The Effect of Agri-Environment Schemes on bees on Shropshire Farms

Lucy I Crowther[a, b] and Francis Gilbert[a]

[a]School of Life Science, University of Nottingham, Nottingham. NG7 2RD.

[b]Lancaster Environment Centre, Lancaster University, Lancaster. LA1 4YW. crowthel@lancaster.ac.uk

Abstract

1. The decline of bees and other invertebrate pollinators is cause for global concern, with modern intensive agriculture identified as a key driver. Government-run agri-environment schemes (AES) have the potential to restore the local landscape to benefit bees.
2. Bee abundance, species richness and foraged plants were surveyed over a season on 18 farms in Shropshire, UK, classified into three treatment groups for comparison: Conventional, Entry-Level Stewardship AES (ELS), and Higher-Level Stewardship AES (HLS).
3. Bee abundance and species diversity were significantly higher on AES-compliant farms: there were only small or non-significant differences between ELS- and HLS-compliant farms.
4. ELS and HLS farms had higher diversity of floral foraging resources than conventionally managed farms. *Cirsium, Heracleum sphondylium,* and *Rubus fruticosus* were important resources for bees through the season.
5. *Synthesis and applications*. These results highlight that key ELS actions, such as set-aside of uncultivated field margins, hedgerow restoration, late-cut meadows and sowing of nectar-rich flower mixes, are effective AES options to improve the landscape for bee communities. Many plants considered agricultural weeds are important forage resources for bees.

Keywords

Agri-environment schemes, bees, ecosystem services, field margins, floral resources, pollination

1. Introduction

The intensification of agriculture over the past 50 years has led to the drastic decline of wildlife associated with British countryside (Kremen et al. 2002; Rundlof et al. 2008). Up to 50% of species within Europe depend on agricultural ecosystems at some level, including threatened species (Stoate et al. 2009). The trade-off between local biodiversity and increases in yields has resulted in a ten-fold decline in economically and environmentally valuable taxa, many directly beneficial to agricultural production (Klein et al. 2007).

Two factors drive this decline: habitat loss and fragmentation (Rundlof et al. 2008; Bartlett et al. 2016), and the extensive use of agrochemicals (Carvell et al. 2007; Fijen et al. 2019). At field scales, farmland biodiversity is directly affected by alterations to farming practice, e.g. large fast-moving machinery, crop-rotation cycles and tillage systems (Holzschuh et al. 2006). With farmland making up more than 70% of the UK landmass (DEFRA, 2017:), an increase in monoculture, lack of non-crop habitats and reductions in connectivity between semi-natural land have all contributed to drastic landscape alterations (Garrett et al. 2017).

Agriculture relies on ecosystem services to function and be productive. Such services that are provided by and contribute towards healthy, productive ecosystems include soil maintenance, nutrient cycling and pollination (Power, 2010). Intensive farming for high crop yields trade-off with ecosystem well-being, since it degrades the environment and associated services through increased soil erosion, nutrient removal and runoff, greenhouse gas emissions and environmental toxicity (Pamminger et al. 2018). Although ecosystem services are the underlying driver to production and environmental regeneration in agricultural systems, research suggests a significant lack of understanding from farmers about how directly land management can manipulate ecosystem services (Teixeira et al. 2018).

The UK Agri-Environment Schemes (AES), first implemented in the 1980s, aim to increase the recruitment of farmers into “wildlife-friendly” farming, encouraging alterations to management activities, reducing production intensity and promoting set aside of land (Pywell et al. 2006; Marja et al. 2019). Setting aside land should not be confused with abandonment; set-aside requires management to increase biodiversity (Firbank et al. 2003). The two main levels of Countryside Stewardship AES are administered by Natural England, Department for Environment Food and Rural Affairs; DEFRA, and the Rural Payments Agency. Entry-level Stewardship (ELS) is a widespread and flexible scheme (this scheme was replaced with the Mid-Tier scheme during 2018). Higher-level Stewardship (HLS) is a more complex scheme, targeting specific natural elements within farmland landscapes and requiring stronger commitment to changing land management methods and losing cultivatable land (Baker et al. 2012). Farmer obligations within these schemes encompass adherence to wildlife-friendly and environmentally friendly actions aimed at promoting species diversity, restoring wildlife populations and enhancing/maintaining natural resources (Carvell et al. 2007; Hardman et al. 2016a).

Assessing the effectiveness of AES is difficult due to complex interactions between biotic environmental components, landscape heterogeneity and differing land management practices among sites (Scheper et al. 2013; Holland et al. 2015; Marja et al. 2019). Since the introduction of such schemes, several reviews have quantified effectiveness. The results are mixed but suggest an overall increase in biodiversity (Whittingham, 2011; Batary et al. 2015). Agri-environment schemes are beneficial to farmland birds (Kleijn et al. 2011; Westbury et al. 2017), plants (Carvell et al. 2007; van Klink et al. 2017), mammals (Broughton et al. 2014) and some invertebrate groups (Fuentes-Montemayor et al. 2011; Hof & Bright, 2010).

With pollination becoming prominent in conservation efforts in recent years (Larson et al. 2017; Wilson, Forister & Carril, 2017), specific actions have been introduced to the AES to benefit pollinators. Set-aside of uncultivated land is known to produce significant benefits to insect pollinators (bees, flies, and butterflies: Raymond et al. 2014; Hardman et al. 2016b), promoting the abundance and diversity of perennial plants and increasing flower densities (Stoate et al. 2009). Additional pollinator-specific actions include mixes of nectar-rich flower species, creation of low-input grasslands (Scheper et al. 2013), enhanced grassland buffer strips, non-rotational grassland strips, and creation/preservation of species-rich grasslands (Wood et al. 2015; Hardman et al. 2016a). These actions highlight the need for landscape heterogeneity and a variable habitat matrix to provide seasonal support for pollinators (Stoate et al. 2009; Breeze et al. 2014). The current demand for crop pollination surpasses the abilities of domesticated *Apis mellifera* and *Bombus terrestris*, and thus the pollination efforts of wild bees have become increasingly important (Breeze et al. 2014; Hardman et al. 2016a). A recent study found that honeybee presence has a negative influence on wild bee abundances through transmission of diseases and direct competition for floral resources (Fijen et al. 2019). Holzschuh et al. (2012) conclude that wild bees can be more efficient at pollinating certain crops than honeybees. This difference could be down to solitary bees and bumblebees having efficient pollen deposition (e.g. buzz pollination), different physiology and phenology, and greater pollen exchange.

Apis mellifera and several common *Bombus* species are well studied, but these make up a small percentage of the total British bee fauna: most bees are solitary and relatively poorly studied (Wood, Holland & Goulson, 2017). Unlike *Apis mellifera*, bumblebees and solitary bees do not store pollen and nectar for extended periods of time, and thus can suffer greatly from gaps in resources over time (Carvell et al. 2015). Management options reduce such gaps are positive aspects of the AES (Rundlof et al. 2008; Wood et al. 2015).

For wild bees, the abundance, timing, and diversity of floral resources are significant factors limiting densities (Scheper et al. 2013; Carvel et al. 2015; Hardman et al. 2016a). Holzschuh et al. (2016) comment on the need for knowledge of the temporal dynamics of bee communities, specifically regarding insect-pollinated crops, highlighting the differences in crop prices, subsidies and rotation methods. Many of the traits and niches of wild bees are little understood, but there are marked differences among species in foraging range, season length, nesting position and tongue length - a crucial indicator of the feeding niche (Goulson & Darvill, 2004; Wood et al. 2015).

This study investigates the effectiveness and viability of agri-environment schemes in terms of pollinator conservation and resource provisioning. The following directional hypotheses are tested; i) AES-compliant farms have significantly higher bee abundance and support a greater number of bee species, ii) AES-compliant farms supply significantly greater flowering plant diversity to act as forage resources. The focus is on bee and flower communities found within field-margin habitats in agricultural landscapes. The study compares *Apis*, *Bombus* and solitary-bee species among Conventional farms and the two levels of AES, identifying any specific actions within the AES levels that provide benefits to local bee communities.

2. Methodology

2.1. Study sites

18 farms were surveyed between April and September 2018 in Shropshire, England. All were based within or around the Shropshire Hills Area of Outstanding Natural Beauty (AONB: see Fig. 1). Farms were chosen to fit one of three treatment categories: Conventional (C: seven farms selected), Entry-Level (ELS: five farms selected) and Higher-Level schemes (HLS: six farms selected). All management techniques implemented on farms enrolled in AES adhered to DEFRA guidelines and complied with Natural England environmental regulations (full details are in Table S1). The weather in the 2018 survey season was unusually hot and dry during midsummer, and this may have influenced bee activity and the longevity of floral resources.

Farms within treatment groups were separated into two approximately equal sets to be surveyed on alternate weeks. Due to differences in landscape heterogeneity and phenological differences, it was not possible to match farms into triplets, one of each treatment. Instead, farms were selected to represent the land-management composition within the region to try to represent farming practices and habitats across the AONB. Four farm types were included: arable (cereal/bean), livestock-arable mixed, livestock-based (cattle and sheep) and dairy. However, farms were not specifically selected based on type, resulting in slight differences among treatment groupings. Livestock-based and livestock-arable mixed were the most frequent farm types, with six livestock-based farms (four conventional, two HLS), and seven livestock-arable mixed farms (two conventional, four ELS and one HLS). There were three arable farms (one ELS, two HLS), and two dairy farms (one conventional, one HLS) (see Table S1).

A questionnaire was supplied to all landowners and tenants to collect information about the management and environment of each farm (for full answers see Table S1).

2.2. Bee surveys

Bombus, *Apis mellifera* and solitary bees were surveyed utilising a transect method adapted from standard butterfly surveys (Pollard, 1977). A total of one kilometre of belt transects was established along typical field-margin habitats (hedgerow, stream, or ditch) of two to three fields on each farm. Fields were selected to be as far apart as possible (greater than 5km) to reduce population overlap, but at smaller farm location there remained a possibility. Start points were selected along field-margin habitats with margins internal to the farm, not along roadsides, and excluding the first 10 metres from the field entrance. Transects were approximately two metres wide, including the field-margin habitats (estimated to be one metre) and one metre of uncultivated field margins (or cultivated land where there were no margins in place). Observations/captures were made up to a height of two metres, between 10.00 and 17.00 on days with acceptable weather conditions (local air temperatures above 13°C, minimum 60% clear sky and no rainfall: Pywell et al. 2006). Each farm within the three treatment groups was selected at random to be surveyed within specific time slots, rotating morning (10:00-12:00), early-afternoon (12.30-14:30) and late-afternoon (15:00-17:00) to reduce the effect of any potential fluctuations in bee abundance over the day.

Two sampling techniques were implemented, taking approximately 60 minutes to complete. Visual encounter surveying along the belt transect recorded all bees, with no separation between queens, workers, or males. To minimise multiple recordings of specimens, bees identified to species on sight were monitored until they left the transect. Bees that could not be immediately identified were caught in a net, identified, and released (these bees left the transect as a result), or caught and retained for identification. Following the transect survey, a sweep net survey was conducted along the same belt transect, specifically to target solitary bee species, sweeping horizontally across the ground of the field margins and vertically along the vegetation face of the margin habitat itself. Specimens were identified at the end of the survey using the keys in Falk (2015) and verified using the local atlas (Jones & Cheeseborough, 2014). The bee names follow Falk (2015), except *Bombus terrestris* and *Bombus lucorum* agg., which were recorded collectively as *B. terrestris/lucorum* agg. because reliable identification of workers in the field is not possible. When any bee was seen feeding on any flowering vegetation, the flower species were recorded to genus or species level where possible.

2.3. Data analysis

The summary data were the counts of the number of individuals of each bee species summed for each farm and for each treatment group, together with some summaries at generic level (*Andrena, Bombus, Lasioglossum*, and *Nomada*). The flower species used by bees were recorded, together with the numbers of each bee species seen foraging on them.

To test the effect of the AES schemes on bee abundance and species diversity, for each survey the total abundance of all bees, and the three standard indices of diversity (Hill numbers: Chao et al. 2014) were calculated: H0 (species richness) emphasizes rare species, H1 puts more weight on common species, and H2 is an index of the number of superabundant species. Hill numbers (exponential Shannon and inverse Simpson) were used to represent the effective number of species, or functional diversity of assemblages, combining other diversity indices into one expression. H1 and H2 assign different weightings basted on commonality, differing from standard species richness which weights common and rare species equally (Chao et al. 2014). The Hill numbers formed the response variables in generalised linear mixed models (due to the use of repeated measures [random factors] of individual farm and survey date) to be able to see the influence of the AES treatments on bee abundance and species diversity. Residuals were checked and the default normal errors were appropriate for all analyses. All models included random factors of farm and date, and the fixed predictors of *AES* group, farm *type,* and the *AES* x *type* interaction, tested by ANOVA. *A priori* contrasts were applied within each ANOVA, predicting that Conventional farms would have lower bee abundance and species diversity than farms managed under either AES (C < ELS + HLS) and that ELS farms would have a lower bee abundance and species diversity than HLS farms (ELS < HLS). In addition, data for bumblebee species were analysed separately. All analyses were conducted with R version 3.5.1 (R Core Team, 2018) using the package *lme4*.

Data for the genus *Bombus* were analysed separately due to the large amount of information collected, including the subgenus *Psithyrus*. Some *Bombus* species were present on all surveyed farms, including both common and rare species, as well as generalist and more specialised species, making this sub-analysis worthwhile. *Bombus* species are now actively being utilised and manipulated as commercial crop pollinators (e.g. *B. terrestris*), and hence a greater insight into the effect of farm management may promote better monitoring and conservation.

Floral diversity was estimated by counting the flowers utilised by foraging bees; means were used to allow for differences in sample sizes among treatment groups. Summing over all transects, the flower x bee matrix of total numbers of visits was formed, and the interactions plotted as community network diagrams using the *bipartite* package in R (Dormann, Gruber & Fruend, 2008). The time-course of the most-used flowers across the survey season highlighted any temporal gaps in forage.

3. Results

3.1. Bee abundance and diversity

A total of 4234 individual bee sightings were recorded over the study period (674 *Apis mellifera*, 2130 *Bombus* spp. and 1430 solitary bees). 1055 bee sightings occurred on Conventional farms, 1407 sightings on ELS and 1772 sightings on HLS (Fig. 2a). 65 species of 12 genera were identified, with a combined total of 44 species identified on Conventional farms, 47 on ELS and 50 on HLS (Fig. 2b; Supporting information Table S2). The records included species locally scarce to Shropshire, such as *Melecta albifrons* and *Lasioglossum malachurum*. Overall species richness differed between farm treatments; Conventional farms ranged from 16 to 24 species between farms, ELS farms between 26 and 33, and HLS farms between 19 and 35.

The 15 most common species (Fig. 3) included seven *Andrena* spp., six *Bombus* spp., *Apis mellifera* and *Halictus rubicundus*. In terms of total sightings, the most species-rich genera were *Andrena* (16 species), *Lasioglossum* (14 species), *Bombus* (11 species) and *Nomada* (11 species). The genera with the greatest abundances were *Bombus* (2130 sightings), *Andrena* (933) and *Apis* (674). The most abundant *Andrena* were *A. nigroaenea*, *A. haemorrhoa,* and *A. chrysosceles*; for *Lasioglossum* they were *L. calceatum* and *L. leucopus*; for *Bombus*, *B. terrestris/lucorum* agg., *B. lapidarius* and *B. pascuorum*; and for *Nomada*, *N. goodeniana* and *N. lathburiana*. The three most common species overall (See Fig. 3 and Fig. 4) were *Apis mellifera* (674 sightings), *B. terrestris/lucorum* agg. (632 sightings), and *B. lapidarius* (606 sightings). A total of 11 *Bombus* species out of the 18 recorded in Shropshire (Jones & Cheeseborough, 2014) were identified across all the study farms. Five species were present on every farm; *Bombus terrestris/lucorum agg*., *B. lapidarius*, *B. pascuorum*, *Apis mellifera,* and *Andrena haemorrhoa*.

Bee phenology varied amongst species: *Bombus* spp. and *Apis mellifera* were present throughout the entire study period, appearing in every week of surveying in varying abundances (Fig. 4a, b, c). *Bombus* (*Psithyrus*) spp. were present only on farms where the associated host was present, appearing in low numbers during April – May and throughout August. *Andrena* spp. appeared early on in relatively high numbers (Fig. 4d), but these started to drop in late July, with no sightings into August. *Nomada* spp., kleptoparasites of *Andrena*, also appeared early on alongside their host species, with sightings occurring from April until June (Fig. 4f). *Halictus* and *Lasioglossum* were present sporadically until July when their abundances increased until the end of the survey period. Numbers of *H.*

rubicundus increased during August (Fig. 4e), after appearing in low abundance throughout the survey period. The numbers of *Sphecodes* spp. fluctuated in association with their hosts (*Andrena, Halictus,* and *Lasioglossum*), appearing when their various host abundances peaked. An individual *Melecta albifrons* was identified, but its host, *Anthophora plumipes*, was not recorded, although common in gardens throughout the local area.

3.2. *Differences among AES treatments*

Bee abundance and diversity per survey were found to be significantly related to land management under AES (Fig. 5; Supporting information Table S3). Using either AES treatment had a significant positive influence compared to Conventional farms on the number of bees and all the measures of diversity, H0, H1, and H2. The first contrast (C < ELS+HLS) was always highly significant ($p << 0.001$: see Supporting information Table S3). Compliance with either AES showed the greatest influence on abundance (Fig. 5a) and species richness (Fig. 5b), indicating that the largest effect was on rare species. The smallest effect was found on H1 (Fig. 5c), which emphasizes common species. The second contrast (ELS < HLS) was not in the predicted direction for any of the Hill numbers (and hence not significant), but there was a small increase in overall bee abundance for HLS (Fig. 5; Supporting information Table S3). Farm type showed no significant effects on any of the response variables (Supporting information Table S3). However, there were significant or near-significant interactions between AES and farm type for all response variables ($p = 0.011 - 0.019$: see Supporting information Table S3; Fig. S1). Species richness (H0) showed the most significant response to the AES x farm type interaction (Supporting information Fig. S1), where the difference between Conventional and HLS farms is smaller in Livestock-based farms than in other types of farm.

For just the bumblebees, the AES treatment had significant effects on abundance and H0 (species richness), but not H1 or H2, both of which place emphasis on common species (Supporting information Table S4). For abundance and H0, again there was a highly significant first contrast (C <

ELS+HLS; *p* << 0.001), but no effect for the second contrast (ELS < HLS). Farm type and the interaction between AES and farm type showed no significant influence on the bumblebee community.

3.3. Community use of floral resources

Bees were recorded utilising 62 flowering plant species across all study sites throughout the season, with 36 used on Conventional, 40 on ELS and 39 on HLS farms. Mean counts showed species diversity remained highest in ELS-compliant farms (see Fig. 6). Species counts on conventional farms ranged from five to 16 species, from 14 to 18 on ELS-compliant farms, and 10 to 18 on HLS-compliant farms. The most dominant flowers being used included *Crataegus monogyna, Taraxacum* spp., *Heracleum sphondylium, Trifolium pratense, Trifolium repens, Rubus fruticosus* and *Cirsium* spp (Fig. 7). *Impatiens glandulifera* (Himalayan Balsam, an aggressive invader) occurred on two farms where it acted as a significant late-season nectar source (Supporting information Fig. S2), attracting many foraging *Bombus* spp. and *Apis mellifera*.

4. Discussion

Both Entry-level and Higher-level stewardship AES were found to influence significantly the abundance and species diversity of bees, with higher numbers of bees and greater species diversity seen on AES-compliant farms. This difference in bee abundance and diversity cannot solely be attributed to AES due to the differences between farming landscapes, although general inferences can be made from the results. Conventional and AES-compliant farms alike produce the environmental conditions to support common species, such as the six common bumblebees (including *B.terrestris, B. lapidarius* and *B. pascuorum*) and *Apis mellifera* (Hanley & Wilkins, 2015). Fijen et al. (2019) show that floral visits are dominated by a small number of species with the ability to exploit mass flowering crops and make a significant contribution to crop pollination. This would suggest that the small collection of species consistently found on all farms, including Conventional, could provide most crop pollination services. Although, each visit should not be considered a successful pollination event, it is likely that more bees lead to more flower visits, which equates to a greater pollination services.

The treatment group that produced the most variable results was HLS, with species diversity ranging from 19 to 35 species across the treatment group. This larger variation in species diversity among HLS sites could be due to management actions on these farms varying greatly. Conventional farms consistently showed the lowest abundances and lowest species diversity. This highlights the significant lack of appropriate habitats for feeding and nesting resources. Likewise, AES-compliant farms supported more flowering plant species recorded as being utilised, providing bees with a greater variety of forage resources than conventionally managed farms, and suggesting greater habitat diversity.

The results in number of bees and species diversity mirror the results found in similar research; Woods et al. (2016) found 105 species across 19 AES-compliant farms with 3km transects, exhibiting a similar array of groups, including a number of *Psithyrus* spp. and parasitic solitary species. Similarly, Rundlof et al. (2008) identified 11 bumblebee species across 12 matched pairs of organic and conventional farms, finding significantly more species in organic heterogeneous landscapes than conventional.

4.1. Agri-environment schemes and landscape context

HLS farms can often focus actions on specific areas of interest, such as woodland, in conjunction or instead of field-level actions (i.e. set aside margins). In comparison, one of the most common ELS actions is land set-aside as field margins (see Table S1). Since ELS farms supported the most diverse bee communities, this suggests that this is more likely to establish favourable environments. This highlights the fact that actions spread across the landscape at field-level could be more beneficial than focusing on specific areas of interest (land sharing vs land sparing; Kremen, 2015). The greater bee abundance on HLS-compliant farms suggests that these can support the level of resources needed to allow bee populations to be sustained at high levels. Pollinator abundance and diversity can decrease with increasing distance from semi-natural habitat (Gill et al. 2016), emphasizing that the spatial structure and configuration of AES actions across the landscape is essential for bee conservation and efficient pollination services (Holland et al. 2015).

Field margins provide foraging resources and refuge habitats at field-level, increasing connectivity between semi-natural, non-cultivated habitats throughout the local landscape (Holzschuh et al. 2006). This habitat connectivity within the agricultural landscape specifically benefits bumblebees and solitary bees through access to seasonally variable forage. In addition to habitat corridors, hedgerows can act as environmental buffers, reducing the spread of agrochemicals (Carvell et al. 2007; Hanley and Wilkins 2015). The positive influences derived from the management of non-crop field margins are likely due to the increase in the availability of flowering plant species, which acts as a key determinant to bee reproductive success (Pywell et al. 2006; Carvell et al. 2015).

4.2. *Pollinator-targeted actions*

Farms that supported a high abundance and species diversity of bees adhered to several similar AES actions, such as sowing and management of nectar and pollen-rich flower mixes (see Table S1). These mixes generally include several legume species and species of tussock grasses, providing both forage and nesting resources (Carvell et al. 2007; Holzschuh et al. 2012). These mixes flower in late summer (see Fig. S2), failing to supply resources early in the season when bumblebee colonies begin establishment. Garibaldi et al (2014) emphasize that creation of set-aside field margin is effective at providing resources that support bee communities. The success of this option can be dependent on how long the margin has been established, with the appearance of *Cirsium* increasing the abundance of several *Bombus* spp. (Carvell et al. 2007). Overspill of pollination services from such margins proves beneficial to crops (Carvell et al. 2015).

The option of hedgerow creation and restoration was taken up on several HLS-compliant farms. Hedgerow restoration and the creation of dense, species-rich hedgerows have been linked to a marked increase in biological diversity (Staley et al. 2015). Hedgerows are valuable habitats for pollinators within agricultural landscapes, and their creation and optimal management can increase pollination services, benefiting crop production (Garrett et al. 2017). Hedgerows provide shelter and forage resources for bees because they host several woody plants and flowers adapted to woodlandedge conditions not found in grassland habitats and on cultivated land (Wratten et al. 2012). Management practice is a significant limiting factor to the success of hedgerows in increasing biodiversity because they need to connect and have structural integrity: both over-trimming and neglect in management reduce biodiversity (Staley et al. 2015).

4.3. Forage provisioning

The diversity of flowering plants varied amongst the farms, with those managed in compliance with ELS having the highest species diversity, followed by HLS farms. Most field margins managed in ELS are low-input, self-regenerating margins, with the dominant flowering plant species being *Cirsium arvense, Cirsium vulgare, Heracleum sphondylium* and *Rubus fruticosus.* These species are rapid colonisers (Pywell et al. 2006) and occurred on farms of all treatment groups. Forage provision acts as a limiting factor on local bee populations and loss of floral diversity in conventionally managed agricultural landscapes is a prominent driver in bee declines (Dicks et al. 2015; Carevll et al. 2015). Marja et al (2019) showed that effective AES focus first on the availability of food resources to enhance pollinator diversity. Greater amounts of semi-natural habitats aid bees through providing resources during time between short mass-flowerings of crop (Holzschuh et al. 2012).

From the data, the intentional sowing of field margins appeared to be successful in increasing the abundance and diversity of bees. Specific species sown on ELS and HLS farms include *Sinapis arvensis*, *Phacelia tanacetifolia*, *Trifolium repens,* and *Melilotus officinalis*, all known to attract bees, especially *Apis mellifera*.

The time-course of foraging bee at flowers (Fig. A2) showed a decline in mid-May, whilst the abundances of the commonly seen species (Fig. 4) did not reflect this decline in sightings. This suggests that there is a gap in the diversity of flowering plants used for foraging at this time. *Crataegus monogyna* and *Taraxacum* spp. were the dominant flowering plants initially utilised at the beginning of the season. Resources at this time in the season are essential for emerging solitary bees and *Bombus* queens to begin nesting (Devoto et al., 2013). Alterations to land management methods can help to alleviate this resource gap via less-intense cutting or not cutting in the previous autumn/winter selected areas of hedgerows where *C. monogyna* is dominant. *Impatiens glandulifera* was identified as an important late-season nectar source, providing resources when many flowering plant species have gone to seed. This invasive plant may have displaced native flowers, actually reducing the diversity of nectar and pollen sources throughout the entire season (Flugel, 2017).

4.4. Implications for agri-environment schemes

This study confirms that the implementation of AES, both at entry and higher levels, could mitigate the influences of modern intensive farming to allow a larger and more complex bee community to be supported. The findings specifically highlight the effectiveness of ELS, under which approximately 60% of UK agricultural land is registered (Carvell et al. 2015), showing that this level of scheme can effectively supply the resources needed to support more bees of more species than conventional farming. Encouraging the uptake of low input but effective options could encourage the more widespread adoption of AES. Research suggests that conservation schemes are most effective in simple, homogeneous landscapes, and therefore efforts in areas of intensive agriculture have a high potential for success due to the large ecological contrast (Garratt et al. 2017; Marja et al 2019). Farm size may also play a role in determining the community composition of bees and floral resources. Larger AES-compliant farms with high landscape heterogeneity may provide more resources than smaller similarly managed farms (Rundlof et al. 2008). In this study, HLS farms averaged the largest in size (340 acres), followed by ELS (180 acres). Integrating a larger farm into an AES may be more worthwhile in terms of financial compensation and area of land to spare from production. With conventional farm size averaging around 70 acres, the influence of the wider landscape may be greater than on larger farms, whether positive through increasing wider landscape heterogeneity, or negative.

Based on the effectiveness of AES shown in this case, the future of agricultural management requires trade-offs between agriculturally viable land in favour of the preservation of ecosystem services such as pollination, biocontrol, and nutrient cycling (Hardman et al. 2016a; Marja et al. 2019). Taking agricultural land out of production does not appear economically advantageous at first, but the additional pollination services can increase crop pollination through overspill (Carvell et al. 2015). Set aside of productive land also reduces the area of land exposed to agrochemicals. Herbicides have been found to negatively impact bees in a myriad of ways; reducing sperm counts and worker survival, and hindering larval development (Belsky & Joshi, 2020). Glyphosate, a known stressor for honeybee larval development and reduce bumblebee and solitary bee longevity, was a commonly used herbicide (Vazquez et al. 2018; Belsky & Joshi, 2020). Other pesticides used included Lambda-Cyhalothrin, which has negative implications on bees learning and memory (Liao et al. 2018), Pyrethroids, which induce a myriad of detrimental effects on honeybees at tissue and cellular levels (Kadala et al. 2019)

The findings of this study also recommend tolerance of flowers currently considered agricultural weeds, such as *Heracleum sphondylium*, *Rubus fruticosus*, and *Cirsium* (Gabriel & Tscharntke 2007; Bretagnolle & Gaba 2015). Preservation of flowering plants in uncultivated habitats supports bee communities, specifically opportunistic pollinators (Fijen et al. 2019), between periods of mass-flowering of crops, keeping pollinators within the landscape for their services. Understanding crop economic thresholds for weed tolerance could allow these pollinator-friendly species to be incorporated into seed mixes without negatively affecting crop yield. They could be the only resource available at a crucial time of low floral resources and are perhaps not best-suited to the needs of bees. Genissel et al. (2003) state that *Taraxacum* has low nutritional value, limiting larval success in *Bombus terrestris* and hence resulting in low fitness. However, Wood et al. (2017) showed that sown floral resources may be not recognised as resources by solitary bees, which instead rely on plants in the wider environment.

The limitations of this study should be considered when reviewing its results. Agrochemical applications could not be controlled on these active commercial farms over the period of study, and may have had an influence on the results. Additionally, as with many bee-related studies, it is difficult to foresee and control the influence of honeybees on local wild bee populations (Mallinger et al. 2017).

5. Conclusion

The current broad agri-environment schemes do have the ability to produce environmental conditions that supply the resources needed to promote abundant and diverse bee communities within agricultural landscapes. Bee abundance and species diversity were positively influenced by AES options, such as the creation of non-crop field margins, hedgerow restoration, late-cut meadows and the sowing of nectar-rich flower mixes. The most widely used level of agri-environment scheme, ELS, has the ability to increase significantly the abundance and diversity of bee species with relatively low input from farmers. This study also identifies the value of flowers currently considered agricultural weeds to foraging bees through the year, highlighting the need for a shift in opinion about their removal. Keeping them will benefit bee communities.

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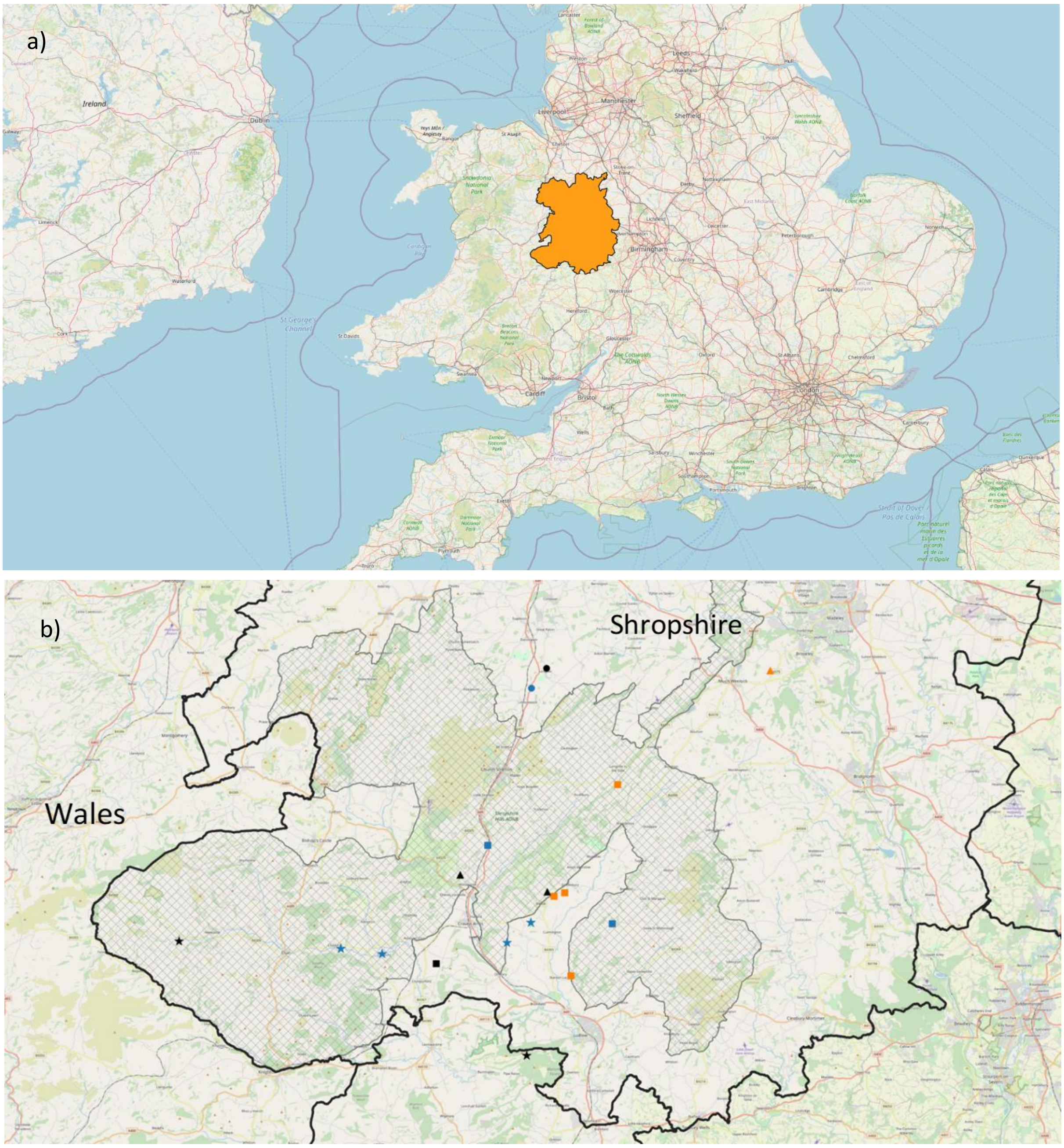

Fig. 1. Study site locations. a) orange indicates Shropshire county. b) black lines indicate county boundaries, grey hatching shows AONB. Colours indicate individual farms; blue=Conventional farms, orange=ELS farms, black=HLS farm. Shapes represent farm types; circle=Dairy, triangle=Arable, star=Livestock-based, square=Livestock-arable mixed. Created using QGIS 3.0.3, data sourced from MAGIC and Ordinance Survey.

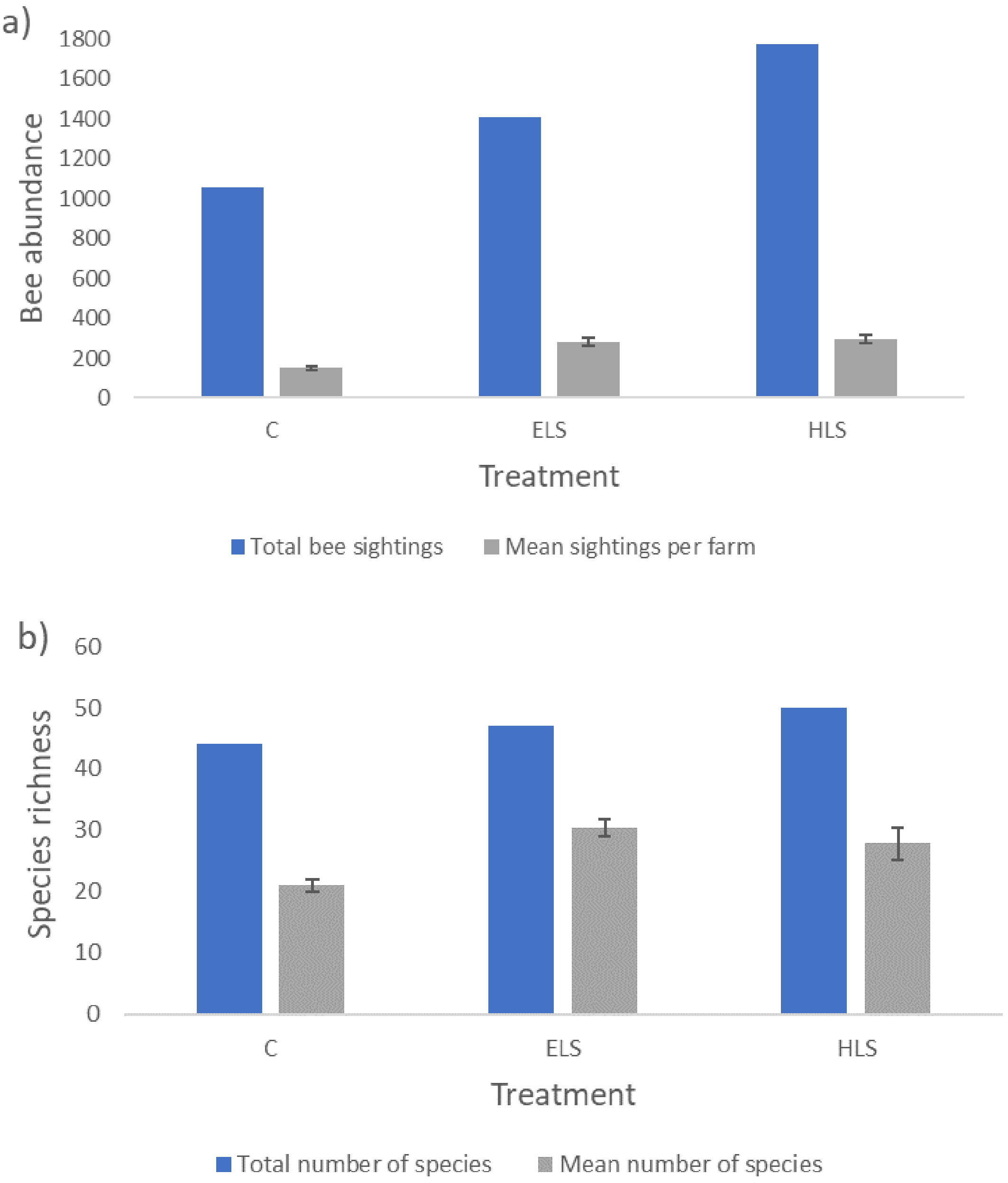

Fig. 2. Overall totals (blue) and means ± se per survey (grey) of (a) bee abundance, and (b) species richness (H0) across the three treatment groups. C=conventional, ELS=entry-level stewardship, HLS=higher-level stewardship.

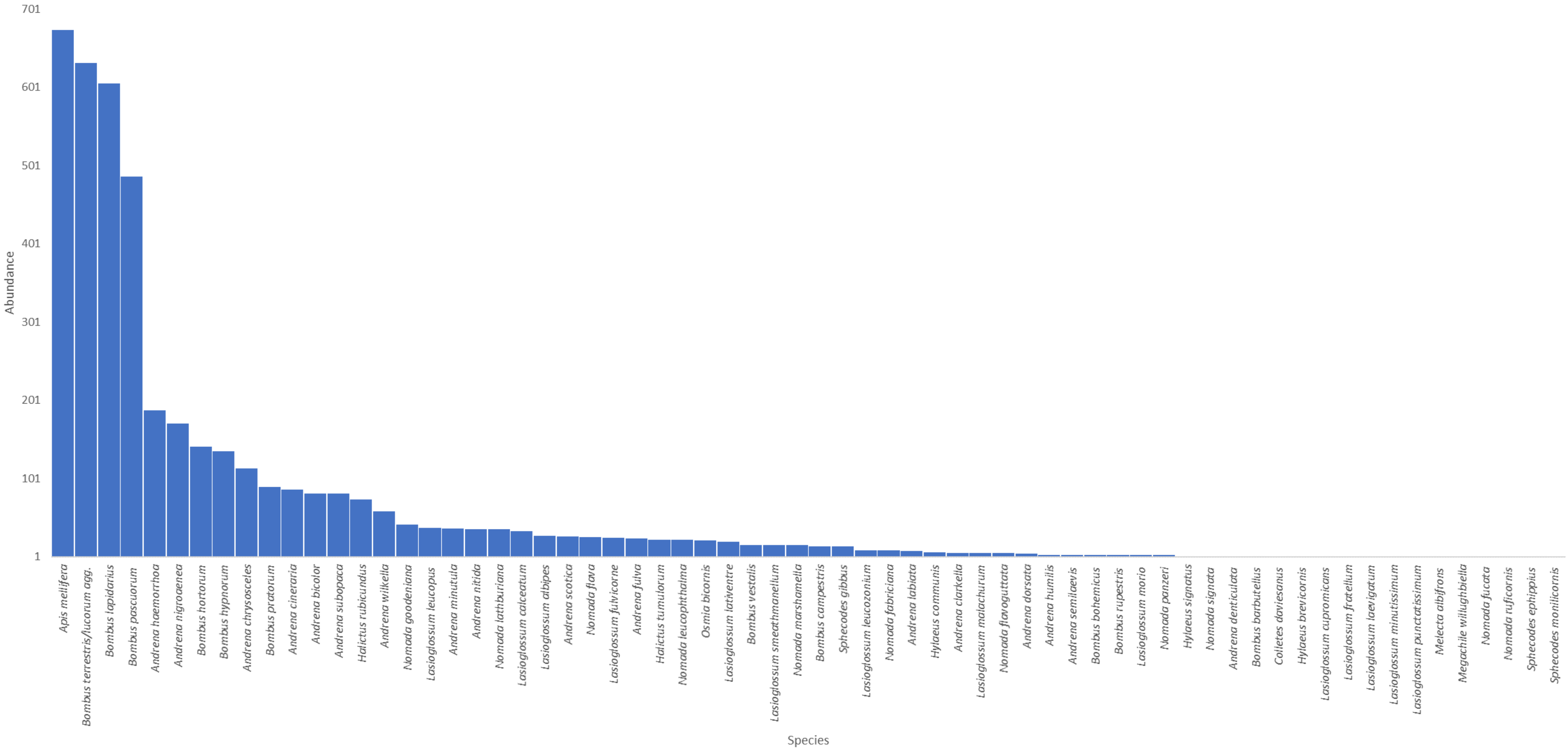

Fig. 3. Total abundance of all species identified throughout the entire study period.

Fig. 4. Mean ± se number of sightings through the season of a collection of common species. w/c=week commencing. a) *Apis mellifera*, b) *Bombus lapidarius*, c) *Bombus terrestris/lucorum* agg., d) *Andrena heamorrhoa*, e) *Halictus rubicundus*, f) *Nomada goodeniana*.

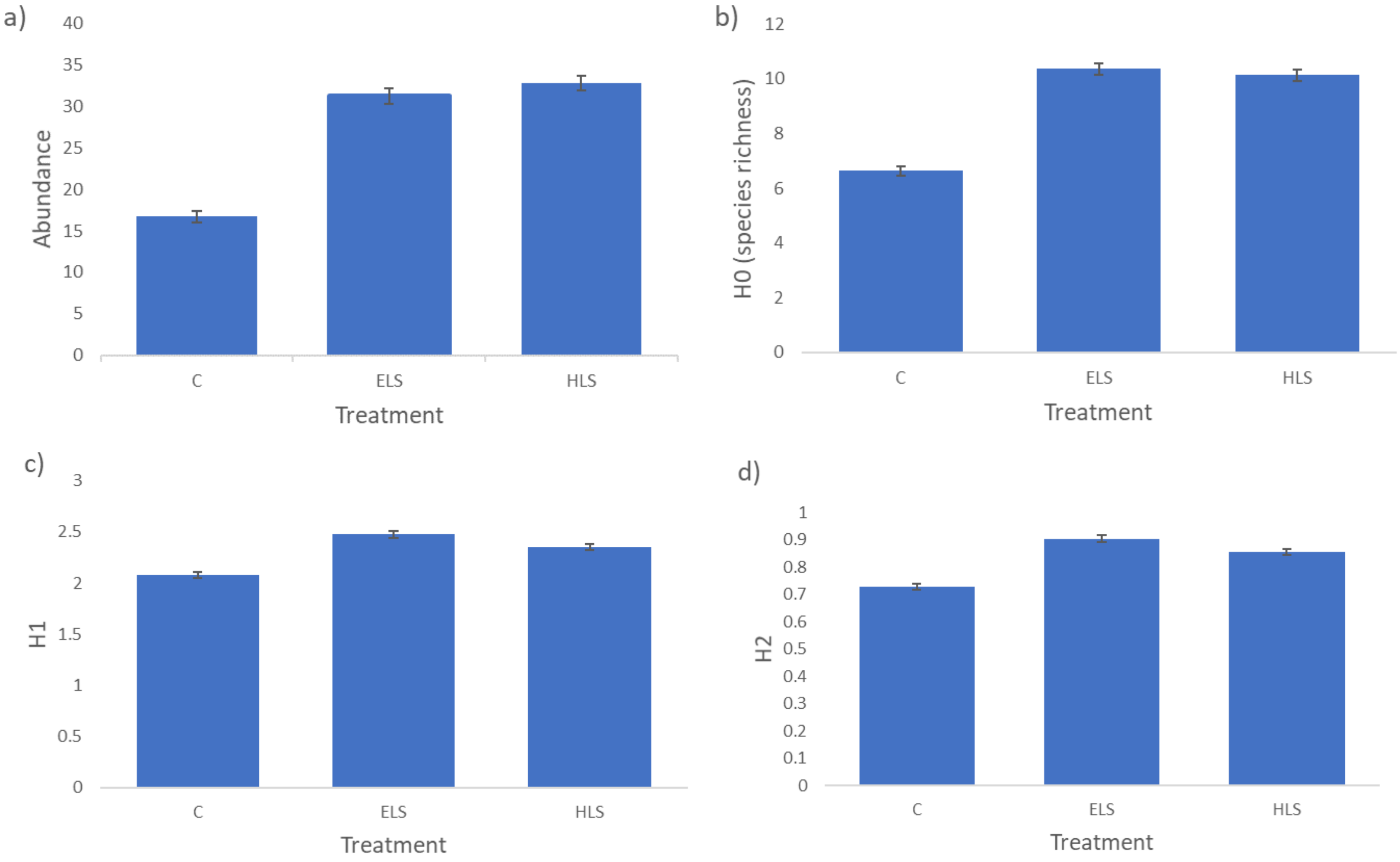

Fig. 5. Marginal means ± se per survey for each treatment group. a) bee abundance, b) Hill #0 (species richness), c) Hill #1 (abundant species), d) Hill #2 (super abundant species). C=conventional, ELS=entry-level stewardship, HLS=higher-level stewardship.

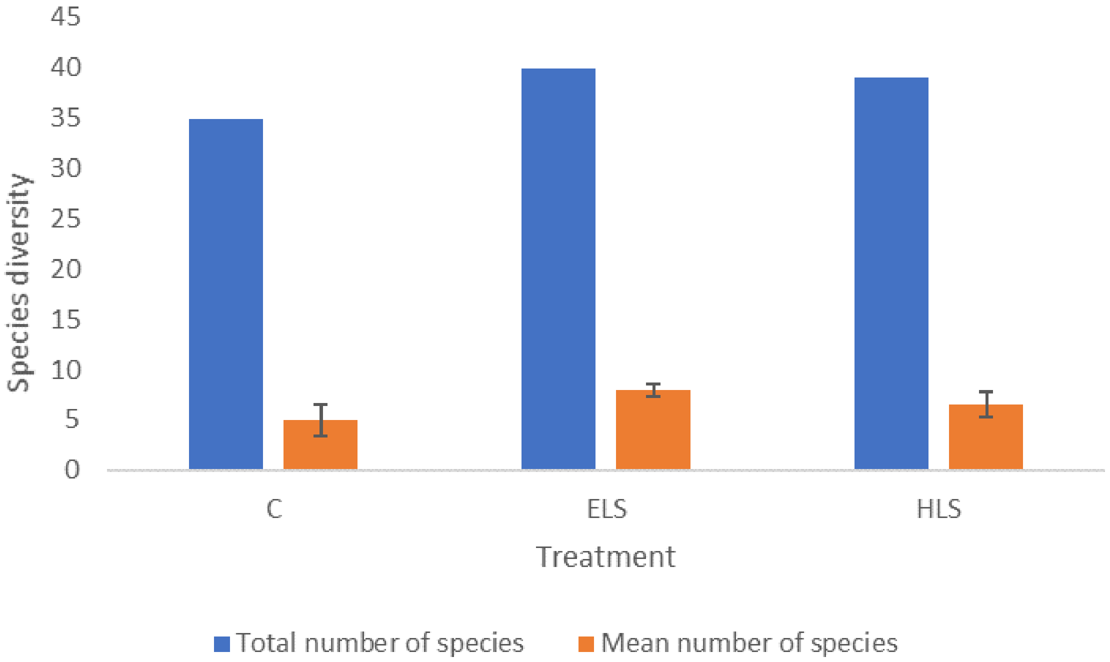

Fig. 6. Overall totals (blue) and means ± se per survey (orange) of floral species diversity across the three treatment groups. C=conventional, ELS=entry-level stewardship, HLS=higher-level stewardship.

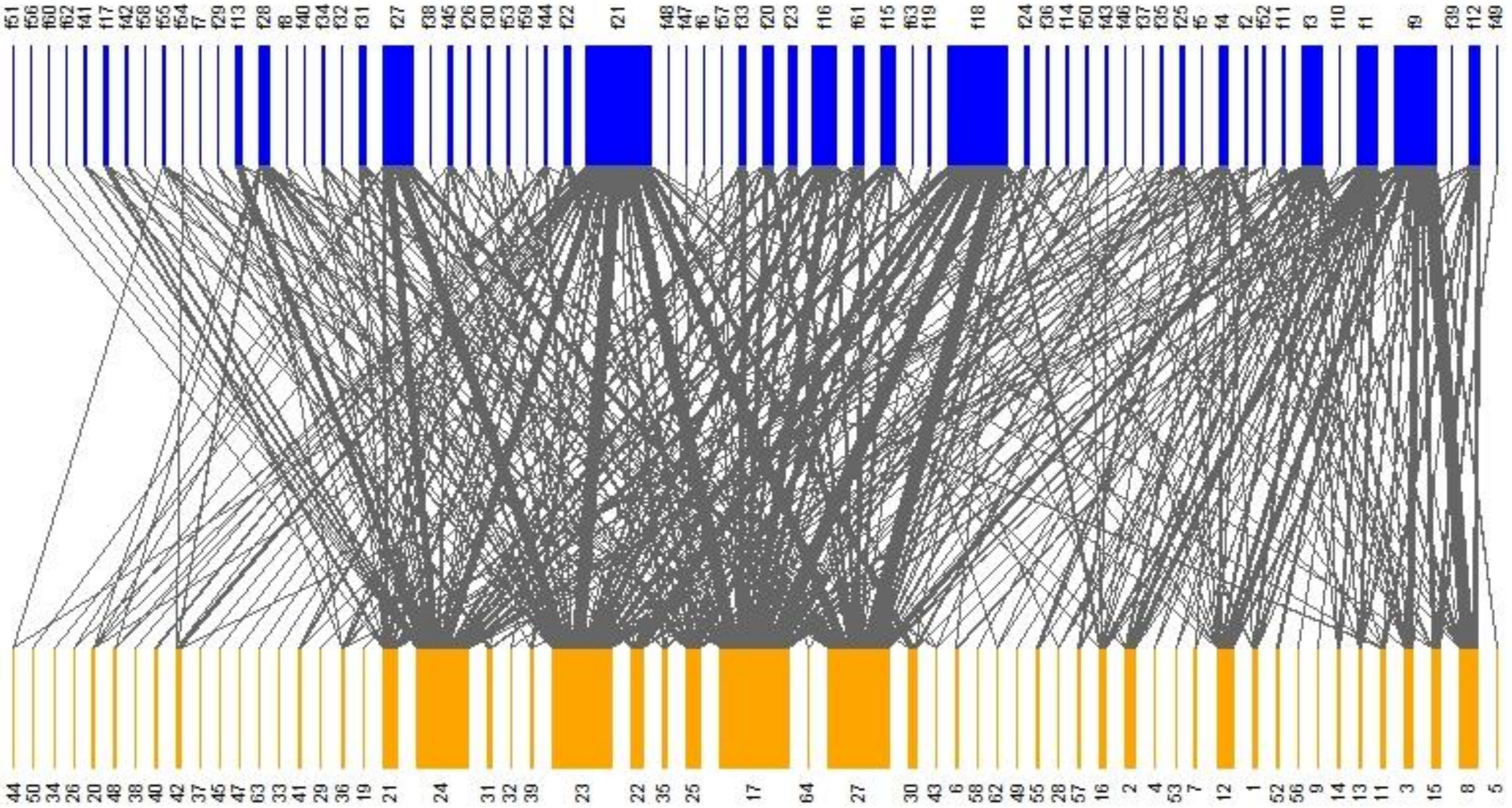

Fig. 7. Overall interactions between bees and flowers. The widths of orange (bee), blue (plant) and grey (interaction) nodes represent frequencies, and numbers refer to the listings in Tables S2 (bees) and S5 (plants). 17=*Apis mellifera*, 23= *Bombus lapidarius*, 24= *B pascuorum*, 27= *B terrestris/lucorum* agg., f9= *Heracleum sphondylium*, f18= *Rubus fruticosus*, f21= *Cirsium arvense*, f27=*C vulgare*.