Role of management in the long-term provision of floral resources on farmland

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Authors: Nichols, R.N.[a]; Wood, T.J.[b]; Holland, J.M.[c]; Goulson, D.[a]

a: School of Life Sciences, John Maynard Smith (JMS) Building, University of Sussex, Falmer, Brighton, BN1 9QG

b: Laboratory of Zoology, University of Mons, Avenue du Champs de Mars 6, 7000, Mons, Belgium

c: Game and Wildlife Conservation Trust, Burgate Manor, Fordingbridge, Hampshire, SP6 1EF

Corresponding author:

Rachel N. Nichols: r.nichols@sussex.ac.uk

Highlights

- Flower-rich agri-environments in the UK were surveyed on eight farms and farmers interviewed regarding land management.
- Floral abundance declined fastest in Pollen & Nectar Strips.
- Few sown species persisted in the habitats over a four-year period.
- Floral communities appear to homogenise over time irrespective of management.
- Farmers often lacked appropriate machinery to carry out prescribed managements.

Abstract

Floral abundance and richness on farmland has been declining since the mid 1900s. Agri-environment schemes (AES) can improve floral resource availability through establishment of flower-rich areas or careful management of areas set-aside to naturally regenerate on farmland. Ideal management regimes include sowing and re-sowing of seed mixes, regular cuts of growth, and removal of cuttings to optimise floral diversity. Our aim was to determine which areas and managements on farmland provided greatest floral resources for insect pollinators, and if these persisted over time. We surveyed 67 non-crop areas across eight farms in the south of England during 2014 and again in 2018, recording each flowering species present and the estimated floral abundance of each species. We then interviewed the farmers to determine management details and history for each surveyed area. Our results showed that floral abundance was initially greatest in sown Pollen & Nectar Strips and Florally Enhanced (FE) Grass Margins, but subsequently declined: from 1-5 years to 6-10 years for Pollen & Nectar Strips, and from 1-10 years to 11-20 years for FE Grass Margins. Additionally, only a handful of sown species known to be beneficial for insect pollinators persisted over time: *Centaurea nigra, Lotus corniculatus, Trifolium pratense* and *Leucanthemum vulgare*. It is vital that policy makers move forward with pollinator-targeting AES that can successfully support a variety of insects, including both pollinators and crop-pest predators. Species lists for AES seed mixes should include higher proportions of persistent perennial species, and a better support structure is needed in order to aid farmers with AES managements.

Keywords:

Wildflower; agri-environment scheme; field margin; seed mix; set-aside

1. Introduction

The decline of floral resources in agricultural areas is strongly linked to agricultural intensification (Robinson and Sutherland, 2002; Foley *et al.*, 2005, 2011). In crop production, the number of herbicides available for use in farmland across the United Kingdom (UK) rose sharply during the latter half of the 20th century (Lockhart *et al.*, 1990), and their widespread use within crops to reduce competition from arable 'weeds' has led to changes in the arable flora (Potts *et al.*, 2010). In addition, the application of nitrogen-rich fertilisers has led to those species better adapted to nutrient rich soils predominating, while the more characteristic and rarer arable plants have continued to decline (Staley *et al.*, 2013). The combined impact of the above resulted in soils where wildflowers were unable to compete with crops and grasses, with only a few species able to persist along field edges where agrochemical inputs are often lower (Barr *et al.*, 1990; Staley *et al.*, 2013). Livestock production has also intensified, with hay meadows being replaced by silage, and grazed mixed pastures converted to monocultures of highly productive grasses that respond to high inputs of nitrogen fertiliser. This overall land-use change has resulted in the decline of floral resources provided by grassland (Gossner *et al.*, 2016; Loos *et al.*, 2021).

Loss of farmland floral resources has been closely linked to the decline in insect pollinators during the last century (Scheper *et al.*, 2014; Powney *et al.*, 2019). Studies have shown an overall decline in wild bee richness and abundance (Winfree *et al.*, 2009), decline of both common and rare hoverflies (Hallmann *et al.*, 2021), and a lack of specialist butterflies on farmland (Habel *et al.*, 2019). Providing sufficient floral richness on farmland is important, as different plant species offer varying quantities and qualities of pollen and nectar (proteins, lipids, sugar concentrations etc.; Hicks *et al.*, 2016), and the brood success of different pollinator species often depends on the diet available during adult foraging and provisioning (Vaudo *et al.*, 2015; Barraud *et al.*, 2022). Additionally, insect pollinator species have varying flight seasons throughout the year and often display specialised foraging niches (Falk, 2015), and so a diverse range of plant species is required throughout the season to more completely support the pollinator community.

Although there is a clear need to provide the maximum floral richness possible to support insect pollinator communities on farmland, recent studies have shown that just 10-15 "key plant species" are required to provide forage for all species within a taxonomic group. For example, key plant species required to attract 100% of wild bee and hoverfly species included *Achillea millefolium*, *Daucus carota*, and *Crepis capillaris* (Warzecha *et al.*, 2018; Nichols, Goulson and Holland, 2019). Therefore, assessing the presence of certain key plant species could determine the potential of a floral habitat to support the local pollinator community.

Agri-environment schemes (AES) are wildlife-friendly measures put in place on farmland to improve biodiversity levels, mitigate climate change and provide ecosystem services (Pywell *et al.*, 2011; Barral *et al.*, 2015). Within the European Union and UK these are voluntary agreements with monetary reward for uptake, and cover a range of management practices, such as grassland restoration (Alison *et al.*, 2017), a variety of crop rotation options (Marja *et al.*, 2018), and set-aside for spontaneous species to naturally regenerate and/or the sowing wildflower seed mixes (Ouvrard, Transon and Jacquemart, 2018; Threadgill *et al.*, 2021). AES that specifically target insect pollinators primarily revolve around enhancing floral richness and abundance. Management practices include: 1) allowing areas to naturally regenerate from the seedbank (Threadgill *et al.*, 2021), 2) sowing (and re-sowing) of wildflower seed mixtures along field margins or unprofitable areas of arable land (Ouvrard, Transon and Jacquemart, 2018), 3) increasing the herbaceous plants in grassland through reduced grazing pressure and reduced agrochemical inputs (Hudewenz *et al.*, 2012), and 4) cutting hedgerows less frequently (Staley *et al.*, 2016).

Each AES has specific requirements and management prescriptions depending on the precise agreement. Some prescriptions specify areas to be cut and these cuttings be removed. This should slow the growth of grasses and weeds, reduce competition for wildflowers, lengthen the flowering season, and prevent nutrients returning to the already fertile soil (Pywell, Meek, Hulmes, *et al.*, 2011; Nowakowski and Pywell, 2016; Chaudron *et al.*, 2020). Therefore, in areas where improving floral resources for insect pollinators is the aim, yearly cuts and the removal of cuttings should produce the best floral resources for pollinators.

It is unclear what management practices the farmers have typically been able to carry out, and how effective these pollinator-targeting AES have been in achieving their goals of long-standing, dense wildflower areas. To address this knowledge gap, 67 non-crop areas receiving varying managements were surveyed twice at an interval of four years across eight farms in southern England. We aimed to identify i) if the presence of an AES agreement or specific management resulted in greater floral resource availability; ii) how the floral communities changed as they aged; iii) which managements resulted in maximum key flower species for insect pollinators, and their persistence.

2. Materials and methods

2.1 Study sites

The study was conducted on eight farms across Hampshire and West Sussex (England, UK) from May to August in both 2014 and 2018 (see Appendix A for map of locations). These farms currently or previously fell under one of two tiers in the UK Environmental Stewardship Schemes, Entry-Level Stewardship (ELS) or Higher-Level Stewardship (HLS), both of which were established in 2005 (DEFRA, 2005, 2013). One transect of 3km was marked out on each farm by TJW in 2013. Each transect covered a range of different habitat types (see Appendix B), resulting in 67 non-crop areas across eight farms. Habitats included hedgerows, sown seed mixtures targeting birds or bees, grass margins, and areas left to naturally regenerate.

2.2 Floral surveys

Floral surveys were conducted along each transect in 2014 in three rounds (TJW): 17th – 27th May, 21st Jun – 9th Jul, and 3rd – 15th Aug (hereon referred to as survey rounds); and in 2018 (RNN), on dates that aligned with the 2014 survey rounds: 14th – 19th May, 20th Jun – 7th Jul, and 3rd – 7th Aug. Each transect was separated into distinguishable sections as it was walked in 2014, and all sections were retained for the 2018 surveys. For each transect section, the flower species were noted and numbers of open flowers estimated within 2m either side of the observer (narrower habitat widths were noted). A "flower" was counted when fully open, and is defined as either a single flower, flowers on an umbel or spike, or a capitulum (following Heard *et al.*, 2007). Estimated counts were calibrated between both surveyors by each estimating flower counts from photographs and then calculating a scaling factor (see Appendix C).

2.3 Management history

The farmers/land managers were interviewed by RNN in Nov 2018 regarding the management history of the farm leading up to 2014 and between 2014 and 2018 (Questionnaire in Appendix D). Transect-specific questions were on sowing and cutting/grazing rates, and whether or not cuttings were removed. Based on the details provided by the land managers, all transect sections were defined, and managements categorised. Transect sections were retained for further analysis if they had a known management history, and if their categorisation "type" (hereon referred to as "management area") had three or more instances each year across all farms (providing replication; Table 1). A summary of the sections retained for further analysis can be seen in Table 2.

Table 1. Descriptions of each transect section retained for analysis and of each management category referred to throughout the paper.

Management Area	Description
Field Edge	The area of protected ground, 2m from the centre of the hedgerow or the treeline.$^{\Psi}$
Field Margin	Minimum of 2m in width around the edge of a field, taken out of production, often alongside a hedgerow or treeline. (Also includes field "sections" or "corners" taken out of production for an AES). Categories included sown areas: Pollen & Nectar Strips, Florally Enhanced (FE) Grass Margins, Grass Margins; and unsown areas: Natural Regeneration.
Verge	Flora along a road, lane, or footpath that forms a bank or verge.

Management Options	Description
AES agreement	Whether or not a section was under AES agreement and therefore payments were received for it.
Age (years)	Time since establishment.
Seed mix	Categorized as either i) Pollen & Nectar Strip mixes comprised of four or more flower species comprising >60% Fabaceae species ii) FE Grass Margin mixes had six or more species, with <50% Fabaceae species iii) Grass Margins were sown with a grass seed mix and <4 additional flower species iv) Natural Regeneration - unsown
Cutting	i) Cut yearly ii) Cut every 2 years iii) Cut less regularly or just for establishment iv) Never cut
Cutting removal	i) Cuttings removed ii) Cuttings not removed

[Ψ]: the minimum set-aside requirements (cross compliance) that UK farmers and land managers must meet if they are claiming rural payments (DEFRA, 2018).

Table 2. Different environmental uptakes on the surveyed farms, the number of transect sections that fell under each category, the percentage that were under an AES agreement, the age range of each management area, and the mean area in m² (±SE) of each management area.

Year	Management area	No. of sections	% under AES	Age range (years: min-max, mean) [Ψ]	Avg. area (m² ±SE)
2014	*Field Edge*	9	0.0	8-34, 16.1	417 ±88
	FE Grass Margin	25	92.0	1-13, 6.7	1339 ±143
	Grass Margin (sown)	7	85.7	13-17, 16.3	969 ±239
	Natural Regeneration	14	57.1	5-16, 8.1	1449 ±209

	Pollen & Nectar Strip	8	100.0	1-8, 3.6	909 ±103
	Verge	4	0.0	5-16, 8.8	577 ±249
2018	*Field Edge*	9	0.0	1-38, 16.0	417 ±88
	FE Grass Margin	22	72.7	2-17, 10.2	1299 ±144
	Grass Margin (sown)	6	83.3	17-21, 20.2	1045 ±269
	Natural Regeneration	15	46.7	2-20, 11.5	1446 ±195
	Pollen & Nectar Strip	7	85.7	1-12, 5.9	958 ±105
	Verge	4	0.0	9-20, 12.8	577 ±249

$^{\Psi}$: certain areas such as field edges and verges have the potential to be much older than reported, however, these ages are based on the current farmers' known management of said area.

2.4 Data analysis

All data analysis was handled in R (R Core Team, 2020), and all figures were produced using 'ggplot2' (Wickham, 2016). Where results were analysed through modelling, floral abundance was tested with Linear Mixed Effects Models (LMM) and floral richness with Generalised Linear Mixed Effects Models (GLMM) (Bates *et al.*, 2015). GLMMs included a Poisson family with log-link, and a 'BOBYQA' optimizer. All model fits were confirmed by checking residual plots. Models were then tested against their null equivalents and their Chi-squared statistics are reported. Post-hoc Tukey tests were carried out on appropriate models that had a significant result.

Firstly, we assessed whether being under any AES agreement (AES presence) was a predictor of higher floral abundance or richness, and how this varied at different times of the season. Flower counts were summed (hereon referred to as floral abundance), and the number of flower species recorded were summed (hereon referred to as floral richness), for each transect section per survey round per year. The presence or absence of an AES agreement for each transect section was noted. To determine the effect of AES presence on 'floral abundance' (log-transformed), we fitted an LMM, and to assess the effect on 'floral richness', we fitted a GLMM. We tested the effects of 'AES presence', 'survey round', and their interaction as predictor variables. Both models (and all further models) also included 'survey year' and 'transect area m^2' (log-transformed) as explanatory variables, and 'section' nested within 'farm' as a random variable. The floral abundance and richness numbers were also divided by the area (m^2) of each transect section, in order to then calculate the mean and standard error for visualisation.

Following this, we assessed the effect of cutting regularity on floral abundance and richness. We summed the 'floral abundance' and 'floral richness' for each transect section per year (in the same way as above, but summing both metrics across all survey rounds). We again fitted an LMM to determine the effect on 'floral abundance', and a GLMM for 'floral richness'. We tested the effects of 'cutting regularity', 'management area', and their interaction as predictor variables.

Next, we considered how age impacted the floral community. We summed 'floral abundance' and 'floral richness' for each transect section per year (as above). An LMM was fitted to determine the effect of age on 'floral abundance, and a GLMM fitted to assess the effect on 'floral richness'. We tested the effects of 'section age', 'management area', and their interaction as predictor variables.

To further assess the effect of age on the floral community, we performed community dissimilarity analysis. Species abundances were combined for all three survey rounds within each transect section, for 2014 and 2018 separately. Bray-Curtis dissimilarity was calculated from the community matrix using the 'vegan' package (Oksanen *et al.*, 2020), followed by Non-metric Multidimensional Scaling to create an NMDS matrix. Section 'age' was tested with 999 permutations, and adjusted using 'Bonferroni' correction. To analyse the community dissimilarity, Permutational Multivariate Analysis of Variance (PERMANOVA) was then conducted using the 'vegan' package. PERMANOVA tests difference in similarities, and rejection of the null hypothesis suggests that groups differ in their location (within the multivariate space), their relative dispersion, or both (Assis *et al.*, 2013). Therefore, when PERMANOVA produced a significant result, a permutation analysis of multivariate dispersion (PERMDISP; Anderson, 2004) was performed on the same Bray–Curtis matrix to determine if variability in dispersion was present, potentially driving the significance seen in the PERMANOVA. The PERMANOVA was conducted with an interaction between 'management area' and section 'age', using 'farm' as a random variable in the 'strata' function and with 999 permutations, the results of which are reported as F-statistics (pseudo-F). To then determine the multivariate spread from the centroid, PERMDISP was performed using the 'vegan' package, assessing the effect of 'management area' using a 'centroid' analysis type, which was then tested with 999 permutations. Results are reported as F-statistics.

Finally, we considered "key plant species" for insect pollinators (Warzecha *et al.*, 2018; Nichols *et al*., 2019). We selected 14 plant species that are known to be attractive to foraging insect pollinators such as bumblebees, solitary bees, and hoverflies: *Achillea millefolium, Agrimonia eupatoria, Centaurea nigra, Cirsium arvense, Crepis capillaris, Daucus carota, Galium verum, Geranium pratense, Heracleum sphondylium, Leucanthemum vulgare, Lotus corniculatus, Trifolium pratense, Trifolium hybridum,* and *Taraxacum officinale agg*. (see Appendix E for supporting evidence). We filtered the data frame to only include these species, and then summed the 'floral abundance' and 'floral richness' in the same way previously described, per year. We built an LMM to assess the effect of 'management area' on 'floral abundance', with 'survey year' and 'transect area m^2' (log-transformed) as explanatory variables, and transect 'section' nested within 'farm' as a random variable. We then ran a GLMM using the same structure as above, to assess the effect of 'management area' on 'floral richness'. Multivariate analysis using Bray-Curtis dissimilarity was also conducted on these floral communities, again using a PERMANOVA and PERMDISP with the same structures as previously described. Results are reported as F-statistics.

3. Results

A total of 1,523,073 flowers were counted over the two years (after calibration), with an average of 190,384 (SE ±39,262) flowers recorded on each farm, comprising of 184 species from 37 botanical families (all species listed in Appendix F). Floral abundance was primarily driven by counts of Fabaceae (51.9%) and Asteraceae (15.8%) flowers in 2014, and Apiaceae (30.9%), Asteraceae (22.3%), and Fabaceae (17.9%) in 2018.

3.1 Management options

3.1.1 Impact of AES presence on floral resources

Areas under an AES agreement had a significantly greater floral abundance (mean: 3.47 flowers per m^2 SE ±0.37) than those not under an AES agreement (1.57 flowers per m^2 ±0.167; LMM: $\chi 2=29.6$, $P < 0.001$). However, there was a significantly lower floral richness in areas under AES agreement (0.008 species per m^2 ±0.00) than those not under AES agreement (0.013 species per m^2 ±0.001; GLMM: $\chi 2=21.7$, $P < 0.001$). Additionally, there was a significant AES presence x survey round interaction on both floral abundance (LMM: $\chi 2=29.1$, $P < 0.001$) and floral richness (GLMM: $\chi 2=21.5$, $P < 0.001$; Fig 1). Floral abundance was significantly greater in both years in the areas under AES agreement during the second survey round, but showed an overall decline from 2014 to 2018. In the first survey round, there is little to no difference in floral abundance between areas under AES agreement and those not, whilst floral richness was significantly greater in areas not under AES agreement.

Figure 1. Comparing all areas under an AES agreement (triangles; 2014: n = 135; 2018: n = 102) against all those not under agreement (circles; 2014: n = 59; 2018: n = 87) for mean floral resources (floral abundance and richness) per meter squared (±SE) during each of the three survey rounds.

3.1.2 Impact of management area on floral resources

Next, we determined the effect of management area on floral resources. Field Edges had the lowest floral abundance and floral richness in both years (Table 3), whilst Pollen & Nectar Strips had the highest floral abundance in both years, followed by FE Grass Margins and Natural Regeneration. Although there was a significant effect of management area on floral abundance (LMM: $\chi 2$= 14.0, P = 0.015), none of the management areas were significantly different from one another after post-hoc analysis corrections. There was also no significant effect of management area on floral richness (GLMM: $\chi 2$= 7.31, P = 0.062).

3.1.3 Impact of cutting regime on floral resources

Thirdly, we considered the different management areas and their cutting regimes. There was a significant interaction effect of management area x cutting regime on floral abundance (LMM: $\chi 2$= 20.3, P = 0.041), but no sole effect of cutting regime on floral abundance (LMM: $\chi 2$= 2.37, P = 0.500). There was no significant interaction effect of management area x cutting regime on floral richness (GLMM: $\chi 2$= 18.0, P = 0.082), as well as no sole effect of cutting regime on floral richness (GLMM: $\chi 2$= 4.73, P = 0.450). Very few sections had cuttings removed, and so the effects of this could not be analysed, but we can see that only FE Grass Margins (16%; Table 3) had cuttings removed up to 2014, with the addition of Natural Regeneration (20%) between 2014 and 2018. During the interviews, the majority of farmers stated that they did not have the appropriate equipment to remove cuttings.

Table 3. Mean sown floral richness per section (only of sections that had wildflowers sown), mean recorded species richness (per meter squared; ±SE), mean floral abundance (per meter squared; ±SE), percentage of transect sections cut yearly, and the percentage of transect sections that had their cuttings removed, for each management area each year.

Year	Management Area (n)	Avg. sown richness (per section)	Avg. sp. richness (/m²)	Avg. fl. abundance (/m²)	% cut yearly	% cuttings removed
2014	Pollen & Nectar Strip (8)	7.8 (±0.8)	0.03 (±0.00)	25.40 (±9.38)	50.0	0.0
	FE Grass margin (23)	13.7 (±1.0)	0.03 (±0.00)	14.30 (±2.55)	72.0	16.0
	Grass margin (7)	-	0.03 (±0.01)	5.62 (±1.25)	14.3	0.0
	Natural Regeneration (14)	-	0.02 (±0.00)	9.27 (±3.38)	42.9	0.0
	Field Edge (9)	-	0.04 (±0.01)	5.03 (±0.98)	11.1	0.0
	Verge (4)	-	0.05 (±0.01)	6.89 (±1.38)	75.0	0.0
2018	Pollen & Nectar Strip (7)	7.9 (±1.0)	0.03 (±0.00)	7.44 (±2.96)	71.4	0.0
	FE Grass margin (22)	13.9 (±1.0)	0.02 (±0.00)	4.58 (±1.03)	77.3	18.2
	Grass margin (6)	-	0.03 (±0.01)	2.96 (±1.01)	16.7	0.0
	Natural Regeneration (15)	-	0.03 (±0.01)	3.28 (±0.83)	53.3	20.0
	Field Edge (9)	-	0.04 (±0.01)	3.27 (±0.97)	11.1	0.0
	Verge (4)	-	0.05 (±0.01)	7.23 (±2.52)	75.0	0.0

3.2 Impact of age on floral resources

We found no significant effect of habitat age on floral abundance (LMM: $\chi2 = 0.58$, $P = 0.445$), and only a marginal interaction effect between age x management area (LMM: $\chi2 = 10.9$, $P = 0.053$). Additionally, there was no significant effect of age on floral richness

(GLMM: $\chi2$= 0.326, P = 0.568), nor a significant interaction effect between age x management area (GLMM: $\chi2$= 5.65, P = 0.342). Therefore, we conducted dissimilarity analysis to determine how floral communities changed as they aged.

Floral communities differed significantly between management area (PERMANOVA: $F_{5,109}$ = 4.48, P = 0.001), with a significant area x age interaction (PERMANOVA: $F_{5,109}$ = 1.96, P = 0.001). The analysis of dispersion suggested that this was caused by variation within each management area (PERMDISP: $F_{5,115}$ = 16.1, P = 0.001), as overlap between the areas was visible (Fig. 2). There was little variation within, and a high level of overlap between floral communities in Sown Grass Margins, Verges, and Field Edges. Their 95% CI ellipses also included most areas of Natural Regeneration not under AES agreement, and the majority of the oldest communities surveyed. These communities were all dominated by species not included in seed mixes, such as *Anthriscus sylvestris, Heracleum sphondylium, Lamium album*, and *Stachys sylvatica* (as seen in Fig. 4).

Field margins of Natural Regeneration and Pollen & Nectar Strips both had high levels of variation within their communities, as well as high levels of overlap with all other management areas. However, a small cluster of the youngest Pollen & Nectar Strips shared no overlap with the other management areas in terms of their floral composition. This cluster of communities were dominated by sown species *Trifolium hybridum, T. pratense,* and *Vicia sativa agg*., along with the annual *Sinapis arvensis* which spontaneously generated from the seedbank. Older Pollen & Nectar Strip communities had significantly lower abundances of these species, but increasing abundances of species such as *H. sphondylium, Chaerophyllum temulum* and *Vicia cracca*.

FE Grass Margins had slightly less variation between floral communities, and shared the majority of their community overlap with Pollen & Nectar Strips and Natural Regeneration, and shared the least amount of overlap with Field Edges. Their communities were dominated by the presence of *C. nigra, Lotus corniculatus, Leucanthemum vulgare, T. repens, Medicago lupulina*, and *A. sylvestris*.

Additionally, the age of an area had a significant role within the ordination after permutation analysis (R^2 = 0.350, P = 0.001; Fig. 2).

Figure 2. Non-metric multidimensional scaling (NMDS) plot using Bray-Curtis dissimilarity distances for floral composition in management areas. Each point (AES agreement present: triangle; no AES agreement present: circle) represents the floral community of a transect section for the whole season (all three survey rounds) in either 2014 or 2018. The red line represents the significance of the age of an area (in years, significant after Bonferroni correction), showing its direction within ordinate space. Ellipses show the 95% CI of multivariate t-distribution for each management area.

To further understand how the floral communities changed over time, we grouped each community into its relevant age bracket (Fig. 3; Fig. 4; Appendix G).

Floral richness showed no clear patterns for each management area as it aged, though the unsown areas (Verges, Field Edges, and Nat Regen) showed higher floral richness peaks than the sown areas (Fig. 3). By contrast, there was a clear correlation with floral abundance and age. Both the Pollen & Nectar Strips and FE Grass Margins showed a strong decrease in floral abundance as they aged. Pollen & Nectar Strips more than halved in floral abundance from 1-5 to 6-10 years (Fig. 3), and abundance continued to decline as these areas aged. FE Grass Margins showed a slower rate of decline in abundance than the Pollen & Nectar Strips (Fig. 3), the oldest areas becoming dominated by Apiaceae and Asteraceae species (Fig. 4). Field Edges, Grass Margins and

Verges had relatively stable floral abundances as they aged, showing peaks and troughs around a shared mean. As the sections aged, a number of species tended to become the predominant plants in the communities (Fig. 4), notably *A. sylvestris, H. sphondylium*, and *L. album*.

Figure 3. Average floral abundance and richness (per m^2) of each management area at different ages (±SE). See Appendix G for accompanying table.

Figure 4. Heatmap showing the floral density of the 25 most prominent species within each management area, over 5- or 10-year increments. Floral density is calculated as the mean number of flowers per m^2 for each species. Species within the Pollen & Nectar Strips reached the highest average densities (~16 flowers per m^2), whereas species within Grass Margins reached average densities of just over one flower per m^2. Species highlighted bold are considered key species for insect pollinators (Results 3.3).

Finally, we considered how sown species faired over time. We selected Pollen & Nectar Strips (n = 5) and FE Grass Margins (n = 22) that were sown prior to the 2014 survey, and remained in place in 2018, in order to assess the persistence of sown species (Table 4). Out of the 14 species sown in Pollen & Nectar Strips, 12 of these species were present during the 2014 surveys, each in at least one strip, and seven of these species disappeared from at least one strip between 2014 and 2018. Five species remained present in a strip or were recorded in additional strips from 2014 to 2018 (*C. nigra, L. corniculatus, S. dioica, T. hybridum,* and *T. pratense*). By comparison, of the 44 species sown in FE Grass Margins, only 24 of these species were recorded in 2014, each in at least one margin, and 21 of these species disappeared from at least one margin between 2014 and 2018. *Centaurea nigra, L. vulgare* and *Ranunculus acris* were three of the species that disappeared from margins between 2014 and 2018, but they remained present in a higher percentage of margins than the other 18 species. Only three species showed no local extinctions (*Anthyllis vulneraria, Centaurea scabiosa*, and *Origanum vulgare*).

Table 4. Persistence of sown species. All species sown in FE Grass Margins (n = 5 margins; 44 species) and Pollen & Nectar Strips (n = 22 margins; 14 species), the percentage of sections each species was sown in (% of sown sections), and the percentage of sections each species was found in during the 2014 and 2018 surveys (% of sections where found). Species where the % change from 2014 to 2018 was less than a 33.3% loss (median value) are in bold.

Management Area	Species	% of sown sections	% of sections where found	
			2014	2018
FE Grass Margin	***Anthyllis vulneraria***	**31.8**	**4.5**	**4.5**
	Centaurea scabiosa	**4.5**	**4.5**	**4.5**
	Centaurea nigra	**100.0**	**90.9**	**86.4**
	Daucus carota	**90.9**	**68.2**	**45.5**
	Knautia arvensis	**72.7**	**50.0**	**40.9**
	Leucanthemum vulgare	**63.6**	**59.1**	**45.5**
	Origanum vulgare	**4.5**	**4.5**	**4.5**
	Papaver rhoeas	**9.1**	**0.0**	**4.5**
	Ranunculus acris	**77.3**	**36.4**	**31.8**
	Ranunculus repens	**27.3**	**22.7**	**18.2**
	Rhinanthus minor	**31.8**	**13.6**	**9.1**
	Silene dioica	**50.0**	**27.3**	**18.2**
	Tripleurospermum inodorum	**9.1**	**0.0**	**4.5**
	Achillea millefolium	86.4	50.0	31.8
	Agrostemma githago	9.1	0.0	0.0
	Anthemis arvensis	9.1	0.0	0.0
	Borago officinalis	9.1	0.0	0.0
	Campanula rotundifolia	4.5	0.0	0.0
	Centaurea cyanus	9.1	0.0	0.0
	Clinopodium vulgare	4.5	4.5	0.0
	Filipendula ulmaria	40.9	0.0	0.0
	Galium verum	59.1	18.2	0.0
	Geranium pratense	27.3	13.6	0.0
	Glebionis segetum	9.1	0.0	0.0

	Lotus corniculatus	22.7	18.2	9.1
	Malva moschata	45.5	4.5	0.0
	Medicago lupilina	9.1	0.0	0.0
	Onobrychis viciifolia	36.4	13.6	0.0
	Phacelia tanacetifolia	9.1	0.0	0.0
	Pimpinella saxifraga	4.5	0.0	0.0
	Plantago lanceolata	13.6	4.5	0.0
	Plantago media	31.8	18.2	0.0
	Primula veris	4.5	4.5	0.0
	Primula vulgaris	27.3	0.0	0.0
	Prunella vulgaris	100.0	54.5	18.2
	Rumex acetosa	50.0	0.0	0.0
	Sanguisorba minor	31.8	0.0	0.0
	Scabiosa columbaria	31.8	0.0	0.0
	Silene latifolia	68.2	27.3	4.5
	Silene noctiflora	9.1	0.0	0.0
	Succisa pratensis	27.3	0.0	0.0
	Trifolium incarnatum	9.1	0.0	0.0
	Trifolium pratense	9.1	4.5	0.0
	Vicia sativa agg.	9.1	0.0	0.0
Pollen & Nectar Strip	***Centaurea nigra***	**100.0**	**40.0**	**80.0**
	Lotus corniculatus	**100.0**	**60.0**	**80.0**
	Onobrychis viciifolia	**100.0**	**60.0**	**40.0**
	Silene dioica	**40.0**	**40.0**	**40.0**
	Trifolium hybridum	**100.0**	**60.0**	**60.0**
	Trifolium pratense	**100.0**	**60.0**	**60.0**
	Leucanthemum vulgare	40.0	20.0	0.0
	Malva moschata	60.0	0.0	0.0
	Medicago lupilina	40.0	0.0	0.0
	Medicago sativa	20.0	20.0	0.0
	Melilotus officinalis	20.0	20.0	0.0
	Phacelia tanacetifolia	20.0	20.0	0.0
	Silene latifolia	20.0	20.0	0.0
	Vicia sativa agg.	80.0	40.0	20.0

3.3 Key plant species for insect pollinators

When considering 14 key plant species that attract a wide range of insect pollinators, there was a significant difference in floral richness between management areas (GLMM: χ^2=25.22, P < 0.001). Post-hoc analysis showed Field Edges had significantly lower richness (four species) than Pollen & Nectar Strips (12 species) and FE Grass Margins (14 species; Fig. 5). There was also a significant difference in floral abundance of key species between management areas (LMM: χ2=45.51, P < 0.001), with post-hoc analysis showing both Pollen & Nectar Strips and FE Grass Margins as having significantly greater floral abundance than Field Edges, Grass Margins, and Natural Regeneration (Fig. 5). A closer look at the abundance of each plant species within management areas (Fig. 5) shows Pollen & Nectar Strips had a skewed high abundance of two *Trifolium spp*. compared to other species, whereas the abundance across species was more evenly distributed in both FE Grass Margins and Natural Regeneration (12 species).

Figure 5. Floral density of key plant species for insect pollinators in each management area. Mean floral density calculated as the number of flowers per m^2 (square-root-transformed) of each key pollinator flower species within each management area. Pairwise post-hoc significance (P<0.05) of floral abundance between management areas denoted by lettering.

Floral communities containing these key species were shown to differ significantly between management areas when using an NMDS analysis (PERMANOVA: $F_{5,112}$ = 6.281, P < 0.001). The analysis of dispersion suggested that this was again caused by variation within groups (PERMDISP: $F_{5,114}$ = 11.314, P < 0.001), as a high level of overlap between groups was visible once more (Fig. 6). Age of a community was again significant within the ordination (R^2 = 0.277, P < 0.001). Eight of the 14 key plant species showed significant presence within the ordination (Fig. 6), and were associated with specific management areas. The *Trifolium spp*. were prominent within the Pollen &

Nectar Strips as well as some areas of natural regeneration under AES agreement. *Lotus corniculatus*, *Daucus carota*, *L. vulgare, C. nigra*, and *A. millefolium* were associated with FE Grass Margins, as well as some areas of Natural Regeneration under AES agreement. *Heracleum sphondylium* (R^2 = 0.16, P = 0.016) was found in areas least similar to the *Trifolium spp*. None of these key species were correlated with age.

Figure 6. Non-metric multidimensional scaling (NMDS) plot using Bray-Curtis dissimilarity distances of key plant species for insect pollinators. The red line represents the age of an area (in years, significant after Bonferroni correction), showing its direction within the ordination space. Key plant species with significant associations are shown with the direction and strengths of their gradients. Ellipses show the 95% CI of multivariate t-distribution for each management area.

4. Discussion

This study provides a unique insight into how the floral composition of different pollinator-targeting AES develops in both the short-term (1-5 years) and the long-term (20 years) under different management strategies. Studies often focus on the first 1-5 years of AES implementation (Pywell, Meek, Loxton, *et al.*, 2011; Scheper *et al.*, 2015; Piqueray *et al.*, 2019), often testing or adhering to specific management prescriptions, sometimes carried out on model farms by scientists or trained staff rather than by professional but untrained farmers (Pywell, Meek, Hulmes, *et al.*, 2011; Piqueray *et al.*, 2019). Here we showed how areas targeted at insect pollinators were implemented and managed in the UK over the last 20 years under real-world conditions, and their ability to provide diverse floral resources for insects to forage on.

Overall, our results showed that floral abundance decreased over time across all management areas. Additionally, floral communities appeared to converge and homogenise over time, regardless of their initial prescriptions (Staley *et al.*, 2013). This resulted in habitats that were less likely to support a wide variety of insect pollinators, potentially impacting their diet and reproductive success (Vaudo *et al.*, 2015), and consequently reducing their overall community size and the pollination services provided to both wildflowers and crops (Klein *et al.*, 2007; Ollerton, Winfree and Tarrant, 2011).

4.1 Impact of management options on floral resources

Areas where an AES agreement was present provided substantially greater floral abundance, particularly during the mid-season surveys in June and July. This suggests that floral resources in sown margins are an improvement on those provided in the minimum set-aside areas (Field Edges), and areas of natural regeneration (also shown in McHugh *et al.*, 2022). Therefore, they should continue to be supported through AES funding.

There was a distinct shortfall of early flowering plants in areas under AES agreement, many of which are vital for spring-emerging insects such as solitary bees and bumblebee queens (see Dicks *et al.*, 2015). This absence of early-flowering species has repeatedly been shown to be a feature of sown herbaceous species (Dicks *et al.*, 2015; Wood, Holland and Goulson, 2017; Ouvrard, Transon and Jacquemart, 2018; Nichols, Holland and Goulson, 2022). Instead of relying on sown species, we suggest that this early-season void could instead be partially addressed by early-flowering ruderal annual species, regularly found in recently cultivated areas that could be created alongside wildflower strips (McHugh *et al.*, 2022; Nichols, Holland and Goulson, 2022). Combined with the management of early-flowering woody species such as *Prunus* spp. and *Crataegus* spp. in hedgerows, early-flying insect pollinators can be better catered for (Wood and Roberts, 2017; McHugh *et al.*, 2022).

The timings of cuts may play a more important role in floral resources than we realised. Although we found no effect of performing a cut on floral abundance or richness, studies have shown that performing mid-summer cuts can improve the floral richness of an area, and removal of cuttings can increase the floral abundance (Noordijk *et al.*, 2009; Pywell, Meek, Hulmes, *et al.*, 2011; Piqueray *et al.*, 2019; though see McHugh *et al.*, 2022 for conflicting evidence). Therefore, the timings of cuts could be taken into consideration for future studies.

A recurring theme during the interviews was the lack of appropriate equipment to remove cuttings. This is regarded as an essential practice to reduce the competition from grasses and reduce the soil fertility. An infrastructure equipped to better support those unable to carry out the desired management is needed, or seed mixes developed that require less management to ensure AES guidelines can be achieved. In the UK, FE grass margin mixes have historically included grasses with an 80% grass: 20% wildflowers being routinely used, however elsewhere in Europe a much lower percentage of grass is recommended (20%) (pers. comm., Bijkirk). Pollen and Nectar mixes were also changed following poor longevity and now don't include grasses. Therefore, the longevity of flowering species in FE grass mixes may also be improved by reducing the proportion of grass seed. In addition, having wider strips or blocks of wildflower areas managed as hay meadows may prove a more effective strategy and be easier for farmers to manage (see Meyer *et al.*, 2017 for meadow management). In particular, narrow strips may not only be subject to fertiliser drift and run-off from the adjacent field, impacting insect pollinator visitations (Russo *et al.*, 2020), they may also prove to be more difficult to perform cuts and removals on due to spatial constraints.

4.2 Impact of age on floral resources

Our study showed that, irrespective of initial input, floral communities homogenised as they aged (also found by Warren *et al.*, 2002), reverting to a habitat typical of modern UK farmland margins which is dominated by grasses and where only a few species are predominant (Barr *et al.*, 1990; Staley *et al.*, 2013; McHugh *et al.*, 2022). In the case of our study, *A. sylvestris, H. sphondylium* and *S. sylvatica* dominated the older margins. This habitat is likely to affect the size and diversity of insect community that can be supported (Potts *et al.*, 2010), as specialist insect species are unable to survive and the insect community becomes dominated by common generalists (Weiner *et al.*, 2014).

The high variation between Pollen & Nectar Strip communities was unexpected considering the simplicity of the seed mixes, and was potentially driven in part by the variation in floral abundance between communities of different ages, and in part by the proportions of different species (the youngest communities had the highest densities and were dominated by Fabaceae species). The rapid decline in floral abundance over time in these Pollen & Nectar Strips is concerning when evidence suggests 1-2ha per 100ha of high-density floral cover is required to provide the minimum resources to rear larvae of just six common farmland bee species populations (Dicks *et al.*, 2015). It is possible that Pollen & Nectar Strips over five years old are not meeting the minimum floral cover requirements. We reaffirm the suggestion that these strips are re-sown every five years (Carvell *et al.*, 2007) and grasses are not included in the seed mix.

Our results suggest that FE Grass Margin mixes create a more stable habitat for floral resource given the slower decline in floral abundance over time. This could be driven by the cutting management as these were the only margins to have cuttings removed prior to the 2014 surveys (Noordijk *et al.*, 2009; Pywell, Meek, Hulmes, *et al.*, 2011). Despite appearing more stable, very few of the sown species maintained a consistent presence from 2014 to 2018. Species that persisted or declined at slow rates included those previously noted as key species for conservation efforts due to their persistence in the environment: *C. nigra, L. corniculatus, T. pratense,* and *L. vulgare* (Carvell *et al.*, 2006; Wood *et al*., 2017). Again, reducing the proportion of grass in the seed mix may help ensure flowering species persist for longer. Flowering cornfield annuals can also be included in the seed mix to act as a nurse plants for the perennials whilst also providing floral resources in the first year.

4.3 Key plant species for insect pollinators

Although FE Grass Margins showed the most promise in providing the greatest number of key plant species for insect pollinators, as the areas aged, only *L. vulgare* remained in high abundance. Therefore, we suggest these areas experience some level of disturbance, either through replacement, scarification, or herbicide application after ten years to encourage higher floral diversity (Potts *et al.*, 2007). Additionally, Pollen & Nectar Strips only had a substantial presence of *Trifolium spp*., species strongly favoured by bumblebees and honeybees, but little else (Wood, Holland and Goulson, 2015).

Finally, it is important to note that sown margins also allow spontaneous plant species to emerge from the seedbank, such as *H. sphondylium*. Spontaneous species provide vital forage for many insect pollinators, and often show better persistence in the environment than many sown species (Wood *et al*., 2017; Gresty *et al.*, 2018).

4.4 Conclusions

Overall, AES that target pollinators have the potential to provide floral resources, but many of the sown species disappeared as the margins aged, primarily because of competition from grasses. This could be due to a number of reasons, such as too much grass in the original seed mix, lack of farmer experience in wildflower management (McCracken *et al.*, 2015), or absence of appropriate equipment to carry out the desired management. Few resources have been provided in previous AES to support practical on-farm biodiversity training and better results may have been achieved if the farmers had received assistance and advice regarding wildflower management. Alternatively, sown species may not have been suited to the soil conditions and instead were outcompeted by better adapted species. Seed mixes can be produced that are targeted to local conditions such as soil type (Nowakowski and Pywell, 2016), and further research in this area might improve the success of sown wildflower strip longevity.

To improve the persistence of wildflowers there are several options to explore: a) reduce the amount of grass seed in the mixes, b) conduct a more regular re-sowing schedule, ideally with locally adapted, diverse mixes including both annual and perennial species, c) reduce competition from grasses using a graminicide d) scarify the margins to open up the sward for flowering species (Westbury *et al.*, 2017). Combined with specific cutting management, such as cutting 50% of the area to conserve habitat areas for insect pollinators and removing the cuttings could improve the floral diversity and longevity of sown wildflower areas (Nowakowski and Pywell, 2016). These proposals would require recognition and financial support through AES funding.

Ethical approval

This study received ethical approval from the University of Sussex Cross Schools Research Ethics Committee (C-REC) (reference number ER/RN225/1). Each interviewee read and signed a consent form regarding the use of the information they provided during the interview. Their data was anonymised and GDPR data protection laws were followed.

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Data availability

Data is available upon request.

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