former type of cropping excludes chemical weed control, while mechanical and preventive weed control measures are expected to be less efficient in controlling weeds (Gayer et al., 2021; Stein-Bachinger et al., 2021; Tuck et al., 2014), and hence, organic fields have more floral resources.

2 | MATERIALS AND METHODS

We sampled large arable fields in the central parts of Östergötland (Table 1), an area dominated by large-scale agricultural activity. The fields were located in an area 78 km east to west and 17 km south to north. In 2021, 15 arable fields were selected, of which 7 were conventional and eight were organic. In 2022, again, 15 arable fields were sampled (1 was identical to the previous year); there were 10 and 5 conventional and organic fields, respectively. Apart from a single autumn rape—a crop that flowers in early May—all fields had cereal crops, and the majority were autumn-sown (Table 1).

2.1 | Transects

In each field, a transect was established along which weeds (2021, 2022) and insects (2021) were sampled. To cover a larger part of the field, the transect was divided into 100 m segments running perpendicular to one of the field edges. Transects length varied between fields (Table 1) depending on its size and shape. Segments ran from random starting points between 0 and 20 m from the edge to avoid repeating the same sampling patterns in relation to direction of farming operations like ploughing, harrowing and weed control. As a consequence, this sampling ensured that the vast majority of the sample originated well away from the field edge.

To achieve sample representative of July—the peak month for most pollinators (Milberg et al., 2024)—transects were visited several times. In 2021, weeds and insects were sampled between 29 June and 4 August at approximately weekly intervals. The target number was five visits, but in nine fields, the start of the harvest season reduced this to four visits. Furthermore, poor weather precluded the sampling of insects on five dates. In 2022, only weeds were sampled, on three visits between 21 June and 27 July.

2.2 | Weeds

The sample of weeds in a field consisted of recording the presence/absence of plant species, and whether they flowered, in non-fixed 0.5 m $\times$ 0.5 m plots (0.25 m^2) arranged at regular distances (approximately 10 m) along the transect. The total sample consisted of between 143 to 215 plots per field in 2021. In 2022, less time was available for weed sampling, so we decided on 150 plots per field. Weed species were classified into one of seven different classes reflecting their importance for pollinators, following Tyler et al. (2021; among our weeds, only six of the classes were represented). We focused on pollinator-friendly weeds that we defined as those scoring 4 or higher in Tyler et al. (2021) (cf. Milberg et al., 2024); 4: nectar production modest (5–20 g sugar/m^2/year); 5: rather large (20–50 g); 6: large (50–200 g). Two species that were missing from Tyler et al. (2021) were assigned values according to the same criteria using other sources: *Taraxacum* coll. (6; Baude et al., 2016) and *Fumaria officinalis* (3; Ouvrard & Jacquemart, 2018).

The weed data were summarised per weed type and field as the average number of occurrences per 0.25 m^2 plot. For example, there were on average 4.7 occurrences of species of pollinator-friendly weeds per 0.25 m^2 in the organic field C1; the corresponding value for other weeds was 2.0.

2.3 | Pollinators

Pollinators were sampled in 2021 using colour pan traps for species identification and transects walks for quantification of insects. Colour pan traps were used to collect flower-visiting insects for species identification. This type of sampling is often biased with a larger catch when flowers are rare (Westerberg et al., 2021) and is therefore not suited for quantitative analyses. The colour pans traps used were painted with either blue, white or yellow UV-reflecting paint (Soppec, Sylva mark fluo marker, Nersac, France). The pans had a diameter of 8.7 cm, a volume of 0.05 L, and were filled with non-toxic propylene glycol (40% concentration), to decrease surface tension and act as a preservative. A small hole

TABLE 1 Fields sampled in 2021 and 2022 in central Östergötland, southern Sweden.

Fält (ID)	Area (ha)	Transect length (m)	Crop	Production type
Used in 2021				
A1[a]	8.2	1740	Winter wheat	Conventional
B1	16	1584	Barley	Conventional
C1	16.8	1224	Barley	Organic
D1	41.7	1808	Autumn-sown cereal	Conventional
E1	10.3	2595	Barley	Organic
F1	9.4	1415	Undersown barley	Organic
G1	5.4	1468	Barley	Organic
H1	13.1	1108	Autumn-sown rape	Organic
I1[b]	32.4	1476	Winter wheat	Conventional
J1	27.3	1916	Autumn-sown cereal	Organic
K1	49.6	2020	Autumn-sown cereal	Organic
L1	11.2	1584	Spring wheat	Conventional
M1	18	1972	Spring wheat	Conventional
N1	4.6	984	Oats	Conventional
O1	24.9	1812	Spring wheat	Organic
Used in 2022				
A2	29.5	1500	Winter wheat	Organic
B2	30.4	1500	Winter wheat	Organic
C2	96.1	1500	Winter wheat	Organic
D2	41.3	1500	Winter wheat	Conventional
E2	9.8	1500	Oats	Organic
F2	9.3	1500	Rye wheat	Conventional
G2	4.7	1500	Winter wheat	Conventional
H2	9.3	1500	Winter wheat	Conventional
I2	27.3	1500	Winter wheat	Conventional
J2	8.5	1500	Winter wheat	Conventional
K2[a]	8.2	1500	Winter wheat	Conventional
L2	24.1	1500	Winter wheat	Conventional
M2	25	1500	Winter wheat	Conventional
N2	17.8	1500	Winter wheat	Conventional
O2	30.8	1500	Winter wheat	Conventional

[a]This was the same field.
[b]This crop flowers in early May, 8 weeks before the first insect survey.

(4 mm in diameter) was drilled at the top of each bowl to ensure that rainwater could drain away while the catch was retained. A pan trap triplet, that is, three pans, one of each colour, was placed on a steel stake. Five or 10 trap triplets were placed along the transect in fields at the same height as the vegetation. Traps were in the field from 28 June to 26 July 2021 and were emptied four times. Syrphidae and Hymenoptera were identified to species level. To make data comparable, the catch was expressed as number of individuals per group, per week and per trap-triplet (cf. Milberg et al., 2021).

Transect walks, conducted to provide quantitative data on insect abundance, followed standard protocols (e.g. Pollard, 1977), and were conducted from 2 July to 4 August 2021, as 3–5 walks in the 15 fields. Transects were 4 m wide. During the walks, which were conducted with a slow but steady pace in weather deemed appropriate for flying insects, the number of the following taxonomic groups were noted: Apoidea, other Hymenoptera, Syrphidae, other Diptera, Hemiptera, Lepidoptera and Coleoptera. These abundance data were then analysed in relation to weed flowering and production systems.

2.4 | Statistical analyses

Observations of abundance of weed and insect groups were pooled at field level for all analyses. The total number of observed specimens, in all transect walks per field was analysed with generalised linear model (GLM). We fitted separate models for each of the seven insect groups

(Apoidea, Coleoptera, Hemiptera, Lepidoptera, other Diptera, other Hymenoptera and Syrphidae) and for all insects. We used the production system as fixed effects: resulting in $N = 15$ fields in the analysis. The natural logarithm of transect length was used as offset to control for differences in effort. The GLM was fitted with glm-nb()-function from the MASS-package (Venables & Ripley, 2002) for R-software (R Core Team, 2023).

The abundance (occurrence in 0.25 m^2 plots) of four weed groups (pollinator-friendly or other weed, and flowering or not flowering) in a season per field, was analysed with a generalised linear mixed model (a GLMM fitted with glmmTMB()-function from the glmmTMB-package (Brooks et al., 2017)). We used the production system as fixed effect and year as random factor to cluster observations from Years 2021 and 2022. Data from the only field revisited were excluded from 2022, giving a total of $N = 29$ fields.

The effect of flowering weeds on insect abundance in transect walks was analysed with negative binomial GLM, similar to the analysis of insect groups. We used the average number of species occurrences per 0.25 m^2 plots of flowering pollinator-friendly weed as fixed effect. Production system was excluded as predictor as it was highly correlated with weed occurrence ($r = 0.81$).

For all three models, the response data were 0 or positive integers, and we compared models with Gaussian, Poisson and negative binomial error distributions and log link functions. For all models a negative binomial distribution both fitted data well (lowest or second lowest AIC-value) and had acceptable residuals. Residuals were evaluated with the DHARMa-package (Hartig, 2022) to ensure acceptable fit. All models included an offset to control for differences in effort; log transect length for insect abundance and effect of flowering weed on insect abundance, and log number of 0.25 m^2 plots per field and year. Predictions with 95% confidence intervals from fitted models were calculated with ggpredict()-function from the ggeffects-package (Lüdecke, 2018) and used to visualise effect size.

3 | RESULTS

3.1 | Pollinator-friendly weeds

Fifty-one plant species were identified in the 30 fields sampled in 2021 and 2022. Of these, 20 were classified as pollinator-friendly based on the amount of nectar and/or pollen provided. One of these species was an under-sown crop (*Trifolium repens* in organic farming) and another was a self-seeded crop (rape). Pollinator-friendly species that were often found were *Fallopia convolvulus*, *Centaurea cyanus*, *Galeopsis bifida/tetrahit*, *Tripleurospermum inodorum*, *Myosotis arvensis* and *Matricaria chamomilla* (Table 2). Among these, *C. cyanus*, *T. inodorum* and *M. arvensis* stood out by often flowering when encountered (Table 2).

TABLE 2 Weeds in two types of production systems in 2021 and 2022.

	Conv. 2021	Organic 2021	Conv. 2022	Organic 2022	Pollinator index
	$N = 7$	$N = 8$	$N = 10$	$N = 5$	
Trifolium repens L.	0.49/0.0	63.6/3.5	0.60/0.0	4.1/0.40	6
Fallopia convolvulus (L.) Á. Löve	17.1/0.14	55.2/2.0	7.8/0.33	40.8/0.27	5
Centaurea cyanus L.	0.0/0.0	48.0/42.7	12.1/8.7	22.8/19.2	5
Galeopsis bifida Boenn./*Galeopsis tetrahit* L.	8.8/0.63	22.4/11.1	7.1/1.1	18.8/1.1	5
Brassica rapa L./*Brassica napus* L.	4.7/0.70	23.5/2.9	0.0/0.0	1.6/0.0	5
Tripleurospermum inodorum (L.) Sch. Bip.	7.1/0.99	30.4/15.2	9.7/1.1	54.0/7.2	4
Myosotis arvensis (L.) Hill	4.2/1.48	27.1/19.6	4.1/1.4	8.5/1.7	4
Matricaria chamomilla L.	6.7/2.61	16.2/10.4	0.40/0.13	3.7/0.0	4
Lamium purpureum L.	5.50/0.92	9.8/2.8	2.7/0.067	3.5/0.0	4
Buglossoides arvensis (L.) I. M. Johnst.	0.0/0.0	13.4/0.0	0.87/0.33	0.67/0.53	4
Stellaria media (L.) Vill.	20.4/1.1	77.2/16.4	23.2/1.7	79.7/5.9	3
Viola arvensis Murray	59.3/26.5	28.3/16.6	22.3/5.9	63.9/28.1	3
Polygonum aviculare L.	12.5/0.70	25.4/10.2	8.7/2.0	13.1/0.40	3
Veronica agrestis	23.7/6.2	15.6/6.3	3.3/0.53	32.8/10.8	3
Fumaria officinalis L.	16.5/4.3	16.4/4.6	12.0/5.6	9.6/0.53	3
Capsella bursa-pastoris (L.) Medik.	12.8/2.9	14.8/3.03	0.0/0.0	12.1/1.2	3
Galium aparine L.	3.3/0.49	29.4/7.6	3.6/1.5	49.5/10.0	2
Chenopodium album L.	2.9/0.42	63.6/17.4	15.1/0.47	65.5/0.80	1
Poa annua L.	7.2/0.0	0.28/0.0	10.0/5.3	18.0/12.9	1

Note: numbers are percentage occurrence/percentage flowering in plots of 0.25 m^2. Furthermore, species' pollinator index (4–6 deemed as 'pollinator friendly'). Only the more frequent species are shown (>10% occurrence in at least 1 of the 2 years and production systems).

3.2 | Pollinators

In the colour pan traps, 5713 individuals of 104 flower-visiting Hymenoptera and Syrphidae species were caught (Table 3). Most numerous were two Syrphidae (1586 *Eupeodes corollae* and 1102 *Sphaerophoria scripta*) and the domestic bee (1130 *Apis mellifera*). *Bombus* spp. was also numerous with 859 individuals of 18 species. Numerous bee species were recorded per field with an average of 16 (SD: 6.6; range: 6–33). Traps caught on average 5.6 bees per trap-triplet per week. The number of species of hoverflies was on average 8.5 (SD: 3.3). On the other hand, fields with few or no flowering weeds often recorded the highest densities of bees (up to 20–25 per trap triplet per week), suggesting a sampling bias using this type of trap (e.g., Westerberg et al., 2021).

In the transects walks, a total of 6308 observations were made. The most numerous group was Syrphidae (878 specimens per hectare), followed by Lepidoptera (662), other Diptera (637) and Apoidea (232). Coleoptera were relatively few (88), as were Hemiptera (28) and other Hymenoptera (25).

3.3 | Does flowering of pollinator-friendly weeds affect insect abundance?

Overall, the statistical model showed insects generally increased with flowering of pollinator-friendly weeds (Table 4). It was also clear from the model that the insect groups differed in their response to flowering of pollinator-friendly weeds (Table 4). The strongest positive effect was seen in Apoidea, followed by Syrphidae (Figure 1). There was also a tendency for other Hymenoptera to increase with pollinator-friendly weeds (Figure 1).

3.4 | Conventional versus organic farming

Overall, the statistical model showed that the type of production system differed in weed occurrence, and the amount of flowering (Table 5). So, organic fields had more pollinator-friendly weeds and more flowering of such weeds than conventional fields (Figure 2). The abundance of such weeds, and their flowering, were about five times higher in organic fields compared with conventional fields (Figure 2).

Overall, the statistical model showed that the type of production system differed in abundance of insects in transect walks, but that species groups differed in their affiliation with a production system (Table 6). Apoidea clearly differed in abundance among conventional and organic fields (Figure 3). There was also a tendency for Syrphidae to be more abundant in organic than conventional fields (Figure 3). Apoidea was about 10 times more numerous in organic fields compared with conventional, while Syrphidae was twice as abundant (Figure 3).

4 | DISCUSSION

4.1 | Pollinator-friendly weeds in arable fields

It comes as no surprise that weeds were ubiquitous in all 30 fields sampled. It is worth stressing that most of the sample plots were distant from the field edge; hence, these data are not affected by a potential edge effect within fields. Even if the frequency can be low in some fields, they are never zero. Even fields used for round-up ready crops contain weeds (Bonny, 2016). So, from the point of view of pollinators and other animals that use non-crop resources, it is important not to dismiss the inner parts of arable fields as non-habitat.

Our hypotheses that organic fields would have more pollinator-friendly weeds and more flowering of such weeds were both confirmed. Pollinator-friendly weeds were five times more likely to be found in 0.25 m^2 sample plots in organic than conventional fields in the two study years. It comes as no surprise that organic fields often have more weeds than conventional, due to chemical weed control being more efficient than other methods (e.g., Gayer et al., 2021; Hald, 1999; Romero et al., 2008; Rydberg & Milberg, 2000; Stein-Bachinger et al., 2021; Tuck et al., 2014). What is more surprising is that the flowering of pollinator-friendly weeds was more frequent in organic than conventional fields. It is likely that the denser conventional stands (Harbo et al., 2022) exacerbate competition and give less room for growth and subsequent flowering of weeds present, than in organic fields.

With c. 20 of the 50 weed species recorded being classified as pollinator-friendly, such species were often in the minority. This suggests that fields might vary in their usefulness for pollinators due to their weed species composition and type of cropping system.

An important feature of floral resources is their temporal pattern of flowering compared with the flight of pollinators. A recent study documented a surprisingly long flowering period of most pollinator-friendly weeds, and that the flight period of all pollinators of agricultural landscape—except early-flying solitary bees—coincided with weed's flowering (Milberg et al., 2024). July was also highlighted as a month with particularly high pollinator activity in northern Europe (Milberg et al., 2024). While weed flowering remains high during July (Milberg et al., 2024), flowering in Swedish species-rich grasslands, at about the same latitude, decreases from 1 July (Roth et al., 2023). So, as grasslands provide less later in the season, the relative importance of arable land might increase (e.g., Ammann et al., 2024).

Although the flowering of pollinator-friendly weed species potentially continues well into the autumn (Milberg et al., 2024), arable land ceases as a potential site for floral resources after harvest, when harrowing and eventually ploughing takes place. In the study region, harvest of spring- and autumn-sown cereals often occurs in the first half of August. This rather abrupt end to the floral resources of weeds occurs when the flight of bees has ceased, so it mainly deprives hoverflies—that generally fly later (Milberg et al., 2024)—of a nectar resource.

TABLE 3 Pollinator catches in colour pantraps (triplets of white, yellow and blue cups).

	Fields with occurrence Conventional	Organic	Average (SD) Conventional	Organic
	N = 7	*N* = 8	Catch per week per trap-triplet	
Syrphidae				
Eupeodes corollae	7	8	31.0 (33.3)	6.1 (7.3)
Sphaerophoria scripta	7	8	17.6 (14.3)	4.8 (3.6)
Melanostoma scalare	7	7	1.29 (0.87)	0.34 (0.21)
Episyrphus balteatus	7	6	6.1 (6.3)	0.90 (0.85)
Scaeva pyrastri	7	4	0.50 (0.28)	0.16 (0.23)
Melanostoma mellinum	5	4	0.51 (0.53)	0.11 (0.15)
Syrphus ribesii	5	2	0.17 (0.14)	0.062 (0.141)
Sphaerophoria philantha	4	5	0.34 (0.44)	0.16 (0.17)
Scaeva selenitica	4	2	0.17 (0.21)	0.038 (0.074)
Platycheirus clypeatus	3	1	0.56 (1.10)	0.012 (0.035)
Helophilus trivittatus	3		0.071 (0.095)	
Anasimyia transfuga	1	2	0.024 (0.063)	0.075 (0.149)
Eristalis anthophorina	1	2	0.057 (0.151)	0.15 (0.35)
Eristalis intricaria	1	2	0.088 (0.227)	0.050 (0.093)
Eupeodes luniger	2		0.052 (0.090)	
Chrysotoxum festivum	1		0.029 (0.076)	
Eristalis interrupta	1		0.014 (0.038)	
Eumerus strigatus	1		0.029 (0.076)	
Parhelophilus versicolor	1		0.029 (0.076)	
Platycheirus sp.	1		0.029 (0.076)	
Anasimyia contracta		1		0.012 (0.035)
Epistrophe nitidicollis		1		0.012 (0.035)
Eupeodes lundbecki		1		0.012 (0.035)
Pipiza quadrimaculata		1		0.025 (0.071)
Syritta pipipens		1		0.025 (0.071)
Volucella bombylans		1		0.050 (0.141)
Solitary Apiformes				
Lasioglossum calceatum	6	6	0.68 (0.52)	0.71 (0.64)
Andrena nigroaenea	4	7	0.22 (0.36)	0.31 (0.16)
Lasioglossum leucopus	5	4	0.36 (0.35)	0.40 (0.58)
Lasioglossum villosulum	4	5	0.16 (0.21)	0.34 (0.37)
Halictus tumulorum	5	3	0.23 (0.21)	0.088 (0.146)
Lasioglossum albipes	3	3	0.21 (0.27)	0.20 (0.41)
Andrena bicolor	2	4	0.11 (0.23)	0.088 (0.099)
Dasypoda hirtipes	1	5	0.17 (0.45)	0.65 (1.08)
Colletes floralis	4	1	0.17 (0.21)	0.025 (0.071)
Lasioglossum leucozonium	2	3	0.086 (0.157)	0.25 (0.38)
Megachile versicolor	2	2	0.11 (0.20)	0.025 (0.046)
Andrena cineraria	3		0.071 (0.095)	
Melitta haemorrhoidalis	2	1	0.052 (0.090)	0.025 (0.071)
Sphecodes ephippius	2	1	0.043 (0.079)	0.025 (0.071)
Lasioglossum zonulum	2		0.043 (0.079)	
Osmia bicornis	2		0.057 (0.098)	

TABLE 3 (Continued)

	Fields with occurrence Conventional	Organic	Average (SD) Conventional	Organic
	N = 7	*N* = 8	Catch per week per trap-triplet	
Andrena nigriceps	1	1	0.029 (0.076)	0.075 (0.212)
Lasioglossum morio	1	1	0.029 (0.076)	0.050 (0.141)
Andrena fucata		2		0.050 (0.093)
Andrena haemorrhoa	1		0.014 (0.038)	
Andrena nitida	1		0.057 (0.151)	
Anthidium manicatum	1		0.029 (0.076)	
Anthophora furcata	1		0.014 (0.038)	
Chelostoma rapunculi	1		0.029 (0.076)	
Colletes daviesanus	1		0.029 (0.076)	
Hylaeus brevicornis	1		0.029 (0.076)	
Lasioglossum fulvicorne	1		0.029 (0.076)	
Macropis europaea	1		0.029 (0.076)	
Megachile ligniseca	1		0.029 (0.076)	
Megachile willughbiella	1		0.014 (0.038)	
Melitta leporina	1		0.014 (0.038)	
Nomada flavopicta	1		0.014 (0.038)	
Panurgus calcaratus	1		0.029 (0.076)	
Epeolus variegatus		1		0.025 (0.071)
Hylaeus communis		1		0.025 (0.071)
Lasioglossum nitidiusculum		1		0.025 (0.071)
Sphecodes geoffrellus		1		0.025 (0.071)
Social Apiformes				
Apis mellifera	7	8	16.9 (16.6)	9.0 (3.2)
Bombus soroeensis	7	7	5.7 (5.5)	2.2 (1.9)
Bombus terrestris	7	7	4.3 (4.2)	1.24 (0.76)
Bombus hortorum	6	7	0.46 (0.54)	0.96 (0.62)
Bombus distinguendus	5	3	0.53 (1.01)	0.062 (0.092)
Bombus hypnorum	4	4	0.21 (0.25)	0.11 (0.12)
Bombus bohemicus	3	5	0.30 (0.55)	0.16 (0.15)
Bombus subterraneus	4	2	0.24 (0.33)	0.050 (0.093)
Bombus lucorum	3	3	0.20 (0.31)	0.11 (0.21)
Bombus lapidarius	3	2	0.086 (0.107)	0.12 (0.24)
Bombus muscorum	3	2	0.23 (0.44)	0.050 (0.093)
Bombus pratorum	3	2	0.095 (0.125)	0.050 (0.093)
Bombus pascuorum	3	1	0.12 (0.15)	0.025 (0.071)
Bombus ruderarius	1	2	0.086 (0.227)	0.038 (0.074)
Bombus jonellus	2		0.086 (0.157)	
Bombus rupestris	2		0.043 (0.079)	
Bombus sylvarum	1	1	0.029 (0.076)	0.025 (0.071)
Bombus humilis	1		0.029 (0.076)	
Bombus sylvestris	1		0.014 (0.038)	
Other Hymenoptera				
Dolichovespula saxonica	3	7	0.30 (0.67)	0.48 (0.50)
Lestica subterranea	5	4	0.30 (0.27)	0.19 (0.34)

(Continues)

TABLE 3 (Continued)

	Fields with occurrence Conventional	Organic	Average (SD) Conventional	Organic
	N = 7	*N* = 8	Catch per week per trap-triplet	
Dolichovespula sylvatica	4	5	0.17 (0.18)	0.14 (0.12)
Vespula germanica	4	4	0.41 (0.48)	0.58 (0.72)
Vespula rufa	3	4	0.071 (0.095)	0.16 (0.20)
Vespula vulgaris	2	3	0.13 (0.24)	0.050 (0.076)
Priocnemis exaltata	2	1	0.057 (0.098)	0.012 (0.035)
Crabro cribrario		3		0.050 (0.076)
Dolichovespula norwegica	1	1	0.029 (0.076)	0.025 (0.071)
Anoplius nigerrimus	1		0.029 (0.076)	
Crossocerus podagricus	1		0.029 (0.076)	
Odynerus spinipes	1		0.014 (0.038)	
Ancistrocerus trifasciatus		1		0.025 (0.071)
Cerceris rybyensis		1		0.012 (0.035)
Dolichovespula media		1		0.012 (0.035)
Ectemnius continuus		1		0.025 (0.071)
Ectemnius lapidarius		1		0.025 (0.071)
Ectemnius rubicola		1		0.012 (0.035)
Myrmosa atra		1		0.025 (0.071)
Pemphredon lugubris		1		0.025 (0.071)
Symmorphus bifasciatus		1		0.025 (0.071)
Tachysphex pompiliformis		1		0.025 (0.071)
Species			82	73
Av. Spp per field			32.4	26.2
Av. Individuals per field			93.0	32.6

Note: First columns are number of fields with catch and last columns are the average number of individuals per week and trap triplet, in the two production systems.

TABLE 4 Outcome of negative binomial GLM of number of individuals recorded in transect walks in 15 arable fields as a function of abundance of flowering pollinator-friendly weeds in the field.

	Estimate (±SE)	95% CI	*z*-value	*p*
All	0.494 (0.195)	0.101–0.899	2.54	0.011
Apiformes	1.80 (0.330)	1.07–2.58	5.46	6.6E−08
Coleoptera	0.142 (0.294)	−0.45 to 0.769	0.483	0.629
Hemiptera	0.496 (0.332)	−0.13 to 1.14	1.50	0.135
Lepidoptera	0.465 (0.329)	−0.24 to 1.22	1.41	0.158
Other Diptera	0.115 (0.237)	−0.32 to 0.568	0.485	0.628
Other Hymenopter	0.861 (0.488)	−0.11 to 1.94	1.77	0.077
Syrphidae	0.650 (0.252)	0.128–1.19	2.58	0.01

Note: The estimate is the effect of flowering pollinator-friendly species on number of observations per unit of transect walked. Separate models were run for each species group and total number of insect observations.
Abbreviations: CI, confidence interval; GLM, generalised linear model; SE, standard error.

4.2 | Pollinators in transects and pan traps

The transect data supported our hypothesis of a positive relationship between the flowering of pollinator-friendly weeds and the density of bees, and partly so for hoverflies. Not surprisingly, bees and partly hoverflies were also more abundant in organic fields than conventional ones. That organic fields carry more pollinators was unsurprising (Gayer et al., 2021; Holzschuh et al., 2007; Stein-Bachinger et al., 2021; Tuck et al., 2014), but the magnitude of the difference is an important take-home message: 10 times more bees and 2 times as many hoverflies in

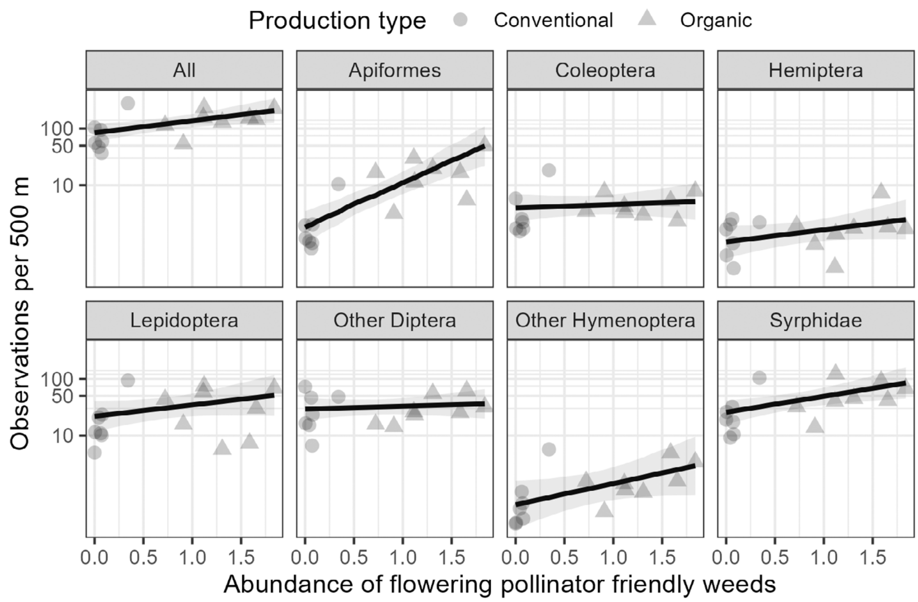

FIGURE 1 Predicted number of observations in transect walks as a function of abundance of pollinator-friendly weeds. Points are raw observations scaled to 500 m transect. Regression lines and confidence interval bands (95%) are predictions from the fitted model (Table 4).

TABLE 5 Outcome of negative binomial GLMM of weed abundance recorded in 0.25 m^2 in 29 arable fields that were either under organic or conventional production systems (estimte is the effect of organic cproduction).

	Estimate (±SE)	95% CI	*t*-value	*p*	SD (year)
Pollinator-friendly weed	1.55 (0.228)	1.10–2.00	6.80	1.04E−11	1.4E−4
Flowering pollinator-friendly weed	1.65 (0.342)	0.976–2.32	4.81	1.51E−6	0.237
Other weed	0.941 (0.149)	0.649–1.23	6.32	2.62E−10	1.54E−5
Other flowering weed	0.974 (0.240)	0.504–1.44	4.06	4.82E−5	2.51E−5

Note: Separate models were run for each weed group. SD (year) is the random effect variance from year as random variable to account for observations from different years.
Abbreviations: CI, confidence interval; GLMM, generalised linear mixed model; SD, standard deviation; SE, standard error.

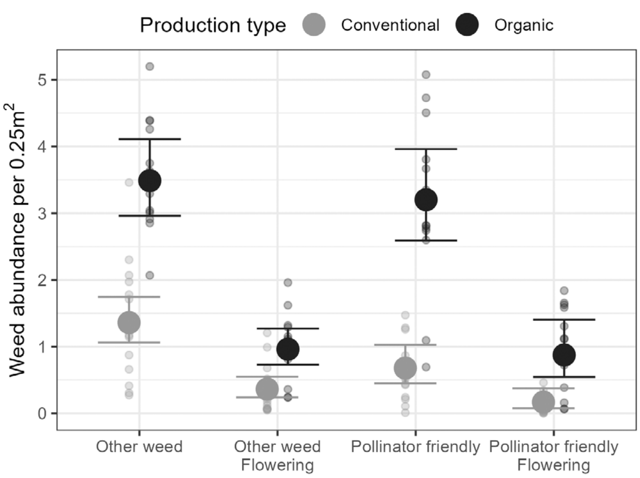

FIGURE 2 Weeds recorded in sample plots (0.25 m^2) in organic and conventionally grown fields, divided among pollinator-friendly weeds and other weeds, as well as whether flowering or not. Small points are raw observations. Estimate and error bars are +95% CI predictions from the fitted model (Table 5). CI, confidence interval.

organic fields compared with conventional. In comparison, the frequency of flowering of pollinator-friendly weeds was about 5 times higher in organic fields. A recent review of studies comparing differences between organic and conventional fields recorded similar average effect sizes, but with large variation among studies (Stein-Bachinger et al., 2021).

More than 100 species of pollinators were identified from 15 fields subjected to colour pan traps in 2021, suggesting that the inner parts of large arable fields are visited by a wide range of species. A growing body of evidence points to a flower-density bias using colour pan traps (Berglund & Milberg, 2019; O'Connor et al., 2019; Westerberg et al., 2021; Westphal et al., 2008). The current study adds to this evidence, as most bees were caught in the fields with the least flowers, in stark contrast to the transect walk data. The number of species recorded per field in the pan traps (16.0) was much higher than expected, for example, compared with a German transect study where a mere 2.1 and 6.9 species were found per conventional and organic fields respectively (Holzschuh et al., 2007).

5 | CONCLUSION

The results from the present study showed that (i) More than 100 species of pollinators were caught in colour pan traps within 15 fields sampled. (ii) Weeds within arable fields, potentially useful for

TABLE 6 Outcome of negative binomial GLM of pollinator abundance recorded in transect walks in 15 arable fields that were either under organic or conventional production systems.

	Estimate (±SE)	95% CI	z-value	p
All	0.452 (0.279)	−0.10 to 0.999	1.62	0.105
Apiformes	2.11 (0.471)	1.17–3.04	4.48	6.6E−8
Coleoptera	−0.056 (0.388)	−0.82 to 0.706	−0.146	0.884
Hemiptera	0.453 (0.461)	−0.46 to 1.36	0.983	0.326
Lepidoptera	0.426 (0.441)	−0.46 to 1.30	0.965	0.335
Other Diptera	−0.031 (0.314)	−0.65 to 0.584	−0.098	0.921
Other Hymenoptera	0.541 (0.697)	−0.87 to 1.93	0.776	0.438
Syrphidae	0.600 (0.358)	−0.11 to 1.30	1.68	0.093

Note: The estimate is the effect of organic compared to conventional production on number of observations per log metre of transect walked. Separate models were run for each species group and total number of insect observations.

Abbreviations: CI, confidence interval; GLM, generalised linear model; SE, standard error.

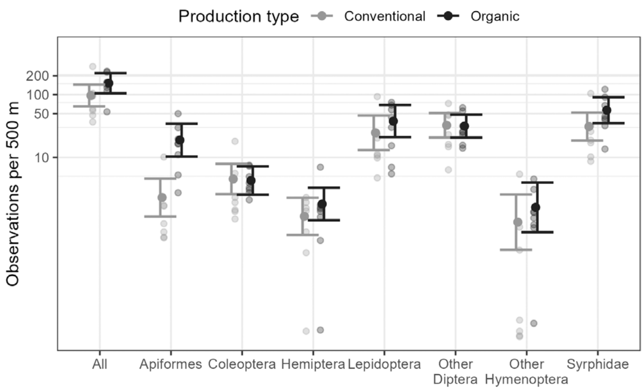

FIGURE 3 The predicted number of specimens observed after 500 m transect walk in conventional and organic production systems. Estimate and error bars are +95% CI predictions from the fitted model (Table 6). CI, confidence interval.

pollinators, were present and flowered during July. (iii) Flowering of pollinator-friendly weeds was positively related to the abundance of bees and partly hoverflies. As expected, organic fields had more pollinator-friendly weeds and more flowering of such weeds, and more pollinators, than conventional fields.

On balance, our study documented the occurrence of both pollinator-friendly weeds and pollinators within arable fields, and that it would be unwise to consider conventional arable land as non-habitat. Instead, we encourage more studies into the neglected biodiversity within arable fields.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data are available in the data repository ZENODO: https://doi.org/10.5281/zenodo.14050772.

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