Pre-print version

Delivery of floral resources and pollination services on farmland under three different wildlife-friendly schemes

Chloe J. Hardman[a], Ken Norris[b], Tim D. Nevard[c], Brin Hughes[d], Simon G. Potts[a]

[a]Centre for Agri Environmental Research, School of Agriculture, Policy and Development, University of Reading, Reading, RG6 6AR, UK

[b]Institute of Zoology, Zoological Society of London, Regents Park, London, NW1 4RY, UK

[c]Research Institute for the Environment and Livelihoods, Charles Darwin University, Darwin, NT0909, Australia

[d]Conservation Grade, 2 Gransden Park, Abbotsley, Cambridgeshire PE19 6TY, UK

Corresponding author: Chloe J. Hardman chloehardman@gmail.com

Abstract

Management that enhances floral resources can be an effective way to support pollinators and pollination services. Some wildlife-friendly farming schemes aim to enhance the density and diversity of floral resources in non-crop habitats on farms, whilst managing crop fields intensively. Others, such as organic farming, aim to support ecological processes within both crop and non-crop habitats. How effective these different approaches are for supporting pollination services at the farm scale is unknown. We compared organic farming with two non-organic wildlife-friendly farming schemes: one prescriptive (Conservation Grade, CG) and one flexible (Entry Level Stewardship, ELS), and sampled a representative selection of crop and non-crop habitats. We investigated the spatial distribution and overall level of: i) flower density and diversity, ii) pollinator density and diversity and iii) pollination services provided to Californian poppy (*Eschscholzia californica*) potted phytometer plants. Organic crop habitats supported a higher density of flowers, insect-wildflower visits, and fruit set of phytometers than CG or ELS crop habitats. Non-crop habitats supported a higher density of flowers and insect-flower visits than crop habitats on CG and ELS farms. Pollination services were higher on organic farms overall compared to CG or ELS. Pollinator diversity and density did not differ between schemes, at the point or farm level. CG farms received the highest total number of insect-wildflower visits. The findings support organic farming practices that increase floral resources in crop habitats, such as sowing clover or reduced herbicide usage, as mechanisms to enhance pollination services. However trade-offs with other ecosystem services are likely and these are discussed. The findings support the CG scheme as a way of supporting pollinators within farms where high wheat yields are required.

Keywords: Agri-environment scheme; bees; ecosystem services; flowers; organic farming; pollinator; phytometer.

1. Introduction

Declines in the abundance, diversity or ranges of insect pollinators have been documented in Britain (Ollerton *et al.*, 2014), China (Xie *et al.*, 2008), Europe (Nieto *et al.*, 2014), and North America (Cameron *et al.*, 2011). Key threats affecting pollinators include habitat loss, agrochemical use, climate change, disease, invasive species and their interactions (Potts *et al.* 2010, Vanbergen *et al.*, 2013, Goulson *et al.* 2015, Kerr *et al.*, 2015). In addition to species conservation concerns, these declines put pollination services at risk, which are important for 78% of wild plants (Ollerton *et al.*, 2011) and 75% of crops (Klein *et al.*, 2007). Demand for crop pollination in Europe has increased faster than honeybee stocks, increasing the dependency on wild pollinators for crop production (Breeze *et al.*, 2014). In Sweden, red clover seed yield has declined and become more variable, most likely due to the homogenisation of the bumblebee visitor community (Bommarco *et al.* 2012). Parallel declines in insect-pollinated plants, bees and hoverflies have been documented in the UK and the Netherlands, suggesting that insect-pollination services to wildflowers have declined (Biesmeijer *et al.*, 2006). However these declines have slowed since 1990, which may be due to conservation efforts (Carvalheiro *et al.*, 2013).

To mitigate declines in pollinators and associated pollination services, the limiting resources or risk factors affecting pollinator populations need to be addressed. Policy responses that benefit pollinators have so far focused on reversing habitat loss, particularly enhancing floral resources. Floral resources are considered to be a major limiting factor for bee populations (Roulston and Goodell, 2011) and have declined over the 20th century in the UK (Carvell *et al.* 2006). Areas managed to enhance floral resources tend to support a higher density and/or diversity of pollinating insects (Carvell *et al.*, 2007, Haaland *et al.*, 2011) and have been associated with higher densities of bumblebee nests (Wood *et al.*, 2015a). How effective floral resource enhancement is for pollinators depends not only on the density and diversity of flowers, but also on the ecological contrast that the management creates. Ecological contrast describes how far a resource is improved compared to a control and compared to the surrounding landscape (Scheper et al. 2013).

It is possible that floral resource enhancement could improve pollination services. Floral resources can influence pollination services through attracting more pollinators to the target plants (Ebeling *et al.*, 2008). This is an example of facilitation: when the surrounding floral display attracts pollinators and increases visitation to the target plant. Multi-species plant assemblages have been found to enhance visitation and pollination up to a threshold, above which the surrounding flowers compete with the target species for pollinator visits (Ghazoul, 2006). Local weed diversity (Carvalheiro *et al.*, 2011), proximity of semi-natural habitat (Garibaldi *et al.*, 2011, Martins *et al.*, 2015), creation of sown flower strips (Blaauw and Isaacs, 2014) and traditional hay meadow management (Albrecht *et al.*, 2007) have all been found to enhance pollination services in the local vicinity.

The main tools in Europe for enhancing floral resources in agriculturally dominated landscapes are wildlife-friendly farming schemes, which include both EU-funded governmental agri-environment schemes and market-funded certification schemes. These schemes vary widely in their objectives and management requirements. Most agri-environment schemes focus on managing land out of production rather than focusing on within-crop practices. For example, the English governmental scheme, Environmental Stewardship (ES), provides a number of options for enhancing floral resources in non-crop habitats. ES had two tiers of whole-farm schemes: Entry Level Stewardship (ELS), a flexible basic scheme and Higher Level Stewardship (HLS), a competitive scheme targeting regions containing high priority natural features. Farmers chose from a menu of management options which each had a payment rate, which in ELS was calculated using a points system. These schemes can be applied to both conventional and organic agricultural systems. In 2013, ELS covered 64.6% of England's agricultural land area, organic ELS covered 3.4% and HLS covered 18.4% (Natural England, 2013). In ELS, the option considered most beneficial for pollinators was sown blocks of legume based nectar flower mixture (Carvell *et al.*, 2007, Breeze *et al.*, 2014). HLS had a similar nectar flower mixture, plus options for floristically enhanced grass buffer strips and maintenance, restoration and creation of species-rich meadows. The adoption of floral resource enhancement options has been higher in HLS (73,126 ha) than in ELS (2,883 ha, Natural England, 2011), likely due to the wide choice of management options available to ELS participants. This high degree of farmer choice reduced the potential of ELS to provide the greatest benefit to pollinators (Breeze *et al.*, 2014).

Creating minimum management requirements that benefit pollinators is one way of encouraging farmers to implement options that provide the greatest benefits to wildlife. This is the approach taken by Conservation Grade (CG), a biodiversity-focused farming protocol, which is funded through sales of 'Fair to Nature' branded food products (http://www.conservationgrade.org). Farmers are required to provide wildlife habitat on at least 10% of the farmed area, of which 4% must be pollen and nectar rich habitat. Given this protocol, we expect non-crop habitats on CG farms to contain more floral resources, higher local pollinator density and diversity and higher pollination services than non-crop habitats on ELS farms.

Another strategy to make agriculture more wildlife friendly is through organic farming practices. These aim to promote ecological processes that aid production; therefore organic farming applies agroecological management to cropped areas more often than non-organic farming. This includes the use of legumes to build soil fertility and restrictions on pesticide inputs to encourage natural enemies. The spatial difference, within the farm, in the allocation of agri-environmental management between organic and non-organic farms in England is demonstrated by the national patterns of ELS option uptake. Organic farms were eight times more likely to undersow spring cereals with a 10% legume mix, and non-organic farms were three times more likely to take a field corner out of management (Natural England, 2011). Furthermore, organic management of crops is associated with a higher diversity and abundance of plants (Fuller *et al.*, 2005). Therefore, we expect to find a higher level of floral resource, a higher density and diversity of bees (as found by Holzschuh *et al.* 2007) and a higher level of pollination service in organic crops compared to non-organic crops.

In this study we compared three contrasting wildlife-friendly farming schemes in England: organic farming, Conservation Grade (CG), and Entry Level Stewardship (ELS). ELS was the baseline scheme in which all study farms participated. From here on, farms in ELS only are referred to as ELS, farms in ELS+CG are referred to as CG and farms in organic ELS are referred to as organic. In our study, three-quarters of the CG and organic farms were also in HLS and the implications of this are discussed. By studying farms managed under these schemes, we were able to compare organic and non-organic approaches and prescriptive versus more flexible approaches towards scheme design. This is the first comparison of how whole-farm agri-environment schemes compare in terms of floral resources, pollinator density and diversity and pollination services, using a sampling approach that takes into account the habitat composition of the farm. We aimed to answer two key research questions: 1) How did floral resources, pollinators and pollination services to phytometers vary between crop and non-crop habitats on farms in these three schemes and; 2) How did farm level floral resources, pollinators and pollination services vary between the schemes?

2. Methods

2.1. Study sites

This study was carried out in July and August 2013 in southern England. Triplets of farms (one in each scheme) were selected that matched as closely as possible in terms of landscape character, as defined by Natural England's National Character Areas, which are designated based on geological, historical, landscape, economic and cultural character (Natural England, 2011), hereafter termed regions. Matching was also based on soil type (NSRI 2011) and production type (the most common commodities were cereals and beef, full list in Appendix A: Table A.1). Four suitable triplets were found (Figure 1a). Farming intensity parameters collected during farmer interviews (nitrogen application, number of insecticide products used and stocking density of livestock, Appendix A, Table A.2) showed no differences between conventional CG and ELS farms. Farm size and number of crops per farm did not differ between schemes (Appendix A). However farmer reported wheat yields and field sizes measured from maps did differ significantly between schemes, with organic wheat yields being significantly lower and field sizes significantly smaller than CG and ELS (appendix A). A high number of our study farms were in HLS (three-quarters of the CG and organic farms). Over 99% of the HLS options by area were for management of non-crop habitats. This means that when interpreting differences between non-crop habitats on organic vs. ELS, and CG vs. ELS farms, we should be aware that the HLS scheme may exaggerate these differences.

2.2 Habitat maps

Farm habitat maps were created in Arc GIS v.10 using cropping plans and Environmental Stewardship (ES) maps (Figure 1b). ES habitats include those in ELS and HLS, which cover a range of management options for arable and grassland, boundaries, historic and landscape features, protection of soil and water resources and trees and woodland. Habitat maps were ground-truthed using a handheld GPS enabled PC with Arc Pad software (accuracy ± 4 m). Hedgerows and tree lines were mapped using Google maps aerial images (Google Maps, 2013). There were no significant differences between schemes in habitat composition of the farms when habitats were grouped into broad categories of ES field margin, ES grassland, improved grassland, mass flowering crop, non-mass flowering crop and other (Appendix A: Table A.3, A.4).

2.3. Landscape variables

The landscape scale effects of area of mass flowering crop and semi-natural habitat in a 1km radius have been shown to affect bees and pollination services (Carvell *et al.* 2011, Holzschuh *et al.* 2011). Therefore, these variables were measured through the ground truthing of the Land Cover Map 2007

(Centre for Ecology & Hydrology, 2011). There was no significant difference between schemes in the proportion of semi-natural habitat (SNH) or mass flowering crop (MFC) in the 1 km buffers around the farms (SNH: Friedman Chi^2=1.5, p=0.47), MFC: Friedman Chi^2=2.5, p=0.28). However, the proportion of semi-natural habitat and mass flowering crop in a 1km radius around each sampling point was highly variable, so was included in pollinator models, to account for the potentially confounding influence of neighbouring off-farm habitat on the pollinator density observed in crop and non-crop habitats on-farm. Two of the landscapes were simple (<20% semi-natural habitat) and two were complex (>20% semi-natural habitat, Appendix, Table A.5).

2.4. Floral resource surveys

One floral resource sampling point was surveyed in every habitat type per farm. In addition, five sampling points per farm were randomly allocated to hedgerows, to representatively sample this highly variable linear habitat that is a common field boundary in England. The total number of sampling points at which floral resources were recorded in each scheme was: ELS: 66, CG: 72, Org: 61. Each floral resource sampling point consisted of 1 m^2 quadrats and transects. Only plants considered rewarding to insects (Appendix B) were recorded. For hedgerows, a column of basal area 1 m^2 and hedge height was surveyed and additional species occurring on the 25 m long x 1 m wide x hedge height transect were recorded. For all other habitats, the number of floral units was recorded in each of three 1 m^2 quadrats. A central quadrat was placed at the randomly allocated point, then another quadrat was placed 50 m north and another 50 m east, with the whole transect fitting within the allocated habitat. Additional insect-rewarding plant species were recorded along the two 50 m x 1m transects between quadrats.

To estimate floral resource availability, we measured the density of open flowers. For composite floral units (defined in Carvell *et al.* 2007), this involved dissecting three typical floral units to count the number of open flowers. The mean number of open flowers per floral unit was multiplied by the number of floral units to estimate open flower abundance per m^2 (flower density). The average flower density per species across the three quadrats was taken and the density per m^2 of additional species recorded on transects was added. For points with open flowers, the Shannon index was used to calculate flower diversity. Only sampling points in non-crop habitats had sufficient open flower species for diversity analysis. A diversity index was used because the relative density of species surrounding the focal plant is likely to influence whether facilitation of pollination occurs (Ghazoul, 2006). The main assumptions in these floral resource estimations are: i) that the distribution of flowers in each habitat was homogeneous, and therefore the sampling plots are representative of the whole habitat area, ii) that the number of open flowers in three floral units was representative of the wider population.

2.5. Pollinator surveys

For pollinator surveys, a proportional stratified sampling design was used to represent the composition of habitats on the farm. The area of each habitat on each farm was calculated in Arc GIS. Then a weighting system was used to give areas of land in Environmental Stewardship (ES) a greater representation in the proportional stratified sample. If stratified solely by area, small areas of high value for biodiversity may have been missed. The habitats not in ES were given a weighting of 1, whereas the ES habitats were weighted using the following equation: ES points or payment per ha/ (85 x 0.9). This equation was used because the lowest number of points that any of the ES options on these farms earned per ha was 85. Therefore the lowest scoring ES option had a weighting of 1.05 and the weighting for other options increased proportionally up to the highest scoring option which earned 485 points and received a weighting of 6.34. The proportion that each habitat's weighted area made of the summed weighted habitat areas for each farm was used to assign the twelve sampling points to habitats. These points were then randomly plotted within habitats using the 'genrandompnts' tool (Beyer 2012, (Figure 1b).

We focused on the density and species richness of bees and hoverflies, which are the main functional groups of pollinators in Europe (Albrecht *et al.*, 2012). For our phytometer species, bees are considered to be the most important pollinator guild (Cook, 1962), but hoverfly visits have also been observed (Wickens, J., personal communication). Pollinator sampling points consisted of three pan trap sampling points 50 m apart and a 100 m observation transect between them, arranged as for floral resource surveys.

Observation transects were used to assess bee and hoverfly density and wildflower visitation over a constant sampling area. This method is recommended by Popic *et al.* (2013) for studying bee-flower interactions. Transects 100 m long were walked at a constant speed over a period of 10 minutes, and wild bees and honeybees (*Apis mellifera* L.) were observed within 2 m either side and in front of the observer and recorded to the most accurate taxonomic level as possible. Specimens not easily identified in the field were collected with a hand net for later identification under the microscope using keys. Species level identification was achieved for 88% of bee observations on transects. *Bombus terrestris* (L.) and *B. lucorum* (L.) (sensu lato) workers were recorded as *B.terrestris/lucorum* because they cannot be reliably distinguished in the field. Wind speed was recorded using an anemometer, cloud cover using visual scale of oktas and maximum temperature using a thermometer. As far as possible, the UK Butterfly Monitoring guidelines for weather conditions for transects were used (Pollard and Yates, 1993). The frequency and species identity of bee-flower visits on transects was recorded.

At each pan trap sampling point, triplicate blue-white-yellow pan traps were set containing dilute soap solution. This method was used to assess bee species richness since this is considered less subjective than net sampling for small solitary bees (Westphal *et al.*, 2008). Contents of pan traps were collected after 24 hours. All three farms in a landscape were sampled as close together in time as possible, normally over a period of four days for logistical reasons. Bees were frozen and then identified to species using the keys of Else (In press) for solitary bees and Prŷs-Jones & Corbet (2011) for bumblebees. Hoverfly species richness was not assessed due to time constraints.

2.6. Pollination service surveys

Ten of the twelve pollinator sampling points also had phytometers present. Phytometers are potted plants that are self-incompatible and insect pollinated. Californian poppy (*Eschscholzia californica,* Cham.) plants were used as phytometers to measure pollination services. Phytometers have been shown to be a consistent and cost effective method for measuring pollination services (Woodcock *et al.*, 2014). Californian poppy was chosen because it is an ornamental species not found in the natural environment that performed well in field trials. This allowed us to standardise the availability of pollen, which is important because it allows us to measure insect pollination services in a way that is not affected by the distribution of a particular native plant species in the landscape. It is an open-access flower accessible by a wide range of pollinators and so can be used as proxy of ambient pollination services.

Phytometer sampling points were allocated using the same proportional stratified sampling design used for pollinator surveys. The proportion of phytometer points in crop habitats was 53.6 % (ELS), 38.0 % (CG) and 47.0 % (Org). Phytometers were placed 50 cm apart at the central point. Phytometers remained in pots which were partly sunk into the soil. Surrounding vegetation was flattened within a 1 m radius to allow access to flowers by pollinators and prevent shading of the phytometers. Phytometers were watered well on setting out, once during the exposure period and once upon collection.

On setting out, phytometers were classified using a three point plant vigour score based on a visual appraisal of health. Where livestock were in fields, phytometers were placed at field edges behind fences. Where possible plants were arranged in a triangle, but if not possible they were arranged in a line. Phytometers were exposed on-site for three weeks, after which they were collected and any damage or drought was noted. They were then left in pollinator exclusion cages whilst fruit ripening occurred. Fruit set, defined as the proportion of nodes which contained at least one developed seed, along with the number of seeds per fruit were counted.

2.7. Data analysis

Sampling points were divided into crop and non-crop habitats to further investigate differences between schemes, since organic farming affects the cropped areas of the farm, whereas the majority of the ELS and CG schemes are focused on non-cropped areas. Crop habitats were defined as fields reseeded annually with a crop other than grass, as part of an arable rotation. Grassland (including grass/clover mixes), hedgerows, field margins, and other non-production areas were classified as non-crop habitats. Improved grassland was not classified with crop habitats as ‘production area’ because the differences between organic and non-organic systems are expected to be largest in arable fields.

To compare floral resources, pollinators and pollination services among schemes we used generalised linear mixed effects models (GLMMs) from the package lme4 (Bates *et al.,* 2014) with nested random effects (farms within regions). The probability of presence of floral resource, pollinators and pollination service at the ten proportionally allocated sampling points were modelled using GLMMs with binomial distributions, with scheme as a predictor variable.

Flower density was log+1 transformed and modelled using a GLMM with Gaussian errors. For flower density models, heteroscedascity of residuals could not be reduced, so estimates and SE values are reported from post-hoc tests as the p values were considered unreliable. Flower diversity was analysed using a GLMM with a Gamma error distribution since it was positive continuous data. Total floral resource at the farm scale was estimated by multiplying the habitat flower density by the habitat area, summing across habitat types, and dividing by total farm area. Area of hedgerows was estimated using length multiplied by a mean width of 1.93 m (data from 14 hedges in Berkshire and Oxfordshire, Garratt, M.P. pers. comm.).

In order to reduce overdispersion, the GLMMs for density of bees and hoverflies used a log-normal Poisson distribution (Elston *et al.,* 2001) and for species richness of bees used a negative binomial distribution. The covariates temperature, wind, cloud, proportion of mass flowering crop and proportion of semi-natural habitat in 1km buffer around sampling points were include in pollinator models. Number of bee species per scheme was rarefied to the minimum number of individuals per scheme using the rarecurve function in the vegan package (Oksanen *et al.,* 2015).

Full pollination service models included plant vigour score, proportion of semi-natural habitat and mass flowering crop in a 1 km radius around sampling points, scheme type, and distance to nearest field edge. The latter variable was included to account for the potentially confounding influence of phytometers needing to be moved to the edge of fields to avoid livestock and farm operations more on some farms than others. Survival in crop vs. non-crop habitats was marginally significantly different between schemes (Non-crop habitats, Org: 61, CG: 59, ELS: 35, Chi^2 (2) = 5.70, p=0.058). Therefore, distance to nearest surviving phytometer (log transformed) was included in models to account for the potential confounding effect of scheme on phytometer mortality. Fruit set was modelled using a binomial GLMM and sampling point was included as a random effect. Due to excess zeros and overdispersion in the number of seeds per plant data, a zero inflated negative binomial (ZINB) model (Zuur *et al.*, 2009) was used. Data were summed at the sampling point level, because random effects could not be incorporated into ZINB models. The full model included a term for the number of surviving nodes at each sampling point. For testing correlations between flower density and fruit set, a binomial error distribution was used. For testing correlations between flower density and seed set, both variables were log+1 transformed and a Gaussian error distribution was used.

Likelihood ratio tests (LRT Chi^2) were used to test for the significance of scheme and the interaction of habitat type (crop/non-crop) with scheme. We applied post-hoc simultaneous tests for general linear hypotheses (from the multcomp package, Hothorn *et al.,* 2008), using contrast matrices to test for differences between crop and non-crop habitats within each scheme type and between schemes within each habitat type. Data analysis was carried out using R version 3.1.2 (R Core Team, 2014).

3. Results

3.1.1. Spatial distribution of floral resources between habitats

The proportion of sampling points with insect-rewarding plants present was higher on organic compared to ELS farms, (LRT Chi^2 (2) = 9.552, p=0.008, Post-hoc test: Org>ELS: 0.001, Figure C.1).

However the proportion of sampling points with bees, hoverflies, insect-flower visits or fruit set present did not vary between schemes (Appendix C, Table C.1).

The total floral resource from crop habitats (cereal and mass flowering crop) was higher on organic farms (46 %) compared to CG (11 %) or ELS farms (0.28 %, Table 1), particularly due to the high contribution from plants in mass flowering crop fields on organic farms. CG farms had the highest average contribution from ES margin and grass habitats combined. ELS farms varied widely in the spatial distribution of floral resources, with one having a particularly large area of floristically dense grassland due to clover having being drilled into improved grass for silage.

The sampling points with the highest flower density in each scheme were all non-crop habitats: CG: field corner, ELS: grass/clover ley and organic: low-input grassland. The plants which contributed the most to each of these habitats were: CG field corner; 96% *Tripleurospermum inodorum* L. Sch.Bip. (scentless mayweed), ELS grass/clover ley; 97% *Trifolium pratense* L. (red clover) and organic low input-grassland; 75% *Leucanthemum vulgare* Lam. (oxeye daisy).

A range of organic crop habitats had open floral resources present, including cereals (arable silage, einkorn, spelt, barley oats and wheat), and mass flowering crops (lucerne, lucerne/sanfoin silage, clover and field beans, Table 1). The three plants with the highest open flower density in organic crop habitats were *Tripleurospermum inodorum, Trifolium repens* L. (white clover) and *Sinapis arvensis* L. (charlock). In organic crop fields, 84% of insect-rewarding flowers were from non-sown species. The most common sown species with open flowers were white clover (9%) and lucerne (6%).

3.1.2. Differences between crop and non-crop habitats in flower density and diversity

There was a significant interaction between scheme and habitat type in explaining variation in flower density (LRT Chi^2(2) = 8.357, p=0.015, Figure 2a). Post-hoc tests revealed that flower density was higher in non-crop habitat than in crop habitats on ELS (Estimate ±SE: 3.31 ±0.74) and CG farms (3.59 ±0.79). Crop habitats supported a higher flower density on organic farms compared to ELS (3.72 ±1.18) or CG farms (3.71 ±1.14). There were no significant differences between schemes in flower Shannon diversity in non-crop habitats (LRT Chi^2 (2) = 0.360, p=0.835, Figure 2b).

3.2.3. Differences between crop and non-crop habitats in pollinator density and diversity

There were no significant interactions between scheme and habitat type (crop or non-crop) in explaining bee species richness (LRT Chi^2 (2) = 0.366, p=0.833, Figure 3a), hoverfly density (LRT Chi^2 (2) = 1.082, p=0.582, Figure 3b) or bee density (LRT Chi^2 (2) = 4.161, p=0.125, Figure 3c). There was a significantly higher density of bees (LRT Chi^2 (1) = 16.60, p<0.001) and species richness of bees (LRT Chi^2 (1) = 4.707, p=0.030) in non-crop habitats than in crop habitats overall. Habitat type did not have a significant independent effect on hoverfly density (LRT Chi^2 (1) = 0.162, p=0.688).

3.1.4. Differences between crop and non-crop habitats in insect-wildflower visitation

There was a significant interaction between scheme and habitat type in explaining density of wildflower visits made by bees (LRT $Chi^2(2) = 11.65$, p=0.003, Figure 3d). Post-hoc tests revealed that on CG and ELS farms there were significantly more bee visits to wildflowers in non-crop compared to crop habitats (CG: $p<0.001$, ELS: $p<0.001$) whereas on organic farms there were no significant differences between crop and non-crop habitats (p=0.292). There was insufficient data on density of hoverfly visits to be analysed.

3.1.5. Differences between crop and non-crop habitats in pollination services

There was an interaction between scheme and habitat type in explaining fruit set of phytometers (LRT $Chi^2=10.79$, p=0.005, Figure 4). Post-hoc tests revealed that organic crop habitats supported significantly higher fruit set than CG crop habitats ($p<0.001$) or ELS crop habitats ($p<0.001$). In addition, ELS non-crop habitats supported significantly higher fruit set than ELS crop habitats (p= 0.022). There was no significant interaction between habitat type and scheme in explaining seeds per node per phytometer plant (LRT $Chi^2 = 1.018$, df=2, p=0.601).

3.2 Farm level flower density, pollinator density, diversity and pollination service

3.2.1 Flower density

Flower density at the farm scale did not differ significantly between schemes (Friedman $Chi^2 = 1.5$, df = 2, p-value = 0.472). The gamma diversity (total species richness per farm) of open flowering plants did not vary significantly between schemes (Friedman $Chi^2=2$, df=2, p=0.368).

3.2.2. Pollinator density and species richness

In pan traps we recorded 52 bee species, and on transects we recorded 925 bee individuals and 386 hoverfly individuals. CG farms showed a weak tendency towards supporting a higher density of bees on transects at the farm level, once an outlier with a particularly high density of honeybees on restored organic heathland was removed, (Org=235, CG=283, ELS=243, $Chi^2(2)=5.214$, p=0.074). ELS farms supported a higher density of hoverflies overall (Org=113, CG=116, ELS=157, $Chi^2(2)=9.394$, p=0.009). At the point level, there were no significant differences in bee density (LRT Chi^2 (2)=0.04, p=0.98) or hoverfly density (LRT Chi^2 (2)=0.523, p= 0.77) between schemes.

There was no significant difference in the total species richness of bees recorded in pan traps between schemes (Org=36, CG=28, ELS=43, $Chi^2(2)=3.159$, p=0.206). Rarefaction reduced differences between schemes (Estimated species richness: ELS: 42.2 ± 0.869, Org: 34.3 ± 1.21, when rarefied to the same level as CG: 28 species, 552 individuals). At the point level, there were no significant overall differences between schemes in bee density (LRT Chi^2 (2)=0.04, p=0.98), bee species richness (LRT Chi^2 (2)=4.38, p=0.219) or hoverfly density (LRT Chi^2 (2)=0.523, p= 0.77).

3.2.3. Insect-wildflower visitation

The total number of bee visits to wildflowers at the farm scale differed significantly between schemes, with CG farms supporting the highest number of insect-flower visits ($\text{Chi}^2(2)$ =8.603, p=0.014, CG =217, ELS=160, Org=190) once the outlier was removed (one sampling point in organic restored heathland with a high density of honeybees). The top three habitats for insect visitation density were a naturally regenerated managed field corner on a CG farm (EF1), a floristically enhanced margin on an organic farm (HE10), and a field margin with a high density of *Centaurea nigra* L. (common knapweed) on an ELS farm. The majority of insect-wildflower visits were carried out by wild bees (66%), followed by honeybees (20%), and hoverflies (14%). The red-tailed bumblebee *Bombus lapidarius* (L.) made up 61% of all wild bee visits to wildflowers. Plants which received particularly high numbers of visits were *Erica tetralix* L. (cross-leaved heather, mostly visited by *Apis mellifera* at the heathland restoration point), *Centaurea nigra*, *Cirsium arvense* (L.) Scop. (creeping thistle) and *Chamerion angustifolium* (L.) Holub (rosebay willowherb).

3.2.4. Pollination service

Survival of phytometers varied between schemes: Org: 97, CG: 89, ELS: 72, (Chi^2 (2) = 13.4, p=0.002). Survival was influenced by drought, damage by farm machinery and herbicide spraying. Farm type had a marginally significant effect on farm level of fruit set per plant (Mean fruit set (%) ± SE: Org = 72.5 ± 2.9, CG = 56.6 ± 3.6, ELS = 51.9 ± 4.4, LRT $\text{Chi}^2(2)$ = 5.773, p=0.056) and organic farms supported higher fruit set than ELS and CG (Post-hoc test: Org>ELS, p=0.011, Org>CG, p=0.021). Seeds per node per plant was not significantly affected by scheme Chi^2 (2)=3.034, p=0.219).

Floral resource density had a significant positive effect on fruit set (LRT $\text{Chi}^2(1)$ = 164, p<0.001), but only explained 16% of the variation (marginal R^2 = 0.159, conditional R^2 = 0.205). Variation in seeds per node per plant was not significantly related to surrounding flower density (LRT $\text{Chi}^2(1)$ = 1.288, p=0.257).

4. Discussion

4.1. Spatial distribution of floral resources, pollinators and pollination services

On organic farms, we found that a greater proportion of the farm had floral resources present in July and August, since both crop and non-crop habitats delivered floral resources. The greater density of flowering plants in organic crop fields was consistent with other studies (Fuller *et al.*, 2005, Holzschuh *et al.*, 2008). Pollination service and bee-wildflower visits were higher in organic crop fields compared to non-organic crop fields. This is in line with findings that organic farming disproportionately benefits insect-pollinated plants (Gabriel and Tscharntke, 2007, Power *et al.*, 2012, Batáry *et al.*, 2013). However, in contrast to other studies (Rundlöf *et al.*, 2008, Holzschuh *et* *al.*, 2007), we did not find a higher species richness or density of bees in organic crop fields. This may be because the pan trap and transect methods intercepted pollinators flying through the habitat, rather than only recording pollinators using the habitat. The moderating effect of landscape context could also explain the low effect size for organic farming on species richness and density of bees in our study. Positive effects of organic farming on bee abundance and species richness have been found in homogeneous landscapes (>60% arable land) but not in heterogeneous landscapes (15-16% arable land) in Sweden (Rundlöf *et al.*, 2008). In our study the proportion of arable land in a 1km radius buffer around our farms was 7- 36%, which is relatively low compared to the Swedish study. This will have reduced the ecological contrast in floral resources that the schemes created compared to the surrounding landscapes.

CG and ELS farms supported a significantly higher density of flowers and insect-wildflower visits in non-crop habitats compared to crop habitats, which was consistent with Pywell *et al.*, (2005). We expected non-crop habitats on CG and organic farms to have higher floral resource densities than those on ELS farms, since three-quarters of the CG and organic farms had HLS scheme managed non-crop areas. Wood *et al.*, (2015b), found higher floral abundance on HLS farms implementing flower-rich margin options compared to ELS farms not implementing such options. However, flower density was not higher in CG compared to ELS non-crop habitats in our study. This appears to have been because some of the ELS farms in our study supported high non-crop densities of floral resource in habitats such as field corners (EF1), buffer strips (EE3), and improved grass/clover leys. However, after field surveys, one ELS farm removed the arable buffer strips (EE3) which contributed a high density of *Centaurea nigra* and insect-flower visits. This demonstrates the vulnerability of habitats in flexible schemes such as ELS, compared to more prescriptive schemes such as CG and longer-term agreements such as HLS.

4.2. Farm level of floral resource, pollinators and pollination services

Farm level floral resource provision and pollinator diversity did not differ significantly between schemes, contrary to expectations. However, CG farms supported a significantly higher overall number of bee-flower visits, showing that the more prescriptive pollinator management was successfully attracting foraging bees. This emphasises the importance of prescriptive non-crop habitats, in addition to organic farming as measures to help reverse species declines in agricultural ecosystems.

Our results suggest that the benefits of organic farming for pollination services were mediated more by the enhancement of local floral resources than by enhancement of the local density and/or diversity of pollinators. Our results concur with those of Power and Stout, (2011) who found that organic farms supported a higher floral abundance and higher level of pollination service to hawthorn (*Crataegus monogyna* Jacq.). Facilitation of pollination services by nearby floral resources has also been found for weeds in sunflower crops (Carvalheiro *et al.*, 2011) and uncultivated areas next to oilseed rape crops (Morandin and Winston, 2006).

4.3 Implications for management

Our study took place in the later stage of the pollinator season in the UK, after the majority of the mass flowering crop (oilseed rape) had flowered. This time of year tends to be when bee populations are most limited by floral resource (Persson and Smith, 2013). Our results emphasise the importance of managed non-crop habitat areas (such as floristically enhanced margins which received the highest density of insect visits in this study) and organic crop areas in providing floral resources for pollinators at this time of year. Further work will examine how the relative contributions of different habitats in the farmed landscape changes throughout the season.

Organic farming supported an ecosystem service (pollination) to a greater extent than non-organic wildlife-friendly farming schemes in our study. Organic farming is an example of ecological intensification: the shift towards managing ecosystem services to support agricultural production and away from synthetic inputs (Bommarco *et al.*, 2013). This type of management will result in trade-offs and synergies for different ecosystem services. We found enhanced pollination services at the farm scale on organic farms and a greater floral resource in organic crop habitats. The management practices which are likely to have contributed (legume cropping and reduced herbicide use) are likely to create synergistic benefits for soil fertility (Watson *et al.*, 2002) and weed seed predation (Diekötter *et al.*, 2010). Management practices commonly used in organic farming, such as reduced herbicide use and sowing clover, are likely to be beneficial in non-organic systems for supporting pollination services at both farm and landscape scales.

When considering management for pollination services, it is important to consider trade-offs with other ecosystem services. Wild plants in crop fields could enhance ecosystem services (pollination, pest control by natural enemies, nitrogen fixation) or provide disservices to crop production (competition for resources with the crop, supporting pests). Determining economic thresholds for weed tolerance in different crops is an important area of future research, and one factor to take into account is the pollinator dependence of the crop (Deguines et al., 2014). There are potentially opposing effects of weeds on yields for insect-pollinator-dependent vs. independent crops (Bretagnolle and Gaba, 2015). Although our study was not designed to look at yields, farm intensity data collected through farmer interviews revealed that organic winter wheat yields were significantly lower than CG and ELS (winter wheat tonnes/ha mean ± SE , ELS: 7.00 ± 0.23, CG:8.04 ± 0.30, Org: 3.06 ± 0.17, Appendix A, Table A.2). Larger sample sizes show the yield gap for winter wheat in England and Wales averaged 50% between 2009-2014 (Moakes, Lampkin & Gerrard 2015, full list of reports in Appendix C). Where farm management aims to support high wheat yields and pollinators within the same farm, our results suggest the CG scheme is likely to be more appropriate.

Deciding which wildlife-friendly farming scheme individual farms should enter is a process that needs to be spatially optimised at both landscape and national scales. Factors to consider include landscape level biodiversity and food production targets, starting conditions and the productivity of the land. Spatial targeting is being used for both tiers in the new Countryside Stewardship scheme which is replacing Environmental Stewardship (Natural England, 2015) and this process has potential to be improved through better data and models. Our study stimulates further research questions on which schemes or management practices will optimise pollination services to specific crops and stimulates debate about potential trade-offs between managing for insect-pollinator dependent and independent crops. This will involve consideration of how best to facilitate crop conspecific pollen transfer and reduce potential pollen competition between crop plants and co-flowering species (Schüepp *et al.,* 2014).

5. Conclusion

Our research has explored three contrasting approaches towards management of biodiversity and ecosystem services in agricultural landscapes. The most holistic approach (organic) supported the highest level of pollination service, and the most prescriptive non-organic approach (CG) supported the highest farm level density of insect visits, but these were more concentrated in non-crop areas. The basic, flexible approach (ELS) still supported high flower densities in non-crop habitats and a similar farm level pollination service to the CG scheme. Our work furthers the understanding of how different habitat elements under contrasting wildlife-friendly farming schemes support pollination services.

Acknowledgements

We would like to thank land owners and farmers for access and Harold Makant for site selection assistance. We thank Cassie-Ann Dodson, Laurine Lemesle, Chris Reilly and Matthew Wisby for assistance with field surveys, Stuart Roberts and Rebecca Evans for help with species identification and Tom Breeze for manuscript comments. We thank Mathilde Baude and Mark Gillespie for advice on floral resource survey methodology. This work was funded by BBSRC (Grant: BB/F01659X/1) and Conservation Grade. SGP sits on the technical advisory board for Conservation Grade.

References

Albrecht, M., Duelli, P., Müller, C., Kleijn, D., Schmid, B., 2007. The Swiss agri-environment scheme enhances pollinator diversity and plant reproductive success in nearby intensively managed farmland. J. Appl. Ecol. 44, 813–822. doi:10.1111/j.1365-2664.2007.01306.x

Albrecht, M., Schmid, B., Hautier, Y., Müller, C.B., 2012. Diverse pollinator communities enhance plant reproductive success. Proc. Biol. Sci. 279, 4845–52. doi:10.1098/rspb.2012.1621

Batáry, P., Sutcliffe, L., Dormann, C.F., Tscharntke, T., 2013. Organic farming favours insect-pollinated over non-insect pollinated forbs in meadows and wheat fields. PLoS One 8, e54818. doi:10.1371/journal.pone.0054818

Bates, D., Maechler, M., Bolker, B., Walker, S., 2014. Linear mixed-effects models using Eigen and S4_. R package version 1.1-7.

Beyer, H.L. (2012) Geospatial Modelling Environment. Available at http://www.spatialecology.com/

Biesmeijer, J.C., Roberts, S.P.M., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T., Schaffers, A.P., Potts, S.G., Kleukers, R., Thomas, C.D., Settele, J., Kunin, W.E., 2006. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. Science (80-.). 313, 351–4. doi:10.1126/science.1127863

Blaauw, B.R., Isaacs, R., 2014. Flower plantings increase wild bee abundance and the pollination services provided to a pollination-dependent crop. J. Appl. Ecol. 51, 890–898. doi:10.1111/1365-2664.12257

Bommarco, R., Lundin, O., Smith, H.G., Rundlof, M., 2012. Drastic historic shifts in bumble-bee community composition in Sweden. Proc. R. Soc. B Biol. Sci. 279, 309–315. doi:10.1098/rspb.2011.0647

Bommarco, R., Kleijn, D., Potts, S.G., 2013. Ecological intensification: harnessing ecosystem services for food security. Trends Ecol. Evol. 28, 230–8. doi:10.1016/j.tree.2012.10.012

Breeze, T.D., Bailey, A.P., Balcombe, K.G., Potts, S.G., 2014a. Costing conservation: an expert appraisal of the pollinator habitat benefits of England’s Entry Level Stewardship. Biodivers. Conserv. 23, 1193–1214. doi:10.1007/s10531-014-0660-3

Breeze, T.D., Vaissière, B.E., Bommarco, R., Petanidou, T., Seraphides, N., Kozák, L., Scheper, J., Biesmeijer, J.C., Kleijn, D., Gyldenkærne, S., Moretti, M., Holzschuh, A., Steffan-Dewenter, I., Stout, J.C., Pärtel, M., Zobel, M., Potts, S.G., 2014b. Agricultural policies exacerbate honeybee pollination service supply-demand mismatches across Europe. PLoS One 9, e82996. doi:10.1371/journal.pone.0082996

Bretagnolle, V., Gaba, S., 2015. Weeds for bees? A review. Agron. Sustain. Dev. 35, 891–909. doi:10.1007/s13593-015-0302-5

Cameron, S.A., Lozier, J.D., Strange, J.P., Koch, J.B., Cordes, N., Solter, L.F., Griswold, T.L., 2011. Patterns of widespread decline in North American bumble bees. Proc. Natl. Acad. Sci. U. S. A. 108, 662–667. doi:10.1073/pnas.1014743108

Carvalheiro, L.G., Kunin, W.E., Keil, P., Aguirre-Gutiérrez, J., Ellis, W.N., Fox, R., Groom, Q., Hennekens, S., Van Landuyt, W., Maes, D., Van de Meutter, F., Michez, D., Rasmont, P., Ode, B., Potts, S.G., Reemer, M., Roberts, S.P.M., Schaminée, J., WallisDeVries, M.F., Biesmeijer, J.C., 2013. Species richness declines and biotic homogenisation have slowed down for NW-European pollinators and plants. Ecol. Lett. 16, 870–8. doi:10.1111/ele.12121

Carvalheiro, L.G., Veldtman, R., Shenkute, A.G., Tesfay, G.B., Pirk, C.W.W., Donaldson, J.S., Nicolson, S.W., 2011. Natural and within-farmland biodiversity enhances crop productivity. Ecol. Lett. 14, 251–9. doi:10.1111/j.1461-0248.2010.01579.x

Carvell, C., Meek, W.R., Pywell, R.F., Goulson, D., Nowakowski, M., 2007. Comparing the efficacy of agri-environment schemes to enhance bumble bee abundance and diversity on arable field margins. J. Appl. Ecol. 44, 29–40. doi:10.1111/j.1365-2664.2006.01249.x

Carvell, C., Osborne, J.L., Bourke, A.F.G., Freeman, S.N., Pywell, R.F., Heard, M.S., 2011. Bumble bee species’ responses to a targeted conservation measure depend on landscape context and habitat quality. Ecol. Appl. 21, 1760–71.

Carvell, C., Roy, D.B., Smart, S.M., Pywell, R.F., Preston, C.D., Goulson, D., 2006. Declines in forage availability for bumblebees at a national scale. Biol. Conserv. 132, 481–489. doi:10.1016/j.biocon.2006.05.008

Centre for Ecology & Hydrology, 2011. Countryside survey: Land Cover Map 2007.

Cook, S.A., 1962. Genetic System, Variation and Adaptation in Eschscholzia californica. Evolution (N. Y). 16, 278–299.

Deguines, N., Jono, C., Baude, M., Henry, M., Julliard, R., Fontaine, C., 2014. Large-scale trade-off between agricultural intensification and crop pollination services. Front. Ecol. Environ. 12, 212–217. doi:10.1890/130054

Diekötter, T., Wamser, S., Wolters, V., Birkhofer, K., 2010. Landscape and management effects on structure and function of soil arthropod communities in winter wheat. Agric. Ecosyst. Environ. 137, 108–112. doi:10.1016/j.agee.2010.01.008

Ebeling, A., Klein, A.-M., Schumacher, J., Weisser, W.W., Tscharntke, T., 2008. How does plant richness affect pollinator richness and temporal stability of flower visits? Oikos 117, 1808–1815. doi:10.1111/j.1600-0706.2008.16819.x

Else, G., (In press). Handbook of the Bees of the British Isles. The Ray Society, London.

Elston, D.A., Moss, R., Boulinier, T., Arrowsmith, C., Lambin, X., 2001. Analysis of aggregation, a worked example: numbers of ticks on red grouse chicks. Parasitology 122, 563–569. doi:10.1017/S0031182001007740

Fuller, R.J., Norton, L.R., Feber, R.E., Johnson, P.J., Chamberlain, D.E., Joys, A.C., Mathews, F., Stuart, R.C., Townsend, M.C., Manley, W.J., Wolfe, M.S., Macdonald, D.W., Firbank, L.G., 2005. Benefits of organic farming to biodiversity vary among taxa. Biol. Lett. 1, 431–4. doi:10.1098/rsbl.2005.0357

Gabriel, D., Tscharntke, T., 2007. Insect pollinated plants benefit from organic farming. Agric. Ecosyst. Environ. 118, 43–48. doi:10.1016/j.agee.2006.04.005

Garibaldi, L.A., Steffan-Dewenter, I., Kremen, C., Morales, J.M., Bommarco, R., Cunningham, S.A., Carvalheiro, L.G., Chacoff, N.P., Dudenhöffer, J.H., Greenleaf, S.S., Holzschuh, A., Isaacs, R., Krewenka, K., Mandelik, Y., Mayfield, M.M., Morandin, L.A., Potts, S.G., Ricketts, T.H., Szentgyörgyi, H., Viana, B.F., Westphal, C., Winfree, R., Klein, A.M., 2011. Stability of pollination services decreases with isolation from natural areas despite honey bee visits. Ecol. Lett. 14, 1062–72. doi:10.1111/j.1461-0248.2011.01669.x

Ghazoul, J., 2006. Floral diversity and the facilitation of pollination. J. Ecol. 94, 295–304. doi:10.1111/j.1365-2745.2006.01098.x

Google Map (2013) Retrieved from http://maps.google.com

Goulson, D., Nicholls, E., Botias, C., Rotheray, E.L., 2015. Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. Science (80-.). 347, 1255957. doi:10.1126/science.1255957

Haaland, C., Naisbit, R.E., Bersier, L.F., 2011. Sown wildflower strips for insect conservation: A review. Insect Conserv. Divers. 4, 60–80. doi:10.1111/j.1752-4598.2010.00098.x

Holzschuh, A., Dormann, C.F., Tscharntke, T., Steffan-Dewenter, I., 2011. Expansion of mass-flowering crops leads to transient pollinator dilution and reduced wild plant pollination. Proc. Biol. Sci. 278, 3444–51. doi:10.1098/rspb.2011.0268

Holzschuh, A., Steffan-Dewenter, I., Kleijn, D., Tscharntke, T., 2007. Diversity of flower-visiting bees in cereal fields: effects of farming system, landscape composition and regional context. J. Appl. Ecol. 44, 41–49. doi:10.1111/j.1365-2664.2006.01259.x

Holzschuh, A., Steffan-Dewenter, I., Tscharntke, T., 2008. Agricultural landscapes with organic crops support higher pollinator diversity. Oikos 117, 354–361. doi:10.1111/j.2007.0030-1299.16303.x

Hothorn, T., Bretz, F., Westfall, P., 2008. Simultaneous Inference in General Parametric Models. Biometrical J. 50, 346–363.

Kerr, J.T., Pindar, A., Galpern, P., Packer, L., Potts, S.G., Roberts, S.M., Rasmont, P., Schweiger, O., Colla, S.R., Richardson, L.L., Wagner, D.L., Gall, L.F., Sikes, Derek, S., Pantoja, A., 2015. Climate change impacts on bumblebees converge across continents. Science (80-.). 349, 177–180.

Klein, A.-M., Vaissière, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C., Tscharntke, T., 2007. Importance of pollinators in changing landscapes for world crops. Proc. Biol. Sci. 274, 303–13. doi:10.1098/rspb.2006.3721

Martins, K.T., Gonzalez, A., Lechowicz, M.J., 2015. Pollination services are mediated by bee functional diversity and landscape context. Agric. Ecosyst. Environ. 200, 12–20. doi:10.1016/j.agee.2014.10.018

Moakes, S., Lampkin, N., Gerrard, C., 2015. Organic Farm Incomes in England and Wales 2013/14.

Morandin, L.A., Kremen, C., 2013. Hedgerow restoration promotes pollinator populations and exports native bees to adjacent fields. Ecol. Appl. 23, 829–39.

Morandin, L.A., Winston, M.L., 2006. Pollinators provide economic incentive to preserve natural land in agroecosystems. Agric. Ecosyst. Environ. 116, 289–292. doi:10.1016/j.agee.2006.02.012

Natural England, 2015. Countryside Stewardship Update [WWW Document]. URL www.gov.uk/natural-england

Natural England, 2013. Land Management Update October 2013 [WWW Document]. URL www.naturalengland.org.uk/ES (accessed 10.30.13).

Natural England, 2011. Natural England [WWW Document]. URL www.gov.uk/how-to-access-natural-englands-maps-and-data (accessed 2.29.12).

Nieto, A., Roberts, S.P.M., Kemp, J., Rasmont, P., Kuhlmann, M., Criado, M.G., Biesmeijer, J.C., Bogusch, P., Dathe, H.H., Rúa, P. De, 2014. European Red List of Bees. Luxembourg. doi:10.2779/77003

NSRI. (2011) National Soil Resources Institute Soilscapes, https://www.landis.org.uk/soilscapes/

Oksanen, J., Blanchet, G., Kindt, R., Legendre, P., Minchin, P.R., O’Hara, B., Simpson, G.L., Solymos, P., Stevens, H.H., Wagner, H., 2015. Vegan: Community Ecology Package.

Ollerton, J., Erenler, H., Edwards, M., Crockett, R., 2014. Extinctions of aculeate pollinators in Britain and the role of large-scale agricultural changes. Science (80-.). 346, 1360–1362.

Ollerton, J., Winfree, R., Tarrant, S., 2011. How many flowering plants are pollinated by animals? Oikos 120, 321–326. doi:10.1111/j.1600-0706.2010.18644.x

Persson, A.S., Smith, H.G., 2013. Seasonal persistence of bumblebee populations is affected by landscape context. Agric. Ecosyst. Environ. 165, 201–209. doi:10.1016/j.agee.2012.12.008

Pollard, E., Yates, T.J., 1993. Monitoring Butterflies for Ecology and Conservation. Chapman & Hall, London.

Popic, T.J., Davila, Y.C., Wardle, G.M., 2013. Evaluation of Common Methods for Sampling Invertebrate Pollinator Assemblages : Net Sampling Out-Perform Pan Traps. PLoS One 8, e66665. doi:10.1371/journal.pone.0066665

Potts, S.G., Biesmeijer, J.C., Kremen, C., Neumann, P., Schweiger, O., Kunin, W.E., 2010. Global pollinator declines: trends, impacts and drivers. Trends Ecol. Evol. 25, 345–53. doi:10.1016/j.tree.2010.01.007

Power, E.F., Kelly, D.L., Stout, J.C., 2012. Organic farming and landscape structure: Effects on insect-pollinated plant diversity in intensively managed grasslands. PLoS One 7. doi:10.1371/journal.pone.0038073

Power, E.F., Stout, J.C., 2011. Organic dairy farming: impacts on insect-flower interaction networks and pollination. J. Appl. Ecol. 48, 561–569. doi:10.1111/j.1365-2664.2010.01949.x

Prŷs-Jones, O.E., Corbet, S.A., 2011. Bumblebees. Pelagic Publishing Limited, Exeter.

Pywell, R.F., Warman, E.A., Carvell, C., Sparks, T.H., Dicks, L.V., Bennett, D., Wright, A., Critchley, C.N.R., Sherwood, A., 2005. Providing foraging resources for bumblebees in intensively farmed landscapes. Biol. Conserv. 121, 479–494. doi:10.1016/j.biocon.2004.05.020

R Core Team, 2014. R: A language and environment for statistical computing.

Roulston, T.H., Goodell, K., 2011. The role of resources and risks in regulating wild bee populations. Annu. Rev. Entomol. 56, 293–312. doi:10.1146/annurev-ento-120709-144802

Rundlöf, M., Nilsson, H., Smith, H.G., 2008. Interacting effects of farming practice and landscape context on bumble bees. Biol. Conserv. 141, 417–426. doi:10.1016/j.biocon.2007.10.011

Scheper, J., Holzschuh, A., Kuussaari, M., Potts, S.G., Rundlöf, M., Smith, H.G., Kleijn, D., 2013. Environmental factors driving the effectiveness of European agri-environmental measures in mitigating pollinator loss-a meta-analysis. Ecol. Lett. 16, 912–20. doi:10.1111/ele.12128

Schüepp, C., Herzog, F., Entling, M.H., 2014. Disentangling multiple drivers of pollination in a landscape-scale experiment. Proc. R. Soc. B 281, 20132667. doi:10.1098/rspb.2013.2667

Watson, C.A., Atkinson, D., Gosling, P., Jackson, L.R., Rayns, F.W., 2002. Managing soil fertility in organic farming systems. Soil Use Manag. 18, 239–247. doi:10.1111/j.1475-2743.2002.tb00265.x

Westphal, C., Bommarco, R., Carre, G., Lamborn, E., Morison, N., Petanidou, T., Potts, S.G., Roberts, S.P.M., Szentgyörgyi, H., Tscheulin, T., Vaissiere, B., Woyciechowski, M., Biesmeijer, J.C., Kunin, W.E., Settele, J., Steffan-Dewenter, I., 2008. Measuring bee diversity in different European habitats and biogeographical regions. Ecol. Monogr. 78, 653–671. doi:http://dx.doi.org/10.1890/07-1292.1

Wood, T.J., Holland, J.M., Hughes, W.O.H., Goulson, D., 2015a. Targeted agri-environment schemes significantly improve the population size of common farmland bumblebee species. Mol. Ecol. 24, 1668–1680. doi:10.1111/mec.13144

Wood, T.J., Holland, J.M., Goulson, D., 2015b. Pollinator-friendly management does not increase the diversity of farmland bees and wasps. Biol. Conserv. 187, 120–126. doi:10.1016/j.biocon.2015.04.022

Woodcock, T.S., Pekkola, L.J., Dawson, C., Gadallah, F.L., Kevan, P.G., 2014. Development of a Pollination Service Measurement (PSM) method using potted plant phytometry. Environ. Monit. Assess. 186, 5041–57. doi:10.1007/s10661-014-3758-x

Xie, Z., Williams, P.H., Tang, Y., 2008. The effect of grazing on bumblebees in the high rangelands of the eastern Tibetan Plateau of Sichuan. J. Insect Conserv. 12, 695–703. doi:10.1007/s10841-008-9180-3

Zuur, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A., Smith, G.M., 2009. Mixed effects models and extensions in ecology with R. Springer, New York, NY, USA.

Table 1. The proportion of total flowers (%) contributed by each habitat type to the total farm level flower abundance on farms in three different wildlife-friendly farming schemes (mean and SE across four farms per scheme). ELS = Entry Level Stewardship, CG = Conservation Grade, org = organic, ES = Environmental Stewardship, Imp. grass = improved grass, MFC = mass flowering crop and other = fallow, tree planting, woodland, game cover.

	ES grass	**ES margin**	**Hedgerow**	**Imp. grass**	**MFC**	**Cereal**	**Other**
ELS	5.2 ± 2.9	50.3 ± 21.0	2.4 ± 1.1	24.7 ± 21.2	0.3 ± 0.2	0 ± 0	0.2 ± 0.15
CG	35.4 ± 10.7	39.2 ± 17.2	9.5 ± 7.4	2.1 ± 1.5	0 ± 0	10.9 ± 9.3	3.08 ± 1.38
Org	39.1 ± 14.9	0.6 ± 0.3	5.4 ± 3.9	8.9 ± 2.8	36.2 ± 15.5	9.8 ± 5.3	0.05 ± 0.04

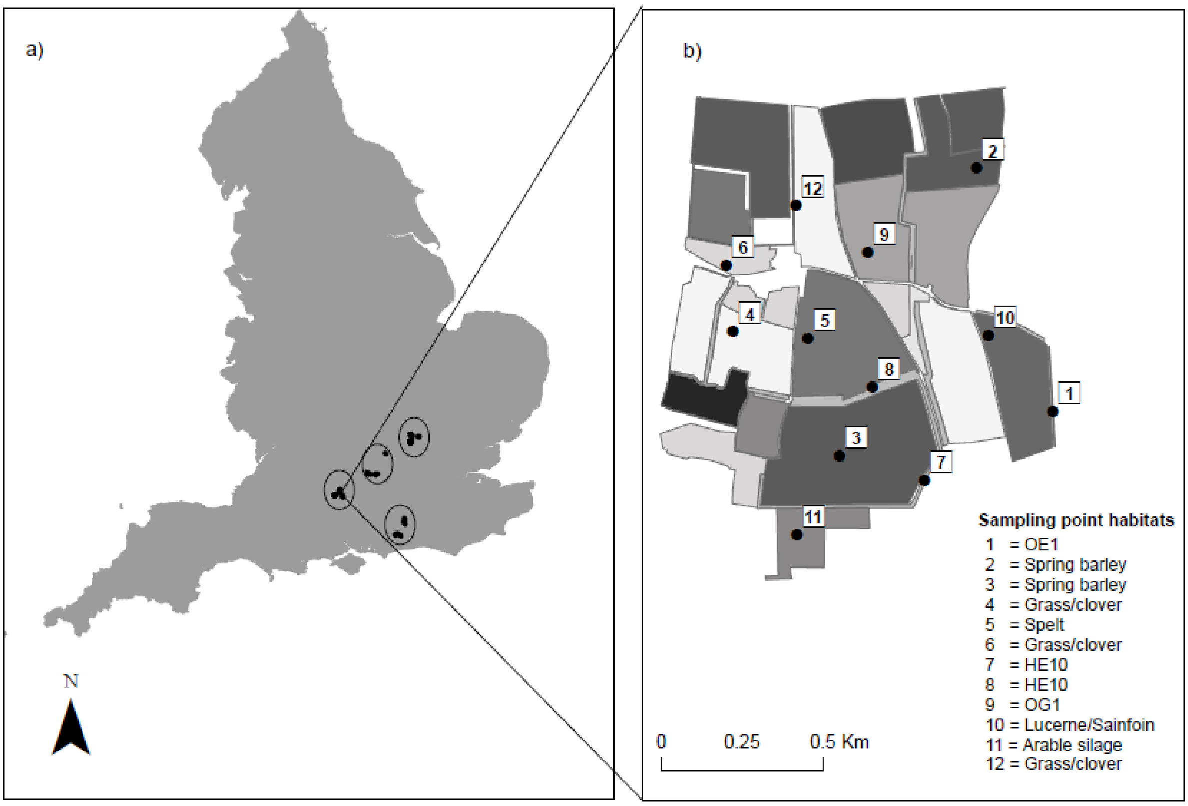

Figure 1: a) Map of England showing the location of the twelve study farms (black dots) in four matched regional triplets (ovals), b) map of one organic study farm showing the location of the twelve pollinator sampling points on a habitat map. The legend shows which habitat each sampling point was in, including some habitats classified using their Environmental Stewardship option codes. The crop habitats were arable silage, einkorn, lucerne/sainfoin, spelt and spring barley. The non-crop habitats were grass/clover, HE10: Floristically enhanced grass buffer strips, OE1: 2 m buffer strips on rotational land and OK3: Permanent grassland with very low inputs.

Figure 2. Bar plots showing mean flower density (a) and flowering plant Shannon diversity (b) in crop and non-crop habitats on farms in three different wildlife-friendly farming schemes (ELS = Entry Level Stewardship, CG = Conservation Grade, Org = Organic). Error bars show 95% confidence intervals.

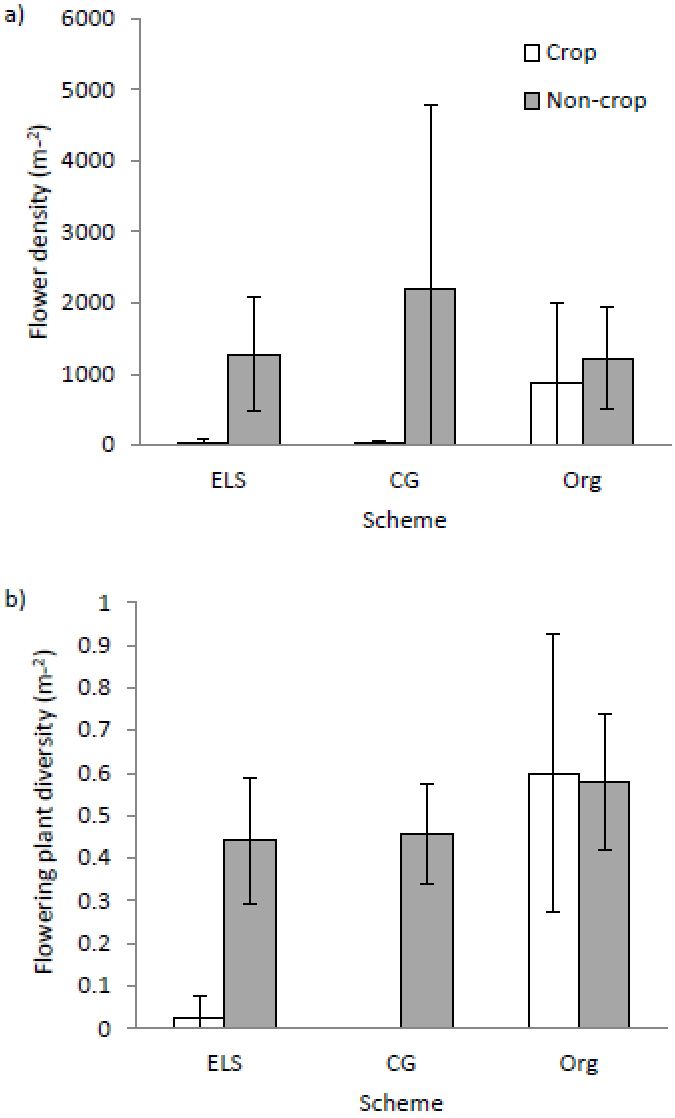

Figure 3: Bar plots showing means with error bars showing 95% confidence intervals for a) bee species richness, b) hoverfly density, c) bee density and d) bee-flower visit density, recorded on twelve transects, each 100 m long and 2 m wide, in crop and non-crop habitats on farms in different wildlife-friendly farming schemes: ELS =Entry Level Stewardship, CG =Conservation Grade and Org =Organic.

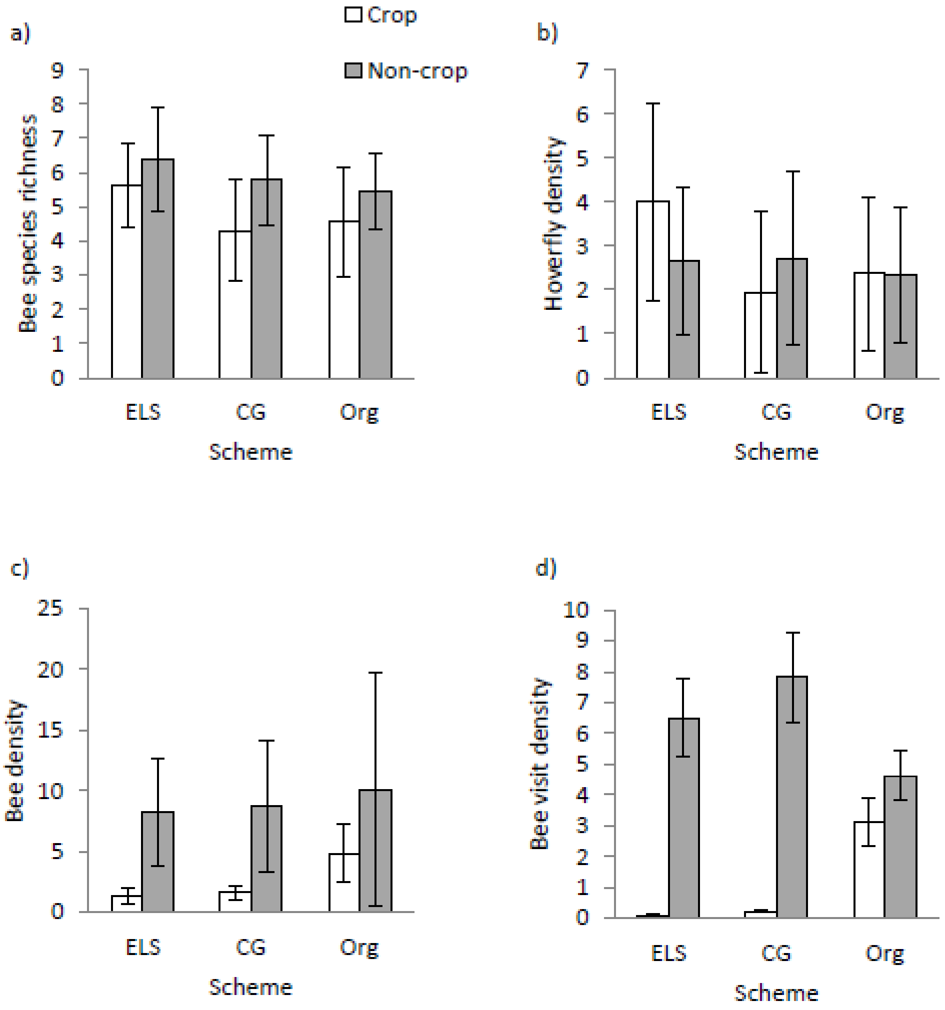

Figure 4: Bar plots showing means for pollination service measured as fruit set and seeds per node per phytometer plant recorded in crop and non-crop habitats on farms in three different wildlife-friendly farming schemes (ELS = Entry Level Stewardship, CG = Conservation Grade, Org = Organic). Error bars show 95% confidence intervals.