Flower margins: attractiveness over time for different pollinator groups

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Flower Margins: Attractiveness over Time for Different Pollinator Groups

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Abstract: Supporting biodiversity in agricultural landscapes is key from both a conservation and ecosystem services perspective. Planting flower margins along crop field edges is one of the most established approaches to try and improve habitat and resources for insect pollinators on farms. Whilst there is growing evidence that these margins can result in increased pollinator abundance and diversity on farms in the short-term, there is little data looking at how these margins perform over longer periods. This study looked at the utilization of pollinator-friendly margins over time in an agricultural landscape in Hungary. 'Operation Pollinator' seed mixes with 12 species, were used at 96 farms in Hungary from 2010 to 2018. Insect pollinators were recorded on the sown flower margins and control margins (with naturally occurring vegetation) using walked transects. Repeated sampling of the margins was done over several years so that data was collected on margins from 0 (planted that season) to 7 years old. The abundance of pollinators in the Operation Pollinator flower margins was greater than in control margins for all groups recorded (honey bees, bumble bees, mining bees, trap-nesting bees, hoverflies and Lepidoptera). The biggest relative increase in abundance was in honey bees (768% increase in average abundance in the flower margin compared to the control across all observations), with mining (566%) and bumble bees (414%) showing the next largest increases. The abundance of bumble bees, trap-nesting bees and Lepidoptera in the margins did not vary with the age of the margin. Honey bees, mining bees and hoverflies all decreased in abundance with increasing margin age, as did flower abundance. The results suggest that for some pollinator groups, regardless of age, flower margins provide important resources in the agricultural landscape. However, this is not universally true and for certain pollinator groups, some re-sowing of the margins may be needed to sustain longer-term benefits.

Keywords: pollinators; field margin; bees; habitat enhancement; agri-environment; flower strips

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1. Introduction

Approximately two fifths (38%) of land in the European Union is devoted to agriculture [1]. Globally, 35% of food production comes from crops that depend on pollinators [2]. Supporting and promoting biodiversity within agricultural landscapes is crucial both for conservation and ecosystem services such as pollination. A well-established method proposed to bolster biodiversity in agricultural systems is sowing crop field margins with wildflower mixes [3]. These mixes can be designed with flowers adapted to local conditions and as such the margins can provide nectar and pollen resources [4–6], as well as nesting resources [7] for pollinating insects. At the landscape scale these uncropped habitats can potentially act as corridors for movement of animals through agricultural landscapes [8] and can provide overwintering sites for insects [9]. Furthermore, pollination is not the only ecosystem service that can benefit from floristically enhanced field margins, there is the potential for these features to improve biological pest control, nitrogen fixation and reduce soil erosion [10–12].

Field margins sown with pollinator-friendly seed mixes have been found to increase pollinator abundance and diversity in the margin itself [13–19]. There are mixed findings with respect to spillover of pollinators into the crop and effects on yield [13,15,20,21]. The flower diversity within the margin and the heterogeneity of the surrounding landscape can both modify the impact on pollinators. Generally, more diverse flower strips support a more diverse pollinator community, and less benefit is seen in heterogenous landscapes [22–24]. Studies looking at the impacts of flower margins are often conducted only over 1–3 years [20] which is shorter than the typical lifetime of a flower margin on farmland. There is little data available on how flower margins perform over longer time periods or how best to manage them in the longer term to ensure the maintenance of floral resources for pollinators and wider biodiversity. One analysis of floristically enhanced margins in England found that Syrphidae abundance was positively related to margin age, but there was no relationship between margin age and wild bee abundance [25].

In this study, the abundance of different pollinator groups was recorded in florally enhanced crop field margins (hereafter referred to as 'flower margins') and compared with control margins in the same farms. Our hypothesis was that all groups would show greater abundance in the flower margins than the controls, with the more mobile groups showing the greatest relative increase as more mobile taxa are better able to colonize resource patches in the wider landscape. For each group, the effect of margin age on abundance was assessed. Our hypothesis was that pollinator abundance would be positively related to flower margin age as there would be greater flower abundance with perennials establishing after 2–3 years. Also, increased, stable resources over several years would be expected to support population growth.

2. Materials and Methods

The study was conducted across Hungary, focusing on the West Danube region which is a predominantly agricultural region where the main crops are wheat, barley, corn, sunflower and oilseed rape. Pollinator-friendly flower margins were sown alongside crop fields in 96 farms between 2010 and 2018. The seed mix was developed for Hungary through the Operation Pollinator scheme (www.operationpollinator.com, accessed on 1 October 2022) using 12 common species of the native flora chosen to attract a range of pollinators (see Table 1 for full species list) and was sown at a rate of 15–20 kg/ha in the margins. The location of the flower margins were chosen in agreement with the farmer, the typical margin size was 1–2 hectares and margins ranged from 4–9 m wide. The soil was prepared by disking followed by harrowing. Drilling was done with a conventional grain driller or direct drilling between mid-March and late-April. In the first year, once the vegetation reached 20–40 cm in height (around the end of June), it was cut back to 15cm to reduce competing weeds. In the following years, growers cut the flower margins 2–3 times in the summer, with a last cut in October. Cuttings were collected and sold as hay or silage.

Observations of insect pollinators in the field margins were carried out from 2012–2018. A 100 m transect was walked along the margins recording the abundance of pollinators of the following groups: honey bees (*Apis mellifera*), bumble bees (*Bombus* spp.), mining bees (solitary bees collecting pollen on their legs), trap-nesting bees (those species which nest above the ground in plant stems, only *Megachile* spp. observed), hoverflies (Syrphidae) and butterflies (Lepidoptera). Every 40 steps (approximately 30 m) along the transect, a one-minute stop was made, followed by a 4 minute observation period recording pollinators within a 3 × 3 m square in front of the observer. These observations were also conducted along control margins in the same farm with no flower plantings. The control margins were located between 1000 and 5000 m from the corresponding flower margins and typically contained species from the following genera: *Lamium*, *Erigeron*, *Achillea*, *Conium*, *Cirsium*, *Tripleurospermum*, *Anthemis* and *Trifolium*. The control margins were pre-existing ruderal margins dominated by grass weeds with flowering plants present in low numbers. The control margins were cut once a year in early July to eliminate allergen weeds (phytosanitary law).

Table 1. The species composition of the Hungarian seed mixture for the Operation Pollinator flower margins surveyed in this study. Species were chosen that attract a range of pollinators, based on observations of pollinator visitation and foraging behaviour in earlier Operation Pollinator seed trials.

Species (Family)	Percent in Seed Mixture	kg/ha When Sown at 25 kg/ha	kg/ha When Sown at 20 kg/ha	Plant Type
Trifolium pratense (Fabaceae)	20	5	4	Perennial
Onobrychis viciaefolia (Fabaceae)	15	3.75	3	Perennial
Fagopyrum esculentum (Polygonaceae)	15	3.75	3	Annual
Medicago sativa (Fabaceae)	12	3	2.4	Perennial
Trifolium incarnatum (Fabaceae)	10	2.5	2	Perennial
Trifolium alexandrinum (Fabaceae)	7	1.75	1.4	Annual
Trifolium repens (Fabaceae)	5	1.25	1	Perennial
Phacelia tanacetifolia (Boraginaceae)	5	1.25	1	Annual
Secale cereale x Secale montanum (Poaceae)	3	0.75	0.6	Perennial
Lotus corniculatus (Fabaceae)	3	0.75	0.6	Perennial
Phleum pratense (Poaceae)	3	0.75	0.6	Perennial
Sinapis alba (Brassicaceae)	2	0.5	0.4	Annual

Transects were conducted between May and September in favourable weather conditions i.e., no precipitation and with the temperature at least 15 °C. On average, each margin was surveyed twice a year. During the surveys of control and flower margins, temperature was recorded along with a score for the abundance of flowers in the margin at that time: 0–5%, 6–19%, 20–49%, 50–100%.

The data were analyzed in R [26] using generalized linear mixed models (glmm) with a negative binomial distribution from the package glmmTMB [27], and the DHARMa package [28] was used for inspecting model residual plots. To investigate the impact of the flower margin for each pollinator group, the abundance of a pollinator group was the dependent variable and there was a random factor for year and nested random factors for date within farm. The explanatory variables were the margin type (i.e., control or flower margin), flower abundance (as an ordered factor with polynomial contrasts), the interaction between margin type and flower abundance and temperature. Although flower abundance was related to treatment i.e., greater flower abundance in the Operation Pollinator flower margins versus control margins, the variance inflation factors for the two explanatory variables were below 5 so both were included. Model selection was done by dropping explanatory variables and comparing models with the Chi-square test. To investigate the impact of margin age, a subset of the data was used including only records from the flower margins (i.e., removing the control data). In these glmm models the abundance of a pollinator group was the dependent variable and there was a random factor for year and nested random factors for date within farm. The explanatory variables were margin age, flower abundance in the margin and temperature. Although flower abundance decreased with margin age (Spearman's rho = −0.20, see Appendix A Figure A1), the variance inflation factors for the two explanatory variables were below 5 and so both were included in the models for pollinator abundance. An initial set of models was generated on this basis, including age as a linear and squared explanatory factor to account for the potential non-linear relationship between age of the margin and pollinator abundance. There is the potential for the use of the flower margin to increase in the early years as perennial plants become established, but decrease in later years due to the dominance of one or two species. Model selection was performed by dropping explanatory variables and comparing models with the Chi-square test.

3. Results

The results of the effect of the flower margins on the abundance of the different pollinator groups is summarized in Table 2. Across all the groups there was a greater abundance of pollinators in the flower margins than in the control margins. The greatest relative increase was seen in honey bees, bumble bees and mining bees, with the lowest relative increase in hoverflies (Figure 1). Pollinator abundance was positively related to the abundance of flowers in the margin for all groups. For bumble bees there was a linear increase in bumble bee abundance with increasing flower abundance. For the other pollinator groups, there was a positive linear and negative quadratic effect of flower abundance, meaning that there was an increase in pollinator abundance with flower abundance which decelerated as flower abundance increased. Hoverflies and mining bees were the two groups that had a significant interaction between the margin type and flower abundance ($p < 0.001$ and $p = 0.013$ respectively). For both, there was a positive relationship between flower abundance in the margin and pollinator abundance, but the rate of increase in pollinator abundance with flower abundance was greater in the flower margins than in the control margins (Figure 2).

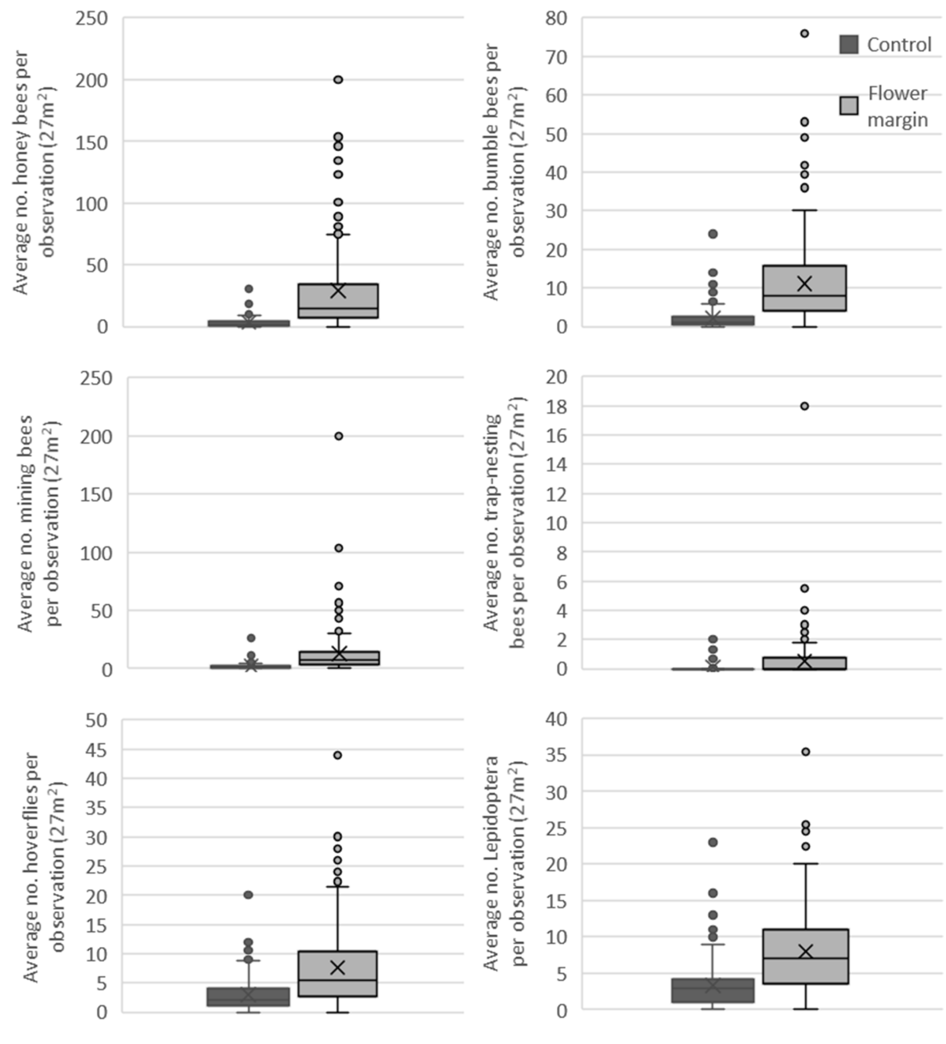

Figure 1. The average number of different pollinator groups observed in a 27 m^2 area (3 observations in a transect of 3 × 3 m) of control field margins and those planted with an Operation Pollinator seed mix (flower margin). The boxes are the interquartile range, the line in the box is the median and the cross is the average. The whiskers are 1.5 times the interquartile range and the dots are data points that fall outside that range.

Table 2. The results of the analysis of transect data recording different pollinator groups on control margins and those sown with a flower mix to support pollinators.

Pollinator Group	Margin Type			Flower Abundance			Temperature			Margin Type × Flower Abundance		
	p Value	ChiSq	Direction [1]	*p* Value	ChiSq	Direction [1]	*p* Value	ChiSq	Direction [1]	*p* Value	ChiSq	Direction [1]
Honey bees	<0.001	117	C < M	<0.001	565	+L, −Q	0.266	1		0.154	5	
Bumble bees	<0.001	123	C < M	<0.001	382	+L	0.733	0		0.052	8	
Mining bees	<0.001	126	C < M	<0.001	346	+L, −Q	0.266	1		0.013	11	+C, +M [2]
Trap-nesting bees	<0.001	41	C < M	<0.001	71	+L, −Q	0.107	2		0.185	5	
Hoverflies	0.013	6	C < M	<0.001	244	+L, −Q	0.003	9	+L	<0.001	17	+C, +M [2]
Lepidoptera	<0.001	53	C < M	<0.001	293	+L, −Q	0.008	7	+L	0.709	1	

[1] C = control, M = flower margin, L = linear, Q = quadratic, + = positive relationship, − = negative relationship; [2] The positive linear relationship with flower abundance was steeper in the flower margins than in the control margins.

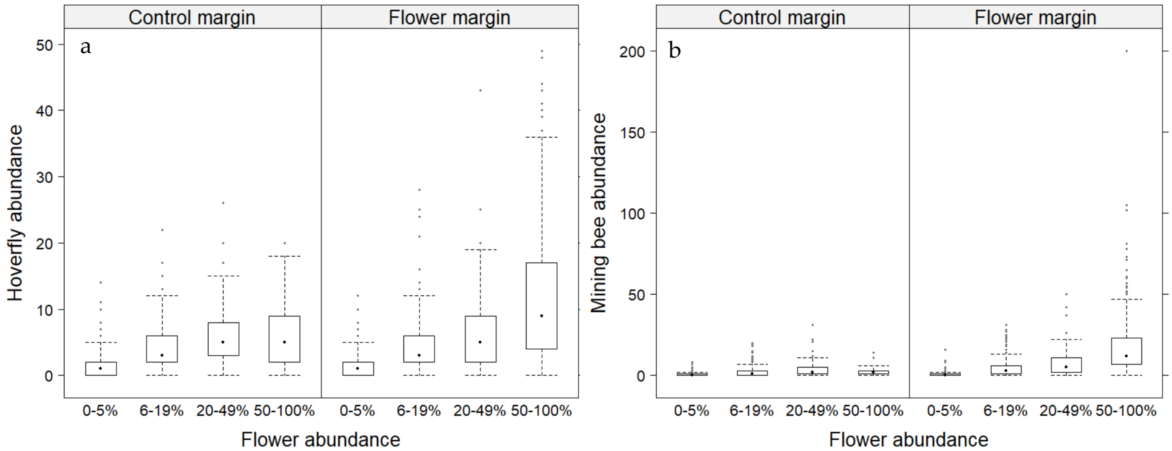

Figure 2. The relationship between pollinator and flower abundance in the control margins and margins planted with a pollinator friendly seed mix, for hoverflies (**a**) and mining bees (**b**). The boxes are the 25th and 75th percentile with the black dot showing the median. The whiskers are 1.5 times the interquartile range and the hollow dots are points falling outside that range.

The results of how the age of flower margins effects the abundance of the different pollinator groups is summarized in Table 3 (Figure 3). For bumble bees (p = 0.130) and Lepidoptera (p = 0.351), the age of the margin did not influence their abundance. The number of trap nesting bees observed increased linearly with flower margin age ($p < 0.001$) but only slightly with a predicted increase of less than one bee for each year of the margin. For honey bees, mining bees and hoverflies, the relationship between pollinator abundance and flower margin age was non linear (Table 3, Figure 3). The negative linear relationship indicates a decrease in abundance with increasing age of the flower margin, whilst the positive age squared value indicates the rate of decrease is greatest early on, i.e., pollinator abundance decreases more rapidly in the early years of the flower margin. For all groups, pollinator abundance in the flower margin was positively related to flower abundance (Table 3). The abundance of hoverflies (p = 0.008) and Lepidoptera (p = 0.013) was positively related to temperature.

Table 3. The results of the analysis of flower margin age (years since sown with a flower mix to support pollinators) on the abundance of different pollinator groups.

Pollinator Group	Flower Margin Age			Flower Abundance			Temperature		
	p Value [1]	ChiSq	Direction [1]	*p* Value	ChiSq	Direction [2]	*p* Value	ChiSq	Direction [2]
Honey bees	<0.001, <0.001	34, 14	−L, +SQ	<0.001	347	+L, −Q	0.262	1	
Bumble bees	0.130	3		<0.001	228	+L	0.907	0	
Mining bees	0.008, 0.009	7, 7	−L, +SQ	<0.001	254	+L, −Q	0.464	1	
Trap nesting bees	<0.001	12	+	<0.001	82	+L	0.501	0	
Hoverflies	<0.001, <0.001	44, 20	−L, +SQ	<0.001	156	+L, −Q	0.008	7	+
Lepidoptera	0.351	1		<0.001	161	+L, −Q	0.013	6	+

[1] Where two *p* values are present, the first is for age as a linear predictor and the second is for age squared which was included in the initial models to allow for a non-linear relationship. The negative linear and positive squared value indicate a decrease, with the rate of decrease being greatest early on. [2] L = linear, Q = quadratic, + = positive relationship, − = negative relationship, SQ = age squared.

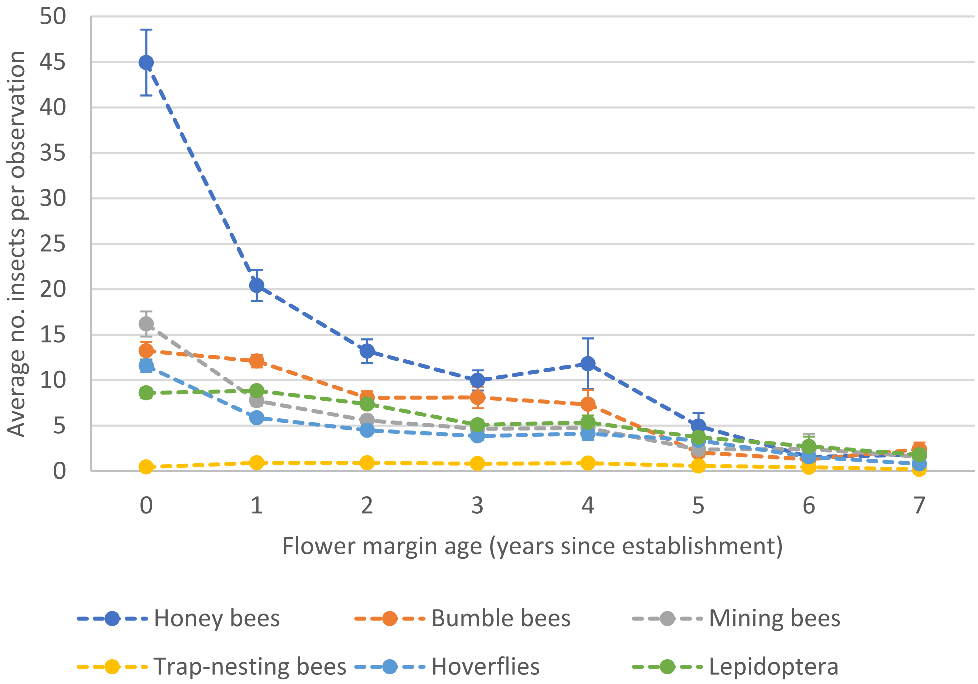

Figure 3. The relationship between pollinator abundance and age of the flower margin in years since establishment.

4. Discussion

Our findings further strengthen the evidence that in agricultural landscapes, sowing flowers in field margins for pollinators can increase their local abundance [3,13,21]. In particular honey bees, bumble bees and mining bees were found to utilize the flower margins. This might reflect the greater mobility of honey and bumble bees, as they can forage several hundred metres [29], which allows them to find and take advantage of floral resources over a wider scale. As honey bees are managed, their local abundance is largely driven by stocking density. However, they are able to recruit other workers in the hive to high value floral resources [30]. For the hoverflies and butterflies, it may be that they benefit from the nectar and pollen in the flower margins but that other resources such as oviposition host plants and larval food were limited or found elsewhere. Other factors that could influence pollinator abundance in the margins but were not included in our analysis are the amount of semi-natural habitat and mass-flowering crops in the surrounding landscape and the availability of nesting resources.

As expected, pollinator abundance was positively related to flower abundance in the margins, across all groups observed [5]. For bumble bees, abundance increased linearly with flower abundance (regardless of margin type), suggesting the flower species in the margins, both sown and naturally present in the control margins were attractive to bumble bees. Hoverflies and mining bees both increased in abundance more sharply in the flower margins compared to the controls, suggesting that the sown species were more attractive to them than those that were naturally present in the control margins.

Margin age (years since sown) did not significantly affect the abundance of bumble bees or Lepidoptera in the flower margins. Flower abundance in the margin was the strongest predictor of all groups' abundance in the margins. Flower diversity did tend to decline in the flower margins by the fourth year, with some of the species in the seed mix becoming more dominant, typically the perennials alfalfa (*Medicago sativa* L.), red and white clover (*Trifolium pratense* L. and *Trifolium repens* L.), birdsfoot trefoil (*Lotus corniculatus* L.) and sainfoin (*Onobrychis viciifolia* Scop.) [31]. Any such change in floral composition in the more established margins did not result in a decline in abundance in bumble bees or Lepidoptera. The number of trap nesting bees was positively related to margin age but overall numbers of Megachile were very low. The positive relationship with age could be due to the greater presence of the aforementioned flowers as the margins matured, which may be preferred by trap nesters or potentially a greater availability of nesting resources.

For honey bees, mining bees and hoverflies, there was a decline in abundance with margin age, particularly after the first year of establishment. Although flower abundance declined with margin age, there was little difference in flower abundance in margins aged 0, 1 and 2 years old. These findings are in contrast to those from other studies, that found positive effects of margin age. McHugh et al. (2022) found a positive relationship between margin age (0–15 years) and the abundance of Syrphidae and *Bombus* spp. but no overall relationship with wild bee abundance [25]. While older margins provide a greater opportunity for colonization, the increase in *Bombus* spp. in particular may have been related to some of the bumble bee species preferring to nest under cover, as the older margins had denser vegetation and less bare ground [25]. Lowe et al. (2021) found that bumble bee and solitary bee abundance increased with margin age (average margin age 3 years) [21]. One reason for the difference in the results could be the relative balance of perennials in the seed mix, as they can take more years to establish. The Operation Pollinator mix in this study was composed of 72% perennials. Flower abundance was highest in the early years of the margins' establishment, it is therefore unclear what caused the drop in the abundance of honey bees, mining bees and hoverflies after one year. Often annual flower margins are resown every 3–5 years, and our results support that without re-sowing the utility of the margins declines over time. A study of pollen and nectar strips in England found that over time the abundance of floral resources rapidly declined and floral communities homogenized [32]. In addition to re-sowing, Natural England recommends regular cutting/grazing (with cuttings removed) of flower-rich margins in the countryside stewardship scheme to initially help the sown species establish and then to prevent grasses dominating (spring) and to reduce soil fertility and help increase subsequent flowering (autumn).

The findings of this study highlight the benefit of flower margins for the local abundance of pollinating insects in agricultural landscapes, with the number of flowers in the margins playing a crucial role. Whether the local benefits observed affect population levels at the landscape scale is outside the scope of this study. The results also indicate that different pollinator groups respond differently to management of the margins, with age of the margin having mixed effects depending on the pollinator taxa. Differences in response to margin age have also been found for ground dwelling invertebrates [33]. Noordijk et al. (2010) found that although there was an overall positive relationship between margin age (0–10 years) and the richness of ground dwelling species groups; predator abundance was negatively related to margin age, herbivore abundance was positively related to margin age and detritivore abundance was not related to margin age [33]. The different resource requirements of diverse pollinator communities in terms of pollen, nectar, oviposition and nesting resources means that there will be no one best-fit solution of margin management for all [34]. It may be that increasing the heterogeneity of floral resources through maintaining a wide range of margin ages could be one way to achieve this at the farm level. Overall, across all pollinator groups Operation Pollinator flower margins were found to enhance the abundance of pollinators. The species in the seed mixture were chosen to provide both pollen and nectar resources for bees with different tongue lengths to attract a range of pollinators. The benefits could be further enhanced through managing the margins over the longer-term to increase the availability and variety of floral resources. Longer-term monitoring of field margins is needed to determine if increases in local abundance also translate into stable population growth in agricultural landscapes [35].

Author Contributions: Conceptualization, V.P.V., R.P. and C.B.; methodology, V.P.V., R.P. and S.B.; formal analysis, C.B.; writing—original draft preparation, C.B.; writing—review and editing, C.B., S.B., R.P., S.G.P., F.J.P.-F. and V.P.V.; project administration, V.P.V.; funding acquisition, V.P.V. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data presented in this study are available from the corresponding author upon reasonable request.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

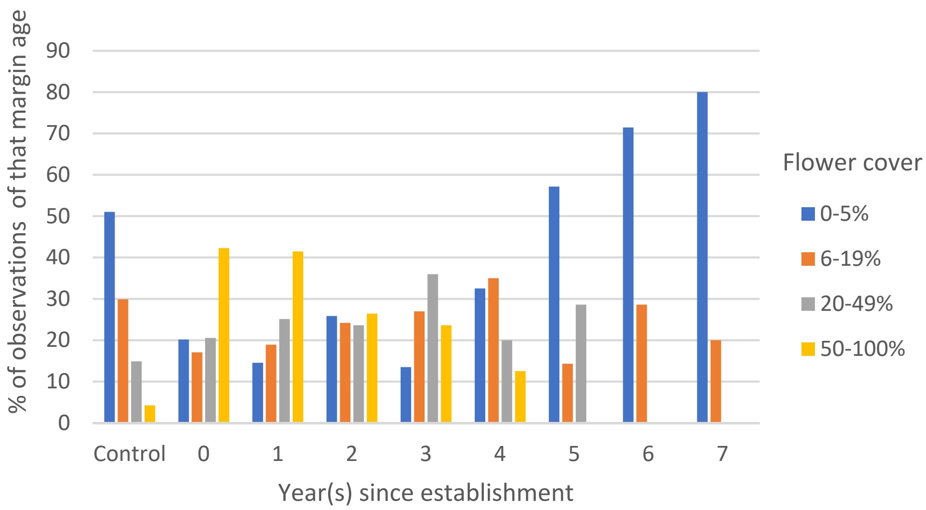

Figure A1. Flower abundance in the Operation Pollinator flower margins was scored as percent cover. The bar chart below shows the breakdown of flower abundance when observations of insect pollinators were conducted in margins of different ages (years since establishment) and also for the control margin.

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