

Article

Wildflower Strips Increase Aculeate Pollinator Diversity but Not Abundance in Agricultural Landscapes with Rapeseed in Crop Rotations

Eduardas Budrys ^{1,*} , Anna Budrienė ¹ , Miglė Lazauskaitė ¹, Jonas A. Skuja ² and Grita Skujienė ² ¹ Nature Research Centre, Akademijos str. 2, 08412 Vilnius, Lithuania; ana.budriene@gamtc.lt (A.B.); migle.lazauskaite@gamtc.lt (M.L.)² Institute of Biosciences, Life Science Center, Vilnius University, Saulėtekio ave. 7, 10257 Vilnius, Lithuania; grita.skujiene@gf.vu.lt (G.S.)

* Correspondence: eduardas.budrys@gamtc.lt

Abstract: The decline of pollinators in agricultural environments poses a significant threat to pollination ecosystem services. Wildflower strips are proposed as a strategy to support pollinator populations and enhance their species richness and diversity. We investigated the efficacy of flowering plant mixture in maintaining aculeate pollinator diversity (wild bees, predatory wasps, and their kleptoparasites) within intensively managed agricultural environments where rapeseed is a common rotational crop. Over four years, pollinators were counted five times per season using 250 m transect walks. Our results demonstrated that the diversity and the evenness of species abundance distribution of aculeate pollinators were higher in the sown wildflower strips, whereas mean abundance per transect was greater in the remnants of semi-natural grassland. The low diversity and evenness within the aculeate pollinator assemblage of the semi-natural habitat were attributed to the dominance of the sweat bee *Lasioglossum pauxillum*, which thrived on mass-flowering rapeseed and concentrated in the flowering grassland fragments after the rapeseed harvest. We conclude that wildflower strips enriched with sown flowering plant mixtures effectively enhance pollinator diversity. Furthermore, both wildflower strips and preserved patches of unmanaged or minimally managed semi-natural grassland habitats can essentially contribute to maintaining pollination ecosystem services within intensive agricultural environments.



Academic Editor: Guy Smagghe

Received: 13 March 2025

Revised: 28 March 2025

Accepted: 4 April 2025

Published: 8 April 2025

Citation: Budrys, E.; Budrienė, A.; Lazauskaitė, M.; Skuja, J.A.; Skujienė, G. Wildflower Strips Increase Aculeate Pollinator Diversity but Not Abundance in Agricultural Landscapes with Rapeseed in Crop Rotations. *Diversity* **2025**, *17*, 263. <https://doi.org/10.3390/d17040263>

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Keywords: ecosystem service; hill diversity numbers; pollination; species richness; wild bee conservation; wildflower strips

1. Introduction

Pollinating insects provide economically valuable ecosystem services, contributing to the pollination of both crops and wild plants, and thereby impacting food production and plant biodiversity [1–8]. However, recent decades of intensive agro-ecosystem management have triggered a decline in pollinators [4,9–11]. Agricultural intensification, a primary driver of impacts on pollinator diversity and their services, promotes the fragmentation, destruction, and loss of semi-natural habitats, consequently reducing pollinators' foraging and nesting opportunities [12–16]. This loss of semi-natural habitats directly results in a decline of native plant species, while reductions in pollinator populations may indirectly contribute to that decline [17–19].

To mitigate the impacts of habitat loss on biodiversity conservation in agricultural landscapes, the EU's Common Agricultural Policy promotes the integration of semi-natural

habitats within arable land and the implementation of agri-environmental schemes [20–22]. A widely adopted agri-environmental measure is the establishment of sown wildflower strips (WFSs), which serve to enhance biodiversity in agricultural landscapes while promoting ecosystem services, such as pollination and pest control [23–27]. Although the positive effects of WFSs on beneficial insect abundance and diversity are well-documented, their effectiveness remains inconsistent across studies [28–33]. Research on the effectiveness of the EU agricultural policy measures targeting biodiversity conservation, including pollinator protection, exhibits a geographic bias, with Central and Eastern European countries being underrepresented [34,35].

A wildflower strip is defined as a strip or plot of sown native, and/or non-native flowering herbaceous plants that provide pollen and nectar resources for native pollinators [31]. WFSs are typically established along field boundaries or within crops, requiring minimal space and easily integrating into farming practices. They are maintained for periods ranging from one to five years [20,36,37]. Notably, pollinator abundance within WFSs may decline over time following WFS establishment [38].

The selection of plant species for seed mixtures is often based on practical and economic criteria, such as cost, seed availability, germination success, or expert opinion, frequently with limited consideration of their ecological role in habitat restoration or plant–pollinator interactions [39,40]. However, optimal pollinator support requires flower mixture compositions with specific biological properties, necessitating careful planning and management [41–45]. Seed mixture design and implementation may vary depending on whether the goal is to promote pollinator diversity conservation or pollination services [46]. It has been suggested that improving the seed mixtures recommended to farmers could enhance their ability to attract a wider range of pollinator species and include plants that support multiple specialized pollinators [17,47–53].

The cultivation of rapeseed (*Brassica napus*) can have significant implications for wild pollinator populations in agricultural landscapes. Overall, numerous studies examining the impact of oilseed rape crops on the WFS have focused on biological pest control [54–57], with fewer studies addressing plant–pollinator interaction effects on pollinator abundance and diversity [58–61]. While rapeseed fields can provide abundant pollen and nectar resources [62], their impact on wild pollinator diversity and abundance depends on the context. Evidence indicates that insect pollination significantly enhances seed yield and quality in rapeseed crops, with honeybees being the most effective pollinators due to their foraging behavior and efficiency in pollen transfer between flowers [63]. However, wild bee abundance and diversity can be significantly higher in adjacent uncultivated areas than in conventional rapeseed fields, highlighting the potential negative effects of monoculture farming on pollinator diversity [64]. WFSs can compete with rapeseed for pollinators, drawing bees away from rapeseed flowers despite increasing the overall wild pollinator population [65]. The landscape context, including the presence of semi-natural habitats surrounding rapeseed fields, can play a crucial role in determining wild pollinator abundance and diversity [66,67]. Increased vegetation diversity in agricultural landscapes can enhance pollinator species richness, suggesting that integrating WFS or maintaining hedgerows could benefit both crop production and pollinator conservation [68–71].

The aim of our case study was to evaluate the potential of species-rich flowering plant seed mixtures, such as *Lebensraum I*[®], developed for German agro-ecosystems, for maintaining aculeate pollinator diversity (wild bees, predatory wasps, and their kleptoparasites) within intensively managed agricultural environments in temperate Eastern Europe, where rapeseed is a common rotational crop. We hypothesized that (1) species-rich plant mixtures in WFSs provide floral resources for a broader range of pollinator species, thereby enhancing the species richness and diversity of pollinator assemblages; (2) the establishment

of WFSs leads to increasing over subsequent years abundance and/or species richness of aculeate pollinator populations due to richer floral resources; and (3) mass-flowering rapeseed fields offer abundant floral resources to certain wild pollinators, thereby positively influencing the abundance of particular species.

2. Materials and Methods

2.1. Study Sites

Field observations were conducted in agricultural environments where rapeseed was part of the crop rotation. We compared the diversity and relative abundance of Hymenoptera Aculeata in three sites in the Kupiškis district of Lithuania, in temperate Europe. These included two available WFSs at the edges of crop fields (Flower strip 1: 425 × 10 m, 55°48'20" N, 25°13'25" E, and Flower strip 2: 300 × 6 m, 55°48'11" N, 25°13'13" E) and a control plot with semi-natural grassland vegetation surrounded by intensively managed crop fields (Control: an approximately 12 m wide unmanaged grassland strip on both sides of a drainage ditch, 55° 48' 07" N, 25° 07' 05" E). The crop rotation in the arable fields surrounding the study sites included winter rapeseed, winter wheat, and, occasionally, faba beans. The nearest narrow strips of semi-natural grassland vegetation along drainage ditches, which are potential pollinator sources, were located approximately 500 m from the WFSs. Larger patches of semi-natural mowed meadows and pastures were situated at distances exceeding 1 km. The WFSs were established in the year 2020, and the diversity of bees and wasps was monitored from 2021 to 2024.

The vegetation of the WFSs was enriched using the plant seed mixture *Lebensraum I* (Saaten Zeller GmbH and Co. KG, <https://www.saaten-zeller.de/>, accessed on 3 March 2025), which originally included 50 flowering plant species. Some sown species did not successfully reach the flowering stage, likely due to competition with other plants, including local weeds. Table 1 details the successfully established sown plant species, the naturally occurring entomophilous plants observed within the WFSs, and the native wildflowers present at the control site. A total of 63 entomophilous plant species were observed flowering in the WFS sites; several non-native annual plant species flowered only during the first one or two years following the establishment of the WFSs. In the semi-natural grassland of the control site, 41 entomophilous flowering plant species were recorded.

Table 1. Lists of sown and naturally occurring entomophilous plants recorded in the wildflower strips and the control site. Non-native species are marked with an asterisk (*).

Plants from the Seed Mixture <i>Lebensraum I</i> in WFS	Wild Entomophilous Plants, Naturally Invading the WFS	Wild Entomophilous Plants in Semi-Natural Grassland of the Control Site
<i>Achillea millefolium</i>	<i>Arctium lappa</i>	<i>Achillea millefolium</i>
<i>Agrimonia eupatoria</i>	<i>Barbarea vulgaris</i>	<i>Aegopodium podagraria</i>
<i>Anethum graveolens</i> *	<i>Capsella bursa-pastoris</i>	<i>Angelica sylvestris</i>
<i>Anthriscus sylvestris</i>	<i>Chaerophyllum aromaticum</i>	<i>Anthriscus sylvestris</i>
<i>Borago officinalis</i> *	<i>Cirsium arvense</i>	<i>Arctium minus</i>
<i>Camelina sativa</i> *	<i>Erodium cicutarium</i>	<i>Barbarea vulgaris</i>
<i>Carthamus tinctorius</i> *	<i>Erysimum cheiranthoides</i>	<i>Centaurea cyanus</i>
<i>Carum carvi</i>	<i>Galeopsis tetrahit</i>	<i>Centaurea jacea</i>
<i>Centaurea cyanus</i>	<i>Hypericum perforatum</i>	<i>Cichorium intybus</i>
<i>Cerastium holosteoides</i>	<i>Knautia arvensis</i>	<i>Cirsium arvense</i>
<i>Cichorium intybus</i>	<i>Lamium purpureum</i>	<i>Cirsium olearceum</i>
<i>Clinopodium vulgare</i>	<i>Medicago lupulina</i>	<i>Cirsium vulgare</i>
<i>Cota tinctoria</i>	<i>Papaver dubium</i>	<i>Daucus carota</i>
<i>Crepis biennis</i>	<i>Polygonum aviculare</i>	<i>Euphrasia officinalis</i>

Table 1. Cont.

Plants from the Seed Mixture <i>Lebensraum I</i> in WFS	Wild Entomophilous Plants, Naturally Invading the WFS	Wild Entomophilous Plants in Semi-Natural Grassland of the Control Site
<i>Daucus carota</i>	<i>Sonchus arvensis</i>	<i>Filipendula ulmaria</i>
<i>Dipsacus fullonum</i> *	<i>Stellaria media</i>	<i>Galium verum</i>
<i>Echium vulgare</i>	<i>Taraxacum officinale</i>	<i>Hypericum perforatum</i>
<i>Fagopyrum esculentum</i> *	<i>Thlaspi arvense</i>	<i>Iris pseudacorus</i>
<i>Galium album</i>	<i>Trifolium repens</i>	<i>Knautia arvensis</i>
<i>Galium verum</i>	<i>Tripleurospermum inodorum</i>	<i>Lathyrus pratensis</i>
<i>Helianthus annuus</i> *	<i>Veronica filiformis</i>	<i>Lycopus europaeus</i>
<i>Heracleum sphondylium</i>	<i>Vicia cracca</i>	<i>Lysimachia vulgaris</i>
<i>Leucanthemum ircutianum</i>	<i>Viola arvensis</i>	<i>Lythrum salicaria</i>
<i>Linum usitatissimum</i> *		<i>Medicago falcata</i>
<i>Malva moschata</i>		<i>Melilotus albus</i>
<i>Malva sylvestris</i>		<i>Melilotus officinalis</i>
<i>Medicago sativa</i> *		<i>Papaver rhoeas</i>
<i>Papaver rhoeas</i>		<i>Pentanema salicinum</i>
<i>Pastinaca sativa</i>		<i>Ranunculus acris</i>
<i>Phacelia tanacetifolia</i> *		<i>Silene flos-cuculi</i>
<i>Plantago lanceolata</i>		<i>Silene latifolia</i>
<i>Poterium sanguisorba</i>		<i>Solidago virgaurea</i>
<i>Salvia pratensis</i>		<i>Taraxacum officinale</i>
<i>Silene dioica</i>		<i>Thalictrum flavum</i>
<i>Silene flos-cuculi</i>		<i>Thalictrum lucidum</i>
<i>Silene latifolia</i>		<i>Tripleurospermum inodorum</i>
<i>Silene vulgaris</i>		<i>Tussilago farfara</i>
<i>Tanacetum vulgare</i>		<i>Valeriana officinalis</i>
<i>Trifolium incarnatum</i> *		<i>Veronica officinalis</i>
<i>Trifolium resupinatum</i> *		<i>Vicia cracca</i>
		<i>Viola arvensis</i>

The plant composition of both WFSs with enhanced floral diversity and the control site with native semi-natural grassland vegetation provided a continuous supply of floral resources from May to early September. The highest abundance and diversity of flowers were observed from June to August (Figure 1a–c).

2.2. Data Collection

Species richness and relative abundance of pollinators were assessed using 250 m long transect walks, with GPS receiver used for length measurement. Such transect length, shorter than the length of the studied WFSs, was selected to prevent oversampling of rarer pollinator species. During the walk, all aculeate pollinators within a 2 m wide band (1 m on each side of the observer) were identified to species where possible, and recorded using a digital voice recorder. Specimens that could not be identified in the field were collected using an entomological net and preserved in ethanol for laboratory verification. Molecular barcoding was applied for specimens of *Lasioglossum* and *Nomada* with uncertain identification. The taxonomy of apoid wasps followed the family-level classification proposed by [72], and species names for insects and plants were validated using the GBIF.org database [73].

Transect walks were performed under sunny weather conditions and lasted approximately 30 min, ranging from 20 to 45 min depending on pollinator abundance. In instances where wild pollinator count exceeded 300 specimens before reaching the 125 m midpoint of transect, the transect length was halved and species counts were doubled. Honeybee

(*Apis mellifera*) counts were excluded from the analysis due to high variability in their abundance resulting from hive relocations by beekeepers. The walks were conducted approximately monthly from May to September (five times per flowering season) over four years (2021–2024), thus generating a dataset of 20 counts for each of the three sites.



Figure 1. Vegetation in the study sites: (a) Flower strip 1 in June; (b) Flower strip 2 in July; and (c) the control site in August.

2.3. Statistical Analysis

Parametric methods were used for species richness analysis, while non-parametric methods (Mann–Whitney and Kruskal–Wallis tests) were employed for abundance comparisons, as the distribution of the latter variable did not follow a normal distribution. Basic statistics (mean, standard error), normality of distribution (Kolmogorov–Smirnov, Lilliefors, and Shapiro–Wilk tests), ANOVA, and non-parametric tests were performed using *Statistica* version 8 (Statsoft, Tulsa, OK, USA). All other calculations were conducted using R 4.4.2 [74] and RStudio 2024.12.0 [75].

Diversity was estimated using Hill's ordered diversity index qD , as recommended by [76]:

$${}^qD = \left(\sum_{i=1}^S p_i^q \right)^{1/(1-q)},$$

where $q \geq 0$ and $q \neq 1$;

S is the total number of species in the assemblage; q is the order or the diversity index qD ; and p_i is the proportion of the i th species in the assemblage;

$$\text{for } q = 1, {}^1D = \exp \left(- \sum_{i=1}^S p_i \log p_i \right); \text{ for } q \rightarrow \infty, {}^\infty D = 1/\max(p_i)$$

The observed Hill's index values (Hill numbers) were calculated using Microsoft Access database queries. The evenness of abundance distribution among species was assessed using the ordered relative evenness index, ${}^qRE = ({}^qD - 1)/(S - 1)$ [77], which represents the 3rd class of evenness measures according to [78]. The relationship between the observed sample size and species richness, assessed using rarefaction, and extrapolation, as well as estimated asymptotic species richness (function *ChaoRichness*) [79,80], estimated asymptotic diversities (functions *ChaoShannon* and *ChaoSimpson*), and estimated Hill diversity profiles (function *estimateD* for sample size 1000), were assessed using the R package *iNEXT* [81]. The estimated sampling completeness (function *Completeness*) and relative evenness (function *Evenness*) were calculated using the R package *iNEXT.4steps* [82]. In cases where the bootstrap method was used to evaluate sampling uncertainty and confidence intervals, we applied 100 bootstrap replications.

To achieve a more symmetrical visualization of Hill number-based ordered diversity measures, which exhibit contrasting sensitivity to species' relative abundance, we propose using $\log_2(q)$ values for the abscissa instead of q . This approach, similar to that applied by [83] for other biodiversity measures, scales the range of $\log_2(q)$ from $-\infty$ to ∞ (corresponding to q from 0 to ∞) in graphical representations of ordered sampling completeness, ordered diversity (qD), and ordered relative evenness (qRE). For visualizing the estimated diversity and evenness profiles, we used $\log_2(q) = 4$ as the maximum abscissa value, since the qD and qRE values for $\log_2(q) \rightarrow \infty$ could not be calculated. The graphs were generated using the R package *ggplot2* [84].

3. Results

3.1. Species Richness and Abundance per 250 m Transect

We recorded a total of 111 aculeate pollinator species, encompassing all six bee families native to the region, as along with six families of apoid wasps and four other wasp families from the superfamilies Chrysidoidea, Pompiloidea, Tiphioidea, and Vespoidea (Table 2). Of these species, 98 were identified in the WFS assemblages, while 55 species were found in the semi-natural grassland of the control site. Notably, 56 species were exclusive to the WFS assemblages and 12 species were exclusive to the control site.

Table 2. Observed abundance of aculeate pollinator species per 250 m transect in three assemblages: Flower strip 1, Flower strip 2, and control (see Section 2).

Species	Flower Strip 1	Flower Strip 2	Control	Species	Flower Strip 1	Flower Strip 2	Control
Apidae				Andrenidae			
<i>Anthophora furcata</i>	0	1	0	<i>Andrena alfkenella</i>	2	0	1
<i>Bombus bohemicus</i>	1	0	3	<i>Andrena bicolor</i>	0	2	0
<i>Bombus hortorum</i>	4	4	0	<i>Andrena cineraria</i>	0	1	0
<i>Bombus humilis</i>	0	1	1	<i>Andrena dorsata</i>	5	3	0
<i>Bombus jonellus</i>	0	2	1	<i>Andrena flavipes</i>	2	2	0
<i>Bombus lapidarius</i>	3	5	6	<i>Andrena fulvago</i>	1	2	0
<i>Bombus lucorum</i>	4	3	3	<i>Andrena haemorrhoa</i>	1	2	0
<i>Bombus magnus</i>	2	0	0	<i>Andrena helvola</i>	0	1	0
<i>Bombus muscorum</i>	0	1	0	<i>Andrena jacobii</i>	0	0	1
<i>Bombus norvegicus</i>	0	0	1	<i>Andrena minutula</i>	4	1	2
<i>Bombus pascuorum</i>	16	5	5	<i>Andrena minutuloides</i>	56	33	6
<i>Bombus ruderarius</i>	2	1	5	<i>Andrena nigroaenea</i>	1	1	1
<i>Bombus rupestris</i>	1	0	0	<i>Andrena ovacula</i>	0	3	0
<i>Bombus soroeensis</i>	4	3	1	<i>Andrena pilipes</i>	1	1	0
<i>Bombus sylvarum</i>	37	9	17	<i>Andrena praecox</i>	0	0	1

Table 2. Cont.

Species	Flower Strip 1	Flower Strip 2	Control	Species	Flower Strip 1	Flower Strip 2	Control
<i>Bombus terrestris</i>	7	35	8	<i>Andrena wilkella</i>	7	3	1
<i>Bombus vestalis</i>	0	1	0	Melittidae			
<i>Bombus veteranus</i>	12	2	9	<i>Dasypoda hirtipes</i>	1	0	0
<i>Eucera longicornis</i>	3	4	1	<i>Melitta leporina</i>	8	1	0
<i>Nomada castellana</i>	0	3	0	Bembicidae			
<i>Nomada flavoguttata</i>	2	0	0	<i>Gorytes quinquecinctus</i>	0	0	1
<i>Nomada lathburiana</i>	0	1	0	Crabronidae			
<i>Nomada marshamella</i>	0	1	0	<i>Crabro cribrarius</i>	2	0	12
<i>Nomada panzeri</i>	0	1	0	<i>Crabro peltarius</i>	0	0	1
<i>Nomada rufipes</i>	1	0	0	<i>Crossocerus podagricus</i>	0	2	0
<i>Nomada succincta</i>	0	1	0	<i>Ectemnius continuus</i>	0	0	11
Megachilidae				<i>Ectemnius fossorius</i>	0	0	4
<i>Coelioxys conoidea</i>	0	1	0	<i>Ectemnius lapidarius</i>	1	0	0
<i>Heriades truncorum</i>	2	3	0	<i>Entomognathus brevis</i>	1	0	0
<i>Megachile centuncularis</i>	0	2	0	<i>Lindenus albilabris</i>	5	3	1
<i>Megachile versicolor</i>	0	1	0	<i>Oxybelus trispinosus</i>	0	2	1
<i>Osmia bicolor</i>	1	0	1	Pemphredonidae			
<i>Osmia rufa</i>	2	2	0	<i>Diodontus luperus</i>	0	1	0
<i>Osmia spinulosa</i>	4	2	0	<i>Pemphredon inornata</i>	0	1	0
Halictidae				Philanthidae			
<i>Halictus maculatus</i>	3	4	1	<i>Cerceris quinquefasciata</i>	0	2	0
<i>Halictus quadricinctus</i>	1	1	2	<i>Cerceris ruficornis</i>	0	0	1
<i>Halictus sexcinctus</i>	1	0	0	<i>Cerceris rybyensis</i>	1	0	0
<i>Halictus subauratus</i>	6	10	2	<i>Philanthus triangulum</i>	0	1	0
<i>Halictus tumulorum</i>	29	13	40	Psenidae			
<i>Lasioglossum albipes</i>	0	0	1	<i>Mimumesa unicolor</i>	1	0	0
<i>Lasioglossum calceatum</i>	4	27	14	<i>Psenulus pallipes</i>	2	0	0
<i>Lasioglossum leucopus</i>	15	5	2	Sphecidae			
<i>Lasioglossum leucozonium</i>	1	2	8	<i>Ammophila sabulosa</i>	0	1	0
<i>Lasioglossum morio</i>	1	1	11	Chrysididae			
<i>Lasioglossum nitidiusculum</i>	2	0	1	<i>Pseudochrysis neglecta</i>	0	1	0
<i>Lasioglossum pauxillum</i>	24	111	1039	Pompilidae			
<i>Lasioglossum quadrinotatum</i>	1	0	0	<i>Ceropales maculata</i>	0	0	1
<i>Lasioglossum sexnotatum</i>	1	0	1	<i>Arachnospila anceps</i>	0	1	0
<i>Lasioglossum zonulum</i>	4	3	4	Tiphiidae			
<i>Sphecodes crassus</i>	0	4	0	<i>Tiphia femorata</i>	0	1	0
<i>Sphecodes ephippius</i>	0	1	4	Vespidae			
<i>Sphecodes geoffrellus</i>	0	2	0	<i>Ancistrocerus nigricornis</i>	1	0	0
<i>Sphecodes gibbus</i>	0	2	0	<i>Dolichovespula saxonica</i>	0	0	25
<i>Sphecodes pellucidus</i>	1	0	0	<i>Dolichovespula sylvestris</i>	2	0	5
<i>Sphecodes scabricollis</i>	0	0	2	<i>Gynomerus laevipes</i>	1	0	0
Colletidae				<i>Odynerus melanocephalus</i>	0	2	0
<i>Colletes daviesanus</i>	2	15	0	<i>Odynerus reniformis</i>	1	2	0
<i>Hylaeus brevicornis</i>	0	0	1	<i>Polistes dominula</i>	17	35	13
<i>Hylaeus communis</i>	0	1	1	<i>Polistes nimpha</i>	0	1	8
<i>Hylaeus confusus</i>	2	0	1	<i>Vespula germanica</i>	6	1	2
<i>Hylaeus nigrinus</i>	11	8	0	<i>Vespula rufa</i>	2	0	3
				<i>Vespula vulgaris</i>	0	1	12
				Total:	349	419	1311

Ordered sampling completeness, which represents the percentage of the observed species relative to the estimated total species richness, approached 100% for abundant species (positive $\text{Log}_2(q)$ in Figure 2a). For all species ($\text{Log}_2(q) = -\infty$), the completeness was 78% and 72% in the wildflower strip assemblages and 57% in the control site. Both this assessment and the Chao richness (Table 3) suggested that approximately 17, 28, and

41 additional scarce species remained unrecorded in Flower strip 1, Flower strip 2, and the control site, respectively. The estimated relationship between the number of specimens and the number of species, assessed using rarefaction and extrapolation methods, revealed significantly higher expected richness in the WFS assemblages compared to the control site (Figure 2b).

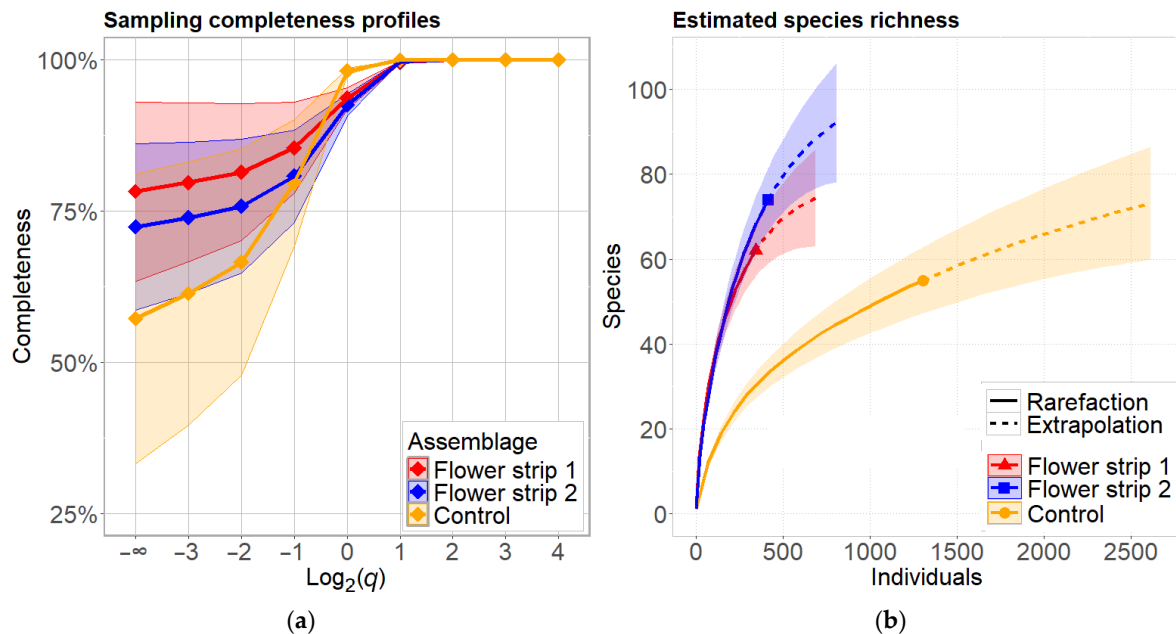


Figure 2. Sampling completeness and estimated species richness in aculeate pollinator assemblages of two flower strips and the control site (average $\pm$ 95% conf.). (a) Ordered estimated sampling completeness profiles. (b) Sample size-based rarefaction and extrapolation curves of estimated species richness.

Table 3. Observed and estimated asymptotic species richness and diversity measures: estimator value $\pm$ SE (95% confidence interval).

Estimator	Flower Strip 1	Flower Strip 2	Control
Observed richness	62	74	55
Estimated Chao richness	79.2 $\pm$ 9.6 (68.2–109.8)	102.2 $\pm$ 13.3 (85.7–142.0)	96.1 $\pm$ 23.8 (69.4–172.7)
Observed Shannon	28.5	23.3	3.30
Estimated Chao Shannon	32.4 $\pm$ 2.4 (28.5–37.1)	26.7 $\pm$ 2.4 (23.3–31.4)	3.43 $\pm$ 0.21 (3.30–3.83)
Observed Simpson	16.2	9.92	1.57
Estimated Chao Simpson	17.0 $\pm$ 1.4 (16.2–19.7)	10.1 $\pm$ 1.0 (9.9–12.0)	1.58 $\pm$ 0.04 (1.57–1.65)

The mean abundance of aculeate pollinators per 250 m transect was markedly higher in the control site (73 ± 51) compared to the WFSs (21.2 ± 3.4) (Figure 3a). However, this difference was not significant (Mann–Whitney U test: $p = 0.19$) due to high variability of this abundance in the control site (coefficient of variation: 296.9%). Species richness per 250 m transect was slightly higher in the flower strips (8.1 ± 0.7) than in the control site (7.1 ± 1.1) (Figure 3b), but this difference was also not significant (ANOVA: $F = 0.63$, $p = 0.43$). Pairwise comparisons of transect observations on the same day revealed no significant differences between the WFSs and the control site (paired t -tests: $t = 0.39$, $p = 0.70$ for Flower strip 1 vs. control; $t = 1.39$, $p = 0.18$ for Flower strip 2 vs. control).

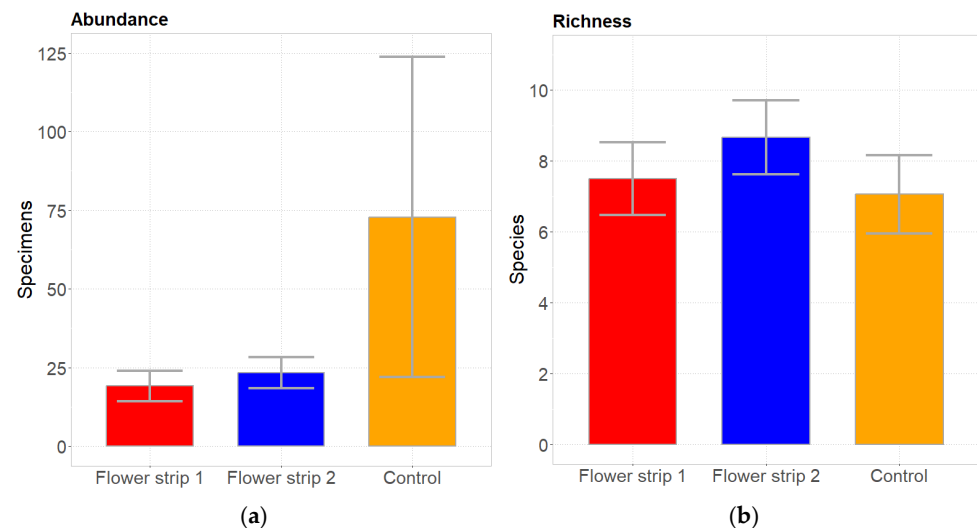


Figure 3. Observed relative abundance and species richness of aculeate pollinators per 250 m transect in three assemblages (average $\pm$ SE). (a) Average abundance. (b) Average species richness.

3.2. Changes During Summer Season

Neither the relative abundance nor the species richness of aculeate pollinators demonstrated significant variation during the summer season (Figure 4a,b). However, a remarkable fluctuation in abundance occurred at the control site in August, reaching 289 ± 214 specimens per 250 m transect compared to 16.6 ± 3.9 specimens at the WFS sites (Figure 4a). Although the difference was substantial, it was not statistically significant (ANOVA: $F = 1.2$, $p = 0.32$). This peak of abundance was primarily due to a high concentration of *Lasioglossum pauxillum* males on still flowering plants within a narrow strip of minimally managed semi-natural grassland vegetation along a drainage ditch, following the winter rapeseed harvest when the surrounding crop fields lacked blooming plants.

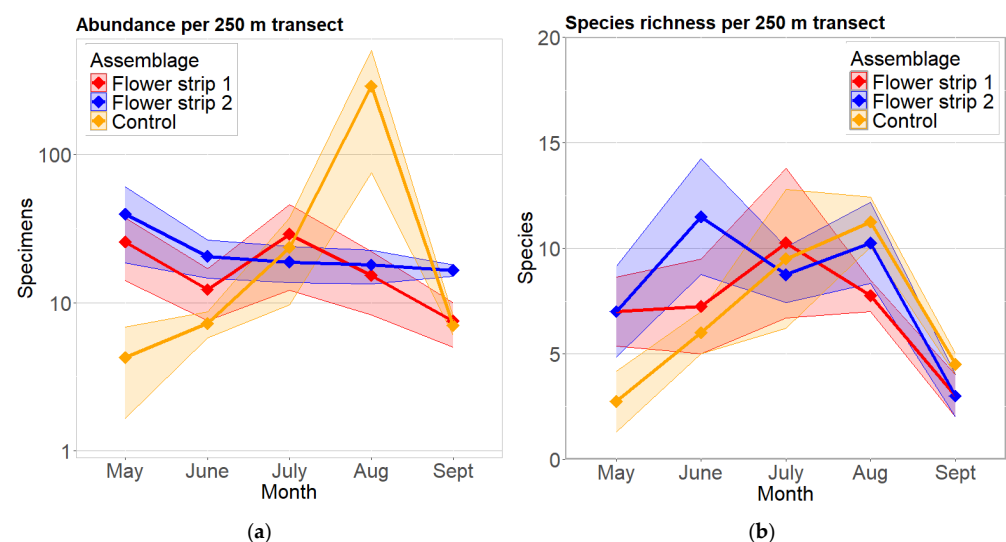


Figure 4. Change in aculeate pollinator assemblages during the summer season (average $\pm$ SE). (a) Change in average abundance per 250 m transect. (b) Change in average species richness per 250 m transect.

Specifically, abundance of this sweat bee species at the control site in August reached 256 ± 206 specimens (primarily males) per 250 m transect, while the combined abundance of all other aculeate pollinator species was 33.3 ± 8.9 specimens per transect. *L. pauxillum*

was also present in the WFS sites but was more commonly recorded in May and June (6.8 ± 3.2 females per transect) than in August (4.6 ± 1.7 , primarily males, per transect).

3.3. Changes over Years

At Flower strip 1, we observed a significant increase in aculeate pollinator mean abundance per 250 m transect over the years, rising from 7.5 ± 3.1 observed specimens in 2021 to 38.4 ± 11.5 in 2024 ($R^2 = 0.34$, regression slope $B = 10.4 \pm 3.6$, $p = 0.01$). Species richness also increased from 5.8 ± 1.9 to 9.8 ± 2.8 ; however, this change was not significant ($R^2 = 0.13$, regression slope $B = 1.37 \pm 0.89$, $p = 0.14$). Similarly, changes in pollinator abundance and richness at Flower strip 2 and the control site were not significant.

3.4. Diversity

Estimated asymptotic diversity measures (Chao Shannon and Chao Simpson estimates) were higher in the assemblages of the WFS sites compared to the control site (Table 3). The observed ordered diversity (Figure 5a), estimated ordered diversity for a sample of 1000 specimens (Figure 5b), and the relative evenness (Figure 5c) were all markedly higher in aculeate pollinator assemblages from the WFSs compared to the control site. This difference was consistent across the entire range of Hill numbers, reflecting all relative abundance classes from total species richness ($\log_2(q) = -\infty$) and those encompassing rare species (negative $\log_2(q)$) to common and dominant species (positive $\log_2(q)$).

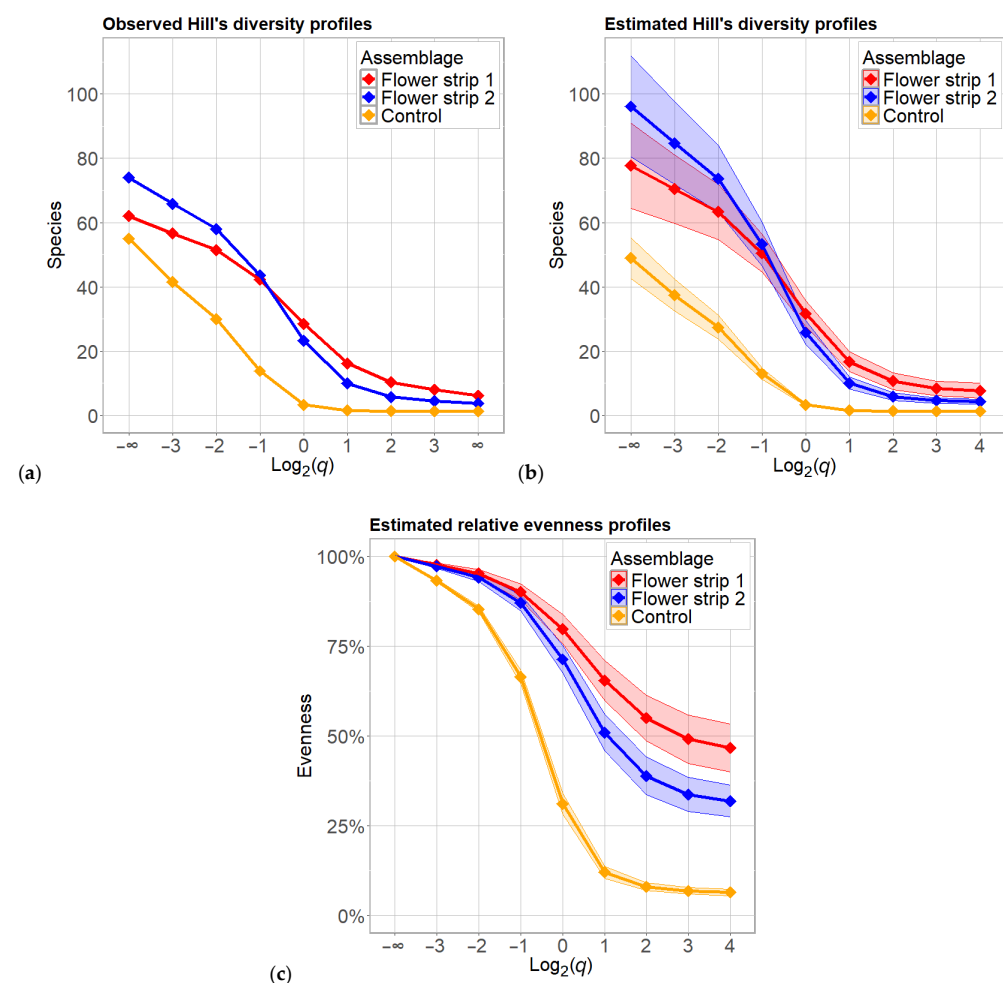


Figure 5. Ordered diversity and evenness profiles of three aculeate pollinator assemblages, observed on two flower strips and on a control site with semi-natural grassland. (a) Observed Hill's diversity profiles. (b) Estimated Hill's diversity profiles (average $\pm$ SE). (c) Estimated relative evenness profiles (average $\pm$ 95% conf.).

4. Discussion

This small-scale case study demonstrated that aculeate pollinator species richness did not exhibit a considerable increase in the WFS site assemblages compared to the control site with semi-natural grassland vegetation (Figure 3b). However, both observed and estimated diversity, along with species distribution evenness, were significantly higher in the WFS assemblages compared to the control site (Figure 5a–c). Therefore, our first hypothesis is partially supported: the WFSs enhanced the diversity of aculeate pollinator assemblages, even though the species richness did not significantly increase. The ordered diversity and relative evenness indices showed that the WFS pollinator assemblages were more diverse across all relative abundance classes, from rare to common and dominant species. These results highlight the positive impact of WFS on the diversity of wild bees and other pollinators, which is a finding consistent with other studies [41,42,60].

An increase in aculeate pollinator abundance over the four years following its establishment was recorded at one of the two WFS sampling sites, which is a trend also observed in previous studies [33,48,60,85]. However, this pattern was not evident at the second WFS site; therefore, our second hypothesis is not strongly supported. We also did not observe a decline in pollinator abundance or diversity within the WFSs over time due to reduction in floral diversity, as reported in another study [38]. Since the impact of sown flower mixtures on pollination services increases with flower diversity and the time since establishment [31], our findings underscore the role of WFSs in enhancing the surviving pollinator diversity, thus likely supporting the pollination ecosystem services in agricultural environments. We suggest that aculeate pollinator populations, already present in small patches of semi-natural grasslands in the agricultural landscapes surrounding the study site, are able to quickly colonize the established WFSs and exploit new floral resources. As a result, a measurable increase in pollinator abundance was observed at one of the study sites.

The remarkably high abundance of *Lasioglossum pauxillum* recorded during late-summer transect counts at the control site, following the rapeseed harvest in surrounding more or less distant fields, suggests that particular species may benefit from flowering crops, relying on semi-natural vegetation patches as a refuge during periods of floral scarcity in agricultural environments. Therefore, we consider these observations to support our third hypothesis. This finding aligns with prior research [86], which demonstrated a positive correlation between bumblebee densities and the availability of mass-flowering oilseed rape. The comparatively lower abundance of *L. pauxillum* per transect count in the WFSs compared to the control site, despite the proximity of rapeseed fields, could be attributed to the larger area and greater floral abundance within the WFS, likely leading to a dilution effect and thus a lower concentration of *L. pauxillum* specimens.

Furthermore, our results suggest that semi-natural or minimally managed vegetation patches along roads or drainage ditches in intensively farmed landscapes can provide critical resources for pollinator populations during periods when flowering crops, such as rapeseed, are no longer in bloom. Semi-natural habitats have been identified as key predictors of pollinator species richness [87]. Although the remnants of such habitats in agricultural environments may support a narrower range of pollinator species compared to WFSs, as evidenced by our control site, they still play a vital role in conserving bee diversity [88]. Our findings corroborate existing evidence that allowing entomophilous weeds to persist within agricultural environments can provide benefits for flower-visiting insects comparable to those of WFSs [89–91]. Furthermore, they do not contradict the assertion that preserved semi-natural habitat patches may sustain greater pollinator abundance than WFSs or mass-flowering monocultures, such as sunflower [92].

5. Conclusions

In intensive agricultural environments, wildflower strips enhanced with species-rich flowering plant seed mixtures (in our case, 50 plant species) can provide floral resources for diverse pollinator assemblages. These assemblages exhibit higher species diversity and relative evenness of abundance distribution compared to pollinator assemblages in patches of semi-natural vegetation.

In this study, the abundance and species richness of aculeate pollinator assemblages remained relatively stable over four years of observations following the establishment of the WFSs. In one case, abundance increased, although the growth in species richness was not significant. These findings suggest that pollinator populations are present in agricultural landscapes, exploiting floral resources from mass-flowering crops, such as rapeseed, and remnants of semi-natural vegetation. These populations can immediately colonize the WFSs and benefit from their establishment.

Mass-flowering crops may serve as suitable resources for certain wild pollinator species, driving their population growth. During periods when mass-flowering crops are not in bloom, these pollinators are able to persist within the semi-natural grassland vegetation patches; therefore, together with WFSs, these patches can play a critical role in sustaining pollinator populations. Consequently, both the establishment of WFSs and the conservation of semi-natural, minimally managed habitats are essential for maintaining the ecosystem service of pollination in intensively managed agricultural systems.

Author Contributions: Conceptualization, E.B. and G.S.; methodology, E.B., M.L., J.A.S. and G.S.; software, E.B.; validation, E.B., A.B. and G.S.; formal analysis, E.B., M.L., J.A.S. and G.S.; investigation, E.B., A.B., M.L., J.A.S. and G.S.; resources, J.A.S. and G.S.; data curation, E.B. and M.L.; writing—original draft preparation, E.B. and A.B.; writing—review and editing, E.B., A.B. and G.S.; visualization, E.B.; supervision, E.B. and G.S.; project administration, G.S.; funding acquisition, G.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research, as part of the ‘Biodiversity: Research in agro-ecosystems and promotion of its conservation’ project, was funded by BASF SE (Germany) and Vilnius University (Lithuania) R&D-Service Agreement Nr. (1.57) 15600-INS-43. The research was carried out using Open Access to research infrastructure of Vilnius University and the Nature Research Centre (Vilnius, Lithuania).

Institutional Review Board Statement: Not applicable.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author (E.B.) upon reasonable request.

Acknowledgments: We express our gratitude to Roma Laurinkienė and Aleksandr Voitkevič (BASF UAB Lithuania) for their managerial support. Special thanks are extended to farmer Zigmantas Aleksandravičius for establishing the flower strips and providing access for field research. We also sincerely thank Sigita Juzėnas (Vilnius University) for assistance with plant identification and Viktorija Kuznecova (Vilnius University) for her help with sample sorting. The authors are grateful to the three anonymous reviewers for their valuable comments and suggestions.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study, in the collection, analyses, or interpretation of data, in the writing of the manuscript, or in the decision to publish the results.

Abbreviations

The following abbreviations are used in this manuscript:

WFS Wildflower strip

References

1. Klein, A.-M.; Vaissière, B.E.; Cane, J.H.; Steffan-Dewenter, I.; Cunningham, S.A.; Kremen, C.; Tscharntke, T. Importance of pollinators in changing landscapes for world crops. *Proc. R. Soc. B.* **2007**, *274*, 303–313. [\[CrossRef\]](#) [\[PubMed\]](#)
2. Kremen, C.; Williams, N.M.; Aizen, M.A.; Gemmill-Herren, B.; LeBuhn, G.; Minckley, R.; Packer, L.; Potts, S.G.; Roulston, T.; Steffan-Dewenter, I. Pollination and other ecosystem services produced by mobile organisms: A conceptual framework for the effects of land-use change. *Ecol. Lett.* **2007**, *10*, 299–314. [\[CrossRef\]](#) [\[PubMed\]](#)
3. Aizen, M.A.; Garibaldi, L.A.; Cunningham, S.A.; Klein, A.M. How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. *Ann. Bot.* **2009**, *103*, 1579–1588. [\[CrossRef\]](#) [\[PubMed\]](#)
4. Potts, S.G.; Imperatriz-Fonseca, V.; Ngo, H.T.; Aizen, M.A.; Biesmeijer, J.C.; Breeze, T.D.; Dicks, L.V.; Garibaldi, L.A.; Hill, R.; Settele, J.; et al. Safeguarding pollinators and their values to human well-being. *Nature* **2016**, *540*, 220–229. [\[CrossRef\]](#)
5. Pardo, A.; Borges, P.A.V. Worldwide importance of insect pollination in apple orchards: A review. *Agric. Ecosyst. Environ.* **2020**, *293*, 106839. [\[CrossRef\]](#)
6. Stanley, D.A.; Msweli, S.M.; Johnson, S.D. Native honeybees as flower visitors and pollinators in wild plant communities in a biodiversity hotspot. *Ecosphere* **2020**, *11*, e02957. [\[CrossRef\]](#)
7. Bishop, J.; Garratt, M.P.D.; Nakagawa, S. Animal pollination increases stability of crop yield across spatial scales. *Ecol. Lett.* **2022**, *25*, 2034–2047. [\[CrossRef\]](#)
8. Devkota, K.; Ferreira, A.B.; Timberlake, T.P.; dos Santos, C.F. The impact of pollinator decline on global protein production: Implications for livestock and plant-based products. *Glob. Ecol. Conserv.* **2024**, *50*, e02815. [\[CrossRef\]](#)
9. Potts, S.G.; Biesmeijer, J.C.; Kremen, C.; Neumann, P.; Schweiger, O.; Kunin, W.E. Global pollinator declines: Trends, impacts and drivers. *Trends Ecol. Evol.* **2010**, *25*, 345–353. [\[CrossRef\]](#)
10. Wagner, D.L. Insect declines in the anthropocene. *Annu. Rev. Entomol.* **2020**, *65*, 457–480. [\[CrossRef\]](#)
11. Zattara, E.E.; Aizen, M.A. Worldwide Occurrence Records Suggest a Global Decline in Bee Species Richness. *One Earth* **2021**, *4*, 114–123. [\[CrossRef\]](#)
12. Tscharntke, T.; Klein, A.M.; Kruess, A.; Steffan-Dewenter, I.; Thies, C. Landscape perspectives on agriculture intensification and biodiversity—Ecosystem service management. *Ecol. Lett.* **2005**, *8*, 857–874. [\[CrossRef\]](#)
13. Ricketts, T.H.; Regetz, J.; Steffan-Dewenter, I.; Cunningham, S.A.; Kremen, C.; Bogdansk, A.; Gemmill-Herren, B.; Greenleaf, S.S.; Klein, A.M.; Mayfield, M.M.; et al. Landscape effects on crop pollination services: Are there general patterns? *Ecol. Lett.* **2008**, *11*, 499–515. [\[CrossRef\]](#) [\[PubMed\]](#)
14. Winfree, R.; Bartomeus, I.; Cariveau, D.P. Native pollinators in anthropogenic habitats. *Annu. Rev. Ecol. Evol. Syst.* **2011**, *42*, 1–22. [\[CrossRef\]](#)
15. Vanbergen, A.J.; The Insect Pollinators Initiative. Threats to an ecosystem service: Pressures on pollinators. *Front. Ecol. Environ.* **2013**, *11*, 251–259. [\[CrossRef\]](#)
16. Goulson, D.; Nicholls, E.; Botias, C.; Rotheray, E.L. Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Science* **2015**, *347*, 1255957. [\[CrossRef\]](#)
17. Cole, L.J.; Kleijn, D.; Dicks, L.V.; Stout, J.C.; Potts, S.G.; Albrecht, M.; Balzan, M.V.; Bartomeus, I.; Bebeli, P.J.; Bevk, D.; et al. A critical analysis of the potential for EU Common Agricultural Policy measures to support wild pollinators on farmland. *J. Appl. Ecol.* **2020**, *57*, 681–694. [\[CrossRef\]](#)
18. Heuel, K.C.; Ayasse, M.; Burger, H. Bee-diverse habitats positively affect seed set in wild plant species. *Front. Ecol. Evol.* **2024**, *12*, 1343885. [\[CrossRef\]](#)
19. Pontarp, M.; Runemark, A.; Friberg, M.; Opedal, Ø.H.; Persson, A.S.; Wang, L.; Smith, H.G. Evolutionary plant–pollinator responses to anthropogenic land-use change: Impacts on ecosystem services. *Biol. Rev.* **2024**, *99*, 372–389. [\[CrossRef\]](#)
20. Haaland, C.; Naisbit, R.E.; Bersier, L.-F. Sown wildflower strips for insect conservation: A review. *Insect Conserv. Divers.* **2011**, *4*, 60–80. [\[CrossRef\]](#)
21. Ouvrard, P.; Transon, J.; Jacquemart, A.L. Flower-strip agri-environment schemes provide diverse and valuable summer flower resources for pollinating insects. *Biodivers. Conserv.* **2018**, *27*, 2193–2216. [\[CrossRef\]](#)
22. Hellwig, N.; Schubert, L.F.; Kirmer, A.; Tischew, S.; Dieker, P. 2022. Effects of wildflower strips, landscape structure and agricultural practices on wild bee assemblages—A matter of data resolution and spatial scale? *Agric. Ecosyst. Environ.* **2022**, *326*, 107764. [\[CrossRef\]](#)
23. Holland, J.M.; Bianchi, F.J.; Entling, M.H.; Moonen, A.C.; Smith, B.M.; Jeanneret, P. Structure, function and management of semi-natural habitats for conservation biological control: A review of European studies. *Pest. Manag. Sci.* **2016**, *72*, 1638–1651. [\[CrossRef\]](#)
24. Kleijn, D.; Bommarco, R.; Fijen, T.P.M.; Garibaldi, L.A.; Potts, S.G.; van der Putten, W.H. Ecological intensification: Bridging the gap between science and practice. *Trends Ecol. Evol.* **2019**, *34*, 154–166. [\[CrossRef\]](#)
25. Kowalska, J.; Antkowiak, M.; Sienkiewicz, P. Flower strips and their ecological multifunctionality in agricultural fields. *Agriculture* **2022**, *12*, 1470. [\[CrossRef\]](#)

26. Pérez-Sánchez, A.J.; Schröder, B.; Dauber, J.; Hellwig, N. Flower strip effectiveness for pollinating insects in agricultural landscapes depends on established contrast in habitat quality: A meta-analysis. *Ecol. Solut. Evid.* **2023**, *4*, e12261. [\[CrossRef\]](#)
27. Jachowicz, N.; Sigsgaard, L. Highly diverse flower strips promote natural enemies more in annual field crops: A review and meta-analysis. *Agric. Ecosyst. Environ.* **2025**, *381*, 109412. [\[CrossRef\]](#)
28. Uyttenbroeck, R.; Hatt, S.; Paul, A.; Boeraeve, F.; Piqueray, J.; Francis, F.; Danthine, S.; Frederich, M.; Dufrêne, M.; Bodson, B.; et al. Pros and cons of flowers strips for farmers. A review. *Biotechnol. Agron. Soc. Environ.* **2016**, *20*, 1. [\[CrossRef\]](#)
29. Uyttenbroeck, R.; Piqueray, J.; Hatt, S.; Mahy, G.; Monty, A. Increasing plant functional diversity is not the key for supporting pollinators in wildflower strips. *Agric. Ecosyst. Environ.* **2017**, *249*, 144–155. [\[CrossRef\]](#)
30. Krimmer, E.; Martin, E.A.; Krauss, J.; Holzschuh, A.; Steffan-Dewenter, I. Size, age and surrounding semi-natural habitats modulate the effectiveness of flower-rich agri-environment schemes to promote pollinator visitation in crop fields. *Agric. Ecosyst. Environ.* **2019**, *284*, 106590. [\[CrossRef\]](#)
31. Albrecht, M.; Kleijn, D.; Williams, N.M.; Tschumi, M.; Blaauw, B.R.; Bommarco, R.; Campbell, A.J.; Dainese, M.; Drummond, F.A.; Entling, M.H.; et al. The effectiveness of flower strips and hedgerows on pest control, pollination services and crop yield: A quantitative synthesis. *Ecol. Lett.* **2020**, *23*, 1488–1498. [\[CrossRef\]](#) [\[PubMed\]](#)
32. Capera-Aragones, P.; Cartar, R.; Foxall, E.; Tyson, R.C. How can we enhance crops with flowers to increase pollination services and stop bee decline? *Agric. Ecosyst. Environ.* **2024**, *367*, 108964. [\[CrossRef\]](#)
33. Lowe, E.B.; Groves, R.; Gratton, C. Field edge flower plantings have variable effects on wild bee abundance, richness, nesting success, and crop pollination, independent of the surrounding landscape. *Agric. Ecosyst. Environ.* **2024**, *362*, 108811. [\[CrossRef\]](#)
34. Sutcliffe, L.M.E.; Batáry, P.; Kormann, U.; Báldi, A.; Dicks, L.V.; Herzon, I.; Kleijn, D.; Tryjanowski, P.; Apostolova, I.; Arlettaz, R.; et al. Harnessing the biodiversity value of Central and Eastern European farmland. *Divers. Distrib.* **2015**, *21*, 722–730. [\[CrossRef\]](#)
35. Holland, J.M.; Douma, J.C.; Crowley, L.; James, L.; Kor, L.; Stevenson, D.R.; Smith, B.M. Semi-natural habitats support biological control, pollination and soil conservation in Europe. A review. *Agron. Sustain. Dev.* **2017**, *37*, 31. [\[CrossRef\]](#)
36. Schmidt, A.; Kirmer, A.; Kiehl, K.; Tischew, S. Seed mixture strongly affects species-richness and quality of perennial flower strips on fertile soil. *Basic Appl. Ecol.* **2020**, *42*, 62–72. [\[CrossRef\]](#)
37. Schütz, L.; Wenzel, B.; Rottstock, T.; Dachbrodt-Saaydeh, S.; Golla, B.; Kehlenbeck, H. How to promote multifunctionality of vegetated strips in arable farming: A qualitative approach for Germany. *Ecosphere* **2022**, *13*, e4229. [\[CrossRef\]](#)
38. Albrecht, M.; Knecht, A.; Riesen, M.; Rutz, T.; Ganser, D. Time since establishment drives bee and hoverfly diversity, abundance of crop-pollinating bees and aphidophagous hoverflies in perennial wildflower strips. *Basic Appl. Ecol.* **2021**, *57*, 102–114. [\[CrossRef\]](#)
39. Harmon-Threatt, A.N.; Hendrix, S.D. Prairie restorations and bees: The potential ability of seed mixes to foster native bee communities. *Basic Appl. Ecol.* **2015**, *16*, 64–72. [\[CrossRef\]](#)
40. Kuppler, J.; Neumüller, U.; Mayr, A.V.; Hopfenmüller, S.; Weiss, K.; Prosi, R.; Burger, H. Favourite plants of wild bees. *Agric. Ecosyst. Environ.* **2023**, *342*, 108266. [\[CrossRef\]](#)
41. Amy, C.; Noël, G.; Hatt, S.; Uyttenbroeck, R.; Van de Meutter, F.; Genoud, D.; Francis, F. Flower Strips in wheat intercropping system: Effect on pollinator abundance and diversity in Belgium. *Insects* **2018**, *9*, 114. [\[CrossRef\]](#) [\[PubMed\]](#)
42. Williams, N.M.; Lonsdorf, E.V. Selecting cost-effective plant mixes to support pollinators. *Biol. Conserv.* **2018**, *217*, 195–202. [\[CrossRef\]](#)
43. Scheper, J.; Bukovinszky, T.; Huigens, M.E.; Kleijn, D. Attractiveness of sown wildflower strips to flower-visiting insects depends on seed mixture and establishment success. *Basic Appl. Ecol.* **2021**, *56*, 401–415.
44. Carvell, C.; Mitschunas, N.; McDonald, R.; Hulmes, S.; Hulmes, L.; O'Connor, R.S.; Garratt, M.P.D.; Potts, S.G.; Fountain, M.T.; Sadykova, D.; et al. Establishment and management of wildflower areas for insect pollinators in commercial orchards. *Basic Appl. Ecol.* **2022**, *58*, 2–14. [\[CrossRef\]](#)
45. Nichols, R.N.; Holland, J.M.; Goulson, D. Can novel seed mixes provide a more diverse, abundant, earlier, and longer-lasting floral resource for bees than current mixes? *Basic Appl. Ecol.* **2022**, *60*, 34–47. [\[CrossRef\]](#)
46. Müller, U.; Bruninga-Socolar, B.; Brokaw, J.; Cariveau, D.P.; Williams, N.M. Integrating perspectives on ecology, conservation value, and policy of bee pollinator seed mixes. *Front. Ecol. Environ.* **2024**, *22*, e2715. [\[CrossRef\]](#)
47. Williams, N.M.; Ward, K.L.; Pope, N.; Isaacs, R.; Wilson, J.; May, E.A.; Ellis, J.; Daniels, J.; Pence, A.; Ullmann, K.; et al. Native wildflower plantings support wild bee abundance and diversity in agricultural landscapes across the United States. *Ecol. Appl.* **2015**, *25*, 2119–2131. [\[CrossRef\]](#)
48. Buhk, C.; Oppermann, R.; Schanowski, A.; Bleil, R.; Lüdemann, J.; Maus, C. Flower strip networks offer promising long term effects on pollinator species richness in intensively cultivated agricultural areas. *BMC Ecol.* **2018**, *18*, 55. [\[CrossRef\]](#)
49. Warzecha, D.; Diekötter, T.; Wolters, V.; Jauker, F.; Didham, R.; Batáry, P. Attractiveness of wildflower mixtures for wild bees and hoverflies depends on some key plant species. *Insect Conserv. Divers.* **2018**, *11*, 32–41. [\[CrossRef\]](#)
50. Nichols, R.N.; Goulson, D.; Holland, J.M. The best wildflowers for wild bees. *J. Insect Conserv.* **2019**, *23*, 819–830. [\[CrossRef\]](#)
51. Burkle, L.A.; Delphia, C.M.; O'Neill, K.M. Redundancy in wildflower strip species helps support spatiotemporal variation in wild bee communities on diversified farms. *Basic Appl. Ecol.* **2020**, *44*, 1–13. [\[CrossRef\]](#)

52. von Königslöw, V.; Mupepele, A.C.; Klein, A.M. Overlooked jewels: Existing habitat patches complement sown flower strips to conserve pollinators. *Biol. Conserv.* **2021**, *261*, 109263. [CrossRef]
53. Schoch, K.; Tschumi, M.; Lutter, S.; Ramseier, H.; Zingg, S. Competition and facilitation effects of semi-natural habitats drive total insect and pollinator abundance in flower strips. *Front. Ecol. Evol.* **2022**, *10*, 854058. [CrossRef]
54. Sutter, L.; Albrecht, M.; Jeanneret, P. Landscape greening and local creation of wildflower strips and hedgerows promote multiple ecosystem services. *J. Appl. Ecol.* **2018**, *55*, 612–620. [CrossRef]
55. Boetzel, F.A.; Krimmer, E.; Krauss, J.; Steffan-Dewenter, I. Agri-environmental schemes promote ground-dwelling predators in adjacent oilseed rape fields: Diversity, species traits and distance-decay functions. *J. Appl. Ecol.* **2019**, *56*, 10–20. [CrossRef]
56. Alarcón-Segura, V.; Grass, I.; Breustedt, G.; Rohlf, M.; Tscharnkte, T. Strip intercropping of wheat and oilseed rape enhances biodiversity and biological pest control in a conventionally managed farm scenario. *J. Appl. Ecol.* **2022**, *59*, 1513–1523. [CrossRef]
57. Serée, L.; Barbottin, A.; Chiron, F.; Valantin-Morison, M.; Gardarin, A. Within-field floral resources have the potential to increase parasitism rates in winter oilseed rape pests more than resources at field margins. *Agric. Ecosyst. Environ.* **2023**, *344*, 108288. [CrossRef]
58. Diekötter, T.; Kadoya, T.; Peter, F.; Wolters, V.; Jauker, F. Oilseed rape crops distort plant–pollinator interactions. *J. Appl. Ecol.* **2010**, *47*, 209–214. [CrossRef]
59. Holzschuh, A.; Dainese, M.; Gonzalez-Varo, J.P.; Mudri-Stojnic, S.; Riedinger, V.; Rundlof, M.; Scheper, J.; Wickens, J.B.; Wickens, V.J.; Bommarco, R.; et al. Mass-flowering crops dilute pollinator abundance in agricultural landscapes across Europe. *Ecol. Lett.* **2016**, *19*, 1228–1236. [CrossRef]
60. Jönsson, A.M.; Ekroos, J.; Dänhardt, J.; Andersson, G.K.S.; Olsson, O.; Smith, H.G. Sown flower strips in southern Sweden increase abundances of wild bees and hoverflies in the wider landscape. *Biol. Conserv.* **2015**, *184*, 51–58. [CrossRef]
61. Osterman, J.; Theodorou, P.; Radzevičiūtė, R.; Schnitker, P.; Paxton, R.J. Apple pollination is ensured by wild bees when honey bees are drawn away from orchards by a mass co-flowering crop, oilseed rape. *Agric. Ecosyst. Environ.* **2021**, *315*, 2021107383. [CrossRef]
62. Harris, C.; Balfour, N.J.; Ratnieks, F.L.W. Floral Resource Wastage: Most Nectar Produced by the Mass-flowering Crop Oilseed Rape (*Brassica napus*) Is Uncollected by Flower-visiting Insects. *Ecol. Evol.* **2024**, *14*, e11453. [CrossRef] [PubMed]
63. Bommarco, R.; Marini, L.; Vaissière, B.E. Insect pollination enhances seed yield, quality, and market value in oilseed rape. *Oecologia* **2012**, *169*, 1025–1032. [CrossRef]
64. Morandin, L.A.; Winston, M.L. Wild bee abundance and seed production in conventional, organica, and genetically modified canola. *Ecol. Appl.* **2005**, *15*, 871–881. [CrossRef]
65. Holzschuh, A.; Dormann, C.F.; Tscharnkte, T.; Steffan-Dewenter, I. Expansion of mass-flowering crops leads to transient pollinator dilution and reduced wild plant pollination. *Proc. R. Soc. B* **2011**, *278*, 3444–3451. [CrossRef]
66. Keitt, T.H. Habitat conversion, extinction thresholds, and pollination services in agroecosystems. *Ecol. Appl.* **2009**, *19*, 1561–1573. [CrossRef]
67. Häussler, J.; Sahlin, U.; Baey, C.; Smith, H.G.; Clough, Y. Pollinator population size and pollination ecosystem service responses to enhancing floral and nesting resources. *Ecol. Evol.* **2017**, *7*, 1898–1908. [CrossRef]
68. Ebeling, A.; Klein, A.-M.; Schumacher, J.; Weisser, W.W.; Tscharnkte, T. How does plant richness affect pollinator richness and temporal stability of flower visits? *Oikos* **2008**, *117*, 1808–1815. [CrossRef]
69. von Königslöw, V.; Fornoff, F.; Klein, A.-M. Wild bee communities benefit from temporal complementarity of hedges and flower strips in apple orchards. *J. Appl. Ecol.* **2022**, *59*, 2814–2824. [CrossRef]
70. von Königslöw, V.; Fornoff, F.; Klein, A.-M. Pollinator enhancement in agriculture: Comparing sown flower strips, hedges and sown hedge herb layers in apple orchards. *Biodivers. Conserv.* **2022**, *31*, 433–451. [CrossRef]
71. Sentil, A.; Reverté, S.; Lhomme, P.; Bencharki, Y.; Rasmont, P.; Christmann, S.; Michez, D. Wild vegetation and ‘farming with alternative pollinators’ approach support pollinator diversity in farmland. *J. Appl. Entomol.* **2022**, *146*, 1155–1168. [CrossRef]
72. Sann, M.; Niehuis, O.; Peters, R.S.; Mayer, C.; Kozlov, A.; Podsiadlowski, L.; Bank, S.; Meusemann, K.; Misof, B.; Bleidorn, C.; et al. Phylogenomic analysis of Apoidea sheds new light on the sister group of bees. *BMC Evol. Biol.* **2018**, *18*, 71. [CrossRef]
73. GBIF.org. GBIF Home Page. 2025. Available online: <https://www.gbif.org> (accessed on 3 March 2025).
74. R Core Team. *R: A Language and Environment for Statistical Computing*; R Foundation for Statistical Computing: Vienna, Austria, 2024.
75. RStudio Team. *RStudio: Integrated Development for R*. RStudio; PBC: Boston, MA, USA, 2025.
76. Chao, A.; Chiu, C.-H.; Jost, L. Unifying species diversity, phylogenetic diversity, functional diversity, and related similarity/differentiation measures through Hill numbers. *Annu. Rev. Ecol. Evol. Syst.* **2014**, *45*, 297–324. [CrossRef]
77. Jost, L. The relation between evenness and diversity. *Diversity* **2010**, *2*, 207–232. [CrossRef]
78. Chao, A.; Ricotta, C. Quantifying evenness and linking it to diversity, beta diversity, and similarity. *Ecology* **2019**, *100*, e02852. [CrossRef]
79. Chao, A. Nonparametric estimation of the number of classes in a population. *Scand. J. Stat.* **1984**, *11*, 265–270.

80. Chao, A. Estimating the population size for capture-recapture data with unequal catchability. *Biometrics* **1987**, *43*, 783–791. [[CrossRef](#)]
81. Hsieh, T.C.; Ma, K.H.; Chao, A. iNEXT: An R package for rarefaction and extrapolation of species diversity (Hill numbers). *Methods Ecol. Evol.* **2016**, *7*, 1451–1456. [[CrossRef](#)]
82. Chao, A.; Kubota, Y.; Zelený, D.; Chiu, C.-H.; Li, C.-F.; Kusumoto, B.; Yasuhara, M.; Thorn, S.; Wei, C.-L.; Costello, M.J.; et al. Quantifying sample completeness and comparing diversities among assemblages. *Ecol. Res.* **2020**, *35*, 292–314. [[CrossRef](#)]
83. da Silva, I.A.; Batalha, M.A. Taxonomic distinctness and diversity of a hyperseasonal savanna in central Brazil. *Divers. Distrib.* **2006**, *12*, 725–730. [[CrossRef](#)]
84. Wickham, H. *ggplot2: Elegant Graphics for Data Analysis*; Springer: New York, NY, USA, 2016.
85. Blaauw, B.R.; Isaacs, R. Flower plantings increase wild bee abundance and the pollination services provided to a pollination-dependent crop. *J. Appl. Ecol.* **2014**, *51*, 890–898. [[CrossRef](#)]
86. Westphal, C.; Steffan-Dewenter, I.; Tschardt, T. Mass flowering crops enhance pollinator densities at a landscape scale. *Ecol. Lett.* **2003**, *6*, 961–965. [[CrossRef](#)]
87. Biegener, C.; Holzschuh, A.; Tanner, B.; Sponsler, D.; Krauss, J.; Zhang, J.; Steffan-Dewenter, I. Landscape management can foster pollinator richness in fragmented high-value habitats. *Proc. R. Soc. B* **2025**, *292*, 20242686. [[CrossRef](#)] [[PubMed](#)]
88. Hadrava, J.; Talašová, A.; Straka, J.; Benda, D.; Kazda, J.; Klečka, J. A comparison of wild bee communities in sown flower strips and semi-natural habitats: A pollination network approach. *Insect Conserv. Divers.* **2022**, *15*, 312–324. [[CrossRef](#)]
89. Balfour, N.J.; Ratnieks, F.L. The disproportionate value of ‘weeds’ to pollinators and biodiversity. *J. Appl. Ecol.* **2022**, *59*, 1209–1218. [[CrossRef](#)]
90. Fountain, M.T. Impacts of wildflower interventions on beneficial insects in fruit crops: A review. *Insects* **2022**, *13*, 304. [[CrossRef](#)]
91. Twerski, A.; Albrecht, H.; Fründ, J.; Moosner, M.; Fischer, C. Effects of rare arable plants on flower-visiting wild bees in agricultural fields. *Agric. Ecosyst. Environ.* **2021**, *323*, 107685. [[CrossRef](#)]
92. Vujanović, D.; Losapio, G.; Mészáros, M.; Popov, S.; Markov Ristić, Z.; Mudri Stojnić, S.; Jović, J.; Vujić, A. Forest and grassland habitats support pollinator diversity more than wildflowers and sunflower monoculture. *Ecol. Entomol.* **2023**, *48*, 421–432. [[CrossRef](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.