Does agri-environment scheme participation in England increase pollinator populations and crop pollination services?

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Abstract

Agri-environment schemes are programmes where landholders enter into voluntary agreements (typically with governments) to manage agricultural land for environmental protection and nature conservation objectives. Previous work at local scale has shown that these features can provide additional floral and nesting resources to support wild pollinators, which may indirectly increase floral visitation to nearby crops. However, the effect of entire schemes on this important ecosystem service has never previously been studied at national scale.

Focusing on four wild pollinator guilds (ground-nesting bumblebees, tree-nesting bumblebees, ground-nesting solitary bees, and cavity-nesting solitary bees), we used a state-of-the-art, process-based spatial model to examine the relationship between participation in agri-environment schemes across England during 2016 and the predicted abundances of these guilds and their visitation rates to four pollinator dependent crops (oilseed rape, field beans, orchard fruit and strawberries).

Our modelling predicts that significant increases in national populations of ground-nesting bumblebees and ground-nesting solitary bees have occurred in response to the schemes. Lack of significant population increases for other guilds likely reflects specialist nesting resource requirements not well-catered for in schemes. We do not predict statistically significant increases in visitation to pollinator-dependent crops at national level as a result of scheme interventions but do predict some localised areas of significant increase in

bumblebee visitation to crops flowering in late spring. Lack of any significant change in visitation to crops which flower outside this season is likely due to a combination of low provision of nesting resource relative to floral resource by scheme interventions and low overall participation in more intensively farmed landscapes.

We recommend future schemes place greater importance on nesting resource provision alongside floral resource provision, better cater for the needs of specialised species and promote more contiguous patches of semi-natural habitat to better support solitary bee visitation.

1 Introduction

Animal pollinators support reproduction in an estimated 87.5% of flowering plant species worldwide, including over three quarters of the world's leading food crops (Klein et al., 2007, Ollerton et al., 2011). In England, the most important pollinator-dependent crops are oilseed rape (*Brassica napus;* hereafter OSR), field beans (*Vicia faba*), orchard fruit (apples, pears, and plums) and soft fruit (mainly strawberries and raspberries) (Breeze et al., 2020; DEFRA, 2017). Pollination of these crops is mainly carried out by wild, unmanaged pollinators – principally bumblebees and solitary bees (Blitzer et al., 2016; Garratt et al., 2014a; Hutchinson et al., 2021; Klatt et al., 2013). There is evidence of widespread declines in wild bee populations in Great Britain between 1980 and 2013 (Powney et al., 2019), echoing a global trend of decline (IPBES, 2016). This can impact food security where floral visitation is insufficient to achieve optimal yield in pollinator-dependent crops (Garratt et al., 2014a; Holland et al., 2020). Even where this risk is not imminent, declining wild bee abundance and diversity can leave areas vulnerable to future shocks in bee populations or instability of other ecosystem services (Hutchinson et al., 2021; Senapathi et al., 2015).

Land use change, particularly the simplification of landscapes through intensified agriculture, is a major driver of pollinator decline (Ollerton et al., 2014; Potts et al., 2016) as the proportion of land used for crops and improved grassland increases at the expense of 'semi-natural habitat' such as hay meadows, fallow land, leys and hedgerows (Firbank et al., 2008; Ridding et al., 2020). Relative to crops and improved grassland, semi-natural habitat provides better quality nesting habitat (Lye et al., 2009) and provides floral resources on which pollinators can forage when managed crops are not in flower (Garratt et al., 2017; Kovács-Hostyánszki et al., 2017; Timberlake et al., 2019). Addressing wild bee declines and associated risks to ecosystem services therefore typically involves creating, restoring, or at least maintaining semi-natural habitat (Bommarco et al., 2013).

Agri-environment schemes (AES) are programmes where landholders enter into voluntary agreements (typically with governments) to manage agricultural land for environmental protection and nature conservation objectives (Dicks et al., 2016). In England, the main AES are *Countryside Stewardship* (CS) scheme (active since 2015) and the previous *Environmental Stewardship* (ES). In both schemes, landholders choose from a selection of over 200 multi-year management options and capital items with associated payment rates per option, based on costs and income forgone for loss of agricultural production.

Many options serve a broad environmental purpose aligned to the farming system such as hedgerow management, grass margins and low-input grassland. Others are specifically designed to restore or maintain habitats such as semi-natural grassland, moorland, and woodland, while capital items provide funding for one-off activities such as hedge planting. Where these options and items increase the quality and quantity of nesting and/or floral resources in a landscape, they can be valuable to pollinators depending on species' preferences (Vaudo et al., 2015). Some CS options have been explicitly designed to provide floral resources for wild bees and other pollinators in arable farms, (e.g. AB1 – Nectar flower mix, and AB16 – Autumn sown bumblebird mix) and its 'Wild Pollinator and Farm Wildlife Package' encourages farmers to bundle these with options that may provide nesting resources (e.g. hedgerows and field corner management).

Several studies demonstrate that these AES features can boost wild bee species richness and abundance at field and farm scale (Balfour et al., 2015; Heard et al., 2012; Scheper et al., 2015). The relationship between AES and crop pollination services is more complex and less well understood. A relationship between provision of AES features in agricultural landscapes and crop pollination services has been demonstrated empirically at farm and field scale (Blaauw and Isaacs, 2014; Morandin et al., 2016; Nicholson et al., 2017; Pywell et al., 2015), but, due to different bees foraging ranges and preferences (Kennedy et al., 2013) this is not consistent across feature type (Albrecht et al., 2020).

However, AES feature effectiveness at local scale does not necessarily translate into whole-scheme effectiveness at national scale. Schemes are not mandatory and even where farmers do participate, the choice of options implemented may not necessarily be the most effective at supporting wild bees due implementation cost influencing option choice (Austin et al., 2015). Since empirical approaches are unfeasible at national scale, detailed modelling that incorporates how bees move around the landscape to nest, forage and reproduce is needed to estimate the impact of AES on pollination service. The process-based pollinator model developed by Lonsdorf et al. (2009) and later developments of it (Häussler et al., 2017; Olsson et al., 2015) have this capability and have already been applied at regional scale to examine the impact of interventions (Cong et al., 2014; Davis et al., 2017; Häussler et al., 2017), while the latest state-of-the-art version (‘poll4pop’) has recently been validated in Great Britain for four wild bee guilds (Gardner et al., 2020).

This study integrates spatially explicit data from multiple sources to generate the most detailed and realistic map yet of AES, crop, and non-crop features across England for the year 2016. It then applies the fully validated poll4pop model to this landscape to predict wild bee abundance and the level of crop and non-crop pollination service provided. By comparing the pollinator model’s predictions including and excluding AES management, we estimate the schemes’ current effectiveness at promoting wild bee abundance and pollination services at national scale. The study provides an assessment of participation in schemes as a whole, including the effects of options that may not explicitly target pollinators but still have an effect through changing the quantity/quality of resources. Based on the findings, recommendations are made to increase the effectiveness and direct/incentivise participation in future AES.

2 Methodology

All modelling/data processing was carried out in ArcGIS 10.7 (ESRI, 2019) and Python 2.7 / 3.5. The Poll4pop model source code was transcribed from R (R Core Team, 2018) to Python to facilitate integration with ArcGIS and improve processing times.

2.1 Model Description

Poll4pop (Gardner et al., 2020; Häussler et al., 2017) is a process-based model that predicts seasonal spatially explicit abundance and floral visitation rates for central-place foraging pollinators in a given landscape including fine-scale features such as hedgerows and grass margins. It can be parameterised for a particular species or for a species grouping (‘guild’) with common attributes. A brief overview of the model is given as follows, but for a more detailed description see Häussler et al. (2017).

The model requires a land cover raster detailing the land class assigned to each cell as well as a rasterised map showing the area of ‘edge’ land classes (features smaller than the cell resolution – 25m^2 in our case) within each cell. Each land class has a score representing the amount of floral resource provided during a given season (floral cover), the attractiveness of that floral resource to the guild (floral attractiveness; representing its nutritional quality), and its attractiveness as a nesting resource to that guild (nesting attractiveness). Floral cover and floral attractiveness are multiplied to generate a floral resource raster by season. The edge features are incorporated by taking the area-weighted sum of the edge and non-edge features in a given cell.

Nests are initially allocated to cells according to a Poisson distribution around the expected number per cell predicted from the nesting attractiveness raster and input maximum nest density. For every season during which the guild is active, foragers from each cell containing nests gather floral resources from cells within a distance-and floral-resource-weighted Gaussian kernel surrounding that cell. The size of the kernel is determined by a guild specific mean foraging distance parameter (β_f). The visitation rate to a given cell (per season) within the kernel is the product of its distance and floral resource weights. The total visitation rate to a given cell for that season (V_s) is the sum of all the visitation from all the nests whose kernels cover that cell.

For solitary guilds, the foragers are reproductive females, but for social guilds the reproductive females (queens) are replaced by foraging workers after the first season. For solitary guilds, the number of new reproductive females produced by a cell (*Q*) depends on the amount of resource gathered during the active period and a lognormal growth function with median, steepness, and maximum parameters specific to that guild. For social guilds, the number of workers produced by a cell (W_s) at the end of a season is determined by the amount of the resources gathered and a similar lognormal growth function specific to that guild. In the final active season for social guilds the resources are used to produce new reproductive females.

At the end of the final active season, new reproductive females disperse to cells within a distance- and nesting-attractiveness-weighted Gaussian kernel. The size of the kernel is determined by a guild specific mean nesting distance parameter (β_n). The number of nests in a given cell (*R*) in the following year is the sum of the nesting dispersal from all the kernels that cover that cell, subject to the maximum nest density parameter. The modelling process is repeated using these nests until the total number of nests in the landscape converges (<1% change between runs).

The model therefore outputs, per guild, three measures of abundance and a measure of visitation as rasters at the same resolution as the input rasters:

- Number of nests in a given cell (*R*).

- Number of workers produced at the end of a given season by the nests in a given cell and thus available to forage in the next season (W_s) – social bees only.
- Number of new reproductive females produced at the end of the final active season by the nests in a given cell (Q).
- Flower visitation rate in a cell for a given season (V_s).

We note that these predicted visitation rates do not include visitation by other non-modelled pollinators, that crop yield ultimately depends non-linearly on this visitation rate and that the relationship between our predicted visitation rates and the rate required for optimum pollination of any given crop is still uncertain (see Discussion). Nonetheless, by simulating foraging and population processes, the model represents the best tool currently available for assessing how fine-scale changes in habitat provision/configuration may influence bee abundance and visitation rates at landscape-scale.

2.2 Model Parameterisation and Validation

Gardner *et al.* (2020) - hereafter G2020 – parameterised and validated the poll4pop model in Great Britain for four guilds: ground-nesting bumblebees, ground-nesting solitary bees, tree-nesting bumblebees, and cavity-nesting solitary bees. We took guild specific parameters for foraging and dispersal distance, population growth and maximum nest density directly from G2020 and Häussler *et al.* (2017).

G2020 used 33 land classes and derived their (guild-specific) floral attractiveness and nesting attractiveness parameters and floral cover parameters across three seasons (spring, summer, autumn) via an expert opinion survey (Table S7-11 in Supplementary Material.). We adopt their values and derive additional attractiveness and floral cover parameters for our extended range of land cover as described in section 2.3.2 below.

We also readjust the seasonal definitions for floral cover to represent early spring (early/mid-March – late April/early May), late spring (late April/early May - early/mid-June) and summer (early/mid-June - early/mid-August) to better capture differences in flowering windows for mass-flowering arable crops (generally late spring flowering) and orchards (generally early spring flowering) relative to floral resources created by AES features (flowering across spring). Our early and late spring floral cover parameters relate to the original spring G2020 parameters as follows:

- OSR, Linseed/flax, Peas, Field beans, Strawberries/raspberries not in polytunnels, Other berries: the G2020 floral cover parameter for spring was allocated 90% to late spring and 10% to early spring.
- Orchards: the G2020 floral cover parameter was allocated 90% to early spring and 10% floral to late spring.
- All other land classes: the G2020 floral cover parameter was allocated 50% to early spring and 50% to late spring.

The 90/10 allocation was used rather than 100/0 since late spring flowering crops will have some inflorescence in Early Spring (see e.g. AHDB (2020) for OSR), whilst some orchard cultivars flower into late spring.

We repeated the validation process carried out by G2020 to confirm that our extended parameter set, and new seasonal definitions still produce model predictions that agree with observed pollinator abundances (see Supplementary Material – Section 5).

2.3 AES Present and AES Absent Scenarios

In order to make predictions for pollinator abundances and visitation rates with, and in the absence of, current AES management, we generated land cover and edge input rasters at 25m^2 resolution for two scenarios: '*AES_Present*' representing the scenario where the AES management was present, and '*AES_Absent*' representing the scenario where AES management was absent. The year 2016 was chosen because it was the most recent to have agricultural, non-agricultural and AES spatial data at sufficient resolution. A brief overview of the process is given in the following section, with a detailed description provided in the Supplementary Material.

2.3.1 Source landcover data

Land cover and edge feature information were sourced to represent as closely as possible the coverage of non-agricultural land, crops and permanent grassland, and land under agri-environment scheme (AES) option management for England during the year 2016. We included a 5km buffer zone into Scotland and Wales to eliminate edge effects based on the largest mean dispersal distance parameter (1km for bumblebee nesting).

Agricultural land cover for England came from 2016 Basic Payment Scheme (BPS) claims data identifying the type and area of crop, grassland or other eligible feature and was assigned to the corresponding polygon from the Land Parcel Information System (LPIS). Orchard polygons were sourced from the Ordnance Survey Master Map Orchards layer (MMOrch; Ordnance Survey, 2017).

Land outside LPIS and MMOrch was classified according to land cover information from the CEH Landcover Map 2015 (LCM; Rowland *et al.*, 2017). Two additional data sources - Crop Map of England 2016 (CROME; Rural Payments Agency, 2019) and OpenStreetMap (OSM; OpenStreetMap contributors, 2017) - were used to determine land class where there was inconsistency between the LCM, LPIS and BPS datasets: i.e. where LCM indicated ‘Arable or Horticulture’ but there was no corresponding LPIS polygon, or where there was a LPIS polygon with no corresponding BPS claim (see Supplementary Material Section 2 for more detail.)

Two English AES schemes had active agreements during 2016: the current Countryside Stewardship (CS) scheme (open since 2015) and Environmental Stewardship (ES), the legacy scheme open to applications prior to 2015. We sourced AES features from both schemes' datasets (CS: Natural England, 2018; ES: Natural England, 2018) selecting only options with agreements active during 2016. Features that would not impact on habitat quality for bees (e.g. water troughs, archaeological site management) or whose management impact was outside the seasonal scope of the model (e.g. winter cover actions) were removed. A full list of excluded options is provided in the Supplementary Material (Table S5).

ES and CS datasets only provide a LPIS reference and the length or area of feature. So, we implemented a process to split up LPIS parcel polygons into smaller components representing the individual AES features and the remainder of the parcel (See Supplementary Material Section 2.3). Where the AES option type was too small to be resolved at $25m^2$ cell resolution in the subsequent raster conversion, we used an analogous process to create polylines (e.g. at the polygon boundary) appropriate to the option.

Buffer strips and hedgerow features in BPS claims relate to Environmental Focus Areas (EFA) under Common Agricultural Policy 'Greening' requirements (Rural Payments Agency, 2018). These were assumed equivalent to the simplest buffer strip creation and hedgerow maintenance options in ES and were converted to appropriate length polylines at the parcel boundary, avoiding duplication with equivalent AES features. Other hedgerow features were created from the CEH Woody Linear Features Framework (WLF; Scholefield et al., 2016) and a woodland edge polyline layer was created at the boundaries of contiguous LCM woodland features.

2.3.2 Parameterising changes in land cover habitat quality

Our combined source data included 28 non-agricultural land cover types, 128 agricultural land cover types and 364 AES land cover types. Below we detail how we align these with the 33 land classes already parameterised by G2020 for use in the poll4pop model and how intermediate parameters are derived where required to represent the more subtle changes generated by AES management. Full details are in the Supplementary Material Section 1.

Land in AES was assigned an *AES_Present* land class and an AES_Absent land class with reference to Defra Reports BD2302 (University of Hertfordshire, 2009) as refined in BD5007 (University of Hertfordshire, 2011); – hereafter, BD2302/5007). These reports describe the expected land cover resulting from the option (used to generate *AES_Present*) and the absence of management (used to generated *AES_Absent*). Assignment of *AES_Present* and *AES_Absent* land classes to CS options was made using an 'Equivalency Table' provided by Natural England (the scheme developer) that links these options to their ES equivalents (Natural England, 2018 *pers. comm*). Option descriptions provided in scheme manuals (Natural England, 2013; 2015) were used where required.

For some options, the descriptions in both the *AES_Present* and *AES_Absent* scenarios could be matched directly to G2020 land classes. For example, land under the CS option LH3 (Creation of heathland from arable or improved grassland) was mapped to "Moorland" in *AES_Present* and an arable crop type or improved grassland in *AES_Absent* as appropriate. These options received the attractiveness and floral cover scores for those land classes in each respective scenario. For other options, the G2020 land classes were not sufficient to match the description given in one or both of the scenarios. G2020 only has land classes for intensively managed land (agricultural crops, improved grassland / meadow) or broad habitats (unimproved grassland / meadow, moorland, wetland, woodland) while the BD2302/5007 descriptions reflect more subtle transitions in land cover. To capture these distinctions, new land classes (e.g. semi-improved grassland, degraded moorland, etc.) were created by blending existing G2020 land classes to approximate the description given in BD2302/BD5007. The attractiveness and floral cover parameters for these blended land classes were set to the weighted average of the parameters from their constituent G2020 land classes. When hedgerows, ditches and woodland edges are not in AES, they are assumed to still be present with the same associated parameter values, but their width is halved in the *AES_Absent* scenario to model the reduced management.

Land not in AES was assigned the same land cover class as G2020 with the exception of semi-natural grassland categories in LCM (acid grassland, neutral grassland, calcareous grassland) which were assigned to a semi-improved grassland category rather than an unimproved grassland category as per the LCM metadata (CEH, 2017). As this land was outside AES in both scenarios, the classification was the same in *AES_Present* and *AES_Absent*. The final parameter values used for all land classes, the weighting rules for new land classes, and the guild-specific parameters are shown in the Supplementary Material (Table S1).

2.3.3 Assessment of change in abundance and visitation rates

The model was run to generate abundance and visitation rate predictions for each guild in each season for the *AES_Present* and *AES_Absent* scenarios, respectively. For solitary bees (active during only one season) we simulated spring-flying and summer-flying populations separately, where spring-flying populations used the cumulative resources from both Early and Late Spring.

The change in predicted visitation rate V for season s (V_s) due to the presence of AES management at cell level was assessed by calculating the log ratio between the predicted visitation rates in the two scenarios ($log_{10}(V_{s\_AES\_Present}/V_{s\_AES\_Absent})$). The ratios are logged to ensure that reductions in visitation rate have the same magnitude as proportionally equivalent increases. Cells with identical visitation rates in both scenarios will therefore have a value of 0, while +1 represents a tenfold increase in visitation rate in the presence of AES features and -1 a tenfold decrease. The same log ratio approach was applied to calculate the predicted change in new reproductive production (Q), new nest production (R), and new worker production per season (W_s).

To estimate the uncertainty in the log ratio caused by uncertainty in the underlying parameter values, 100 simulations were run where the nesting attractiveness, floral attractiveness and floral cover score for each land class were drawn from a beta distribution ($B(a, b)$) with mean ($\mu = a / (a + b)$) and variance ($\sigma^2 = \mu(1 - \mu) / (a + b + 1)$) equal to the mean and variance of the G2020 expert opinion scores for that parameter. A beta distribution was used as the scores are bounded and, since *B(a, b)* is only defined on the interval (0,1), the randomly drawn scores are rescaled to the appropriate scale for that parameter. For new blended land classes, where the mean value was generated by averaging the scores of two existing classes, the variances were calculated using error propagation (Hughes and Hase, 2010). Draws for land classes were constrained as described in the Supplementary Material to prevent instances that unreasonably exceeded the range of expert opinion.

The significance of the change in visitation rate with respect to the uncertainty in underlying habitat quality parameters was assessed by calculating the standard deviation of the 100 simulations of the log ratio visitation rate and then measuring how many standard deviations a given cell or region's log ratio visitation rate was from the no change value of zero (the point at which the ratio would be 1:1). A log ratio more than 2 standard deviations away from zero was considered to show a significant change in visitation rate between *AES_Present* and *AES_Absent* scenarios. Locations where the log ratio was more than 3 standard deviations from zero were considered a highly significant difference.

To examine the overall impact at national scale on different land resources such as pollinator-dependent crops and semi-natural habitat, the land classes are grouped into categories (Table 1). Detail of individual land class allocations to these categories is given in Table S1 (Supplementary Material). The total impact of AES participation and its significance on a particular land category at national level is calculated for the log ratio of the sum of V_s, Q, R, and W_s across all cells in England within that category for *AES_Present* and *AES_Absent* respectively.

Table 1: Land Categories

Land Category	Description
Oilseed Rape (OSR)	Pollinator-dependent crop
Field Beans	Pollinator-dependent crop
Strawberries	Pollinator-dependent crop; includes all open-grown strawberries (i.e., excluding those grown in polytunnels) and Raspberries
Orchards	Pollinator-dependent crop

Other Crops	Any other crop not listed above
Improved Grassland	
Semi-natural Habitat	This covers all land that is not a classified as crop, improved grassland, suburban or urban. It therefore includes hedgerows, ditches, grass/flower margins, fallow areas, grass/legume leys, semi-natural grassland, moorland, heathland, wetland, woodland, and coastal habitats.
Suburban	Suburban areas (areas with a mixture of buildings and gardens), parks
Urban	Built-up areas with little vegetation, e.g. city centres & industrial estates, Also includes other null value land cover such as open water and rock
All Land	All land classes listed above

2.4 Exemplar Area

To illustrate the fine-scale effects predicted by our 25m^2 resolution simulations at farm-scale, we selected an exemplar area in western England to present alongside the national maps. This area was chosen because it is one of the few areas in England to grow all four pollinator-dependent crops and it represents a heterogeneous landscape incorporating a variety of agri-environment interventions.

3 Results

3.1 Area and distribution of crops and land under AES

The pollinator-dependent crops OSR (621,014 ha) and field beans (189,332 ha) were grown across much of lowland England during 2016, while orchard fruit (39,335 ha) and strawberries (2,914 ha) were concentrated in certain areas of south-east and western England (Figure 1a; Figure S13a-b; Figure S14a-b). Otherwise, England's agricultural area was dominated by other crops (not pollinator-dependent) and improved grassland. There was over 3.5M ha of semi-natural habitat of potential value to wild bees including hedgerows, ditches, grass/flower margins, heathland, and woodland. ~1.5M ha of this was under AES management (Figure S15a) but the rest was outside the CS and ES schemes (Figure S15b). Suburban parks and gardens (highly valuable pollinator habitat) covered ~1.0M ha.

Only 108,237 ha (~7% of the AES area) involved the creation of semi-natural habitat at the expense of crops or improved grassland (Figure 1b). The remaining area comprised options that aim to maintain, restore, or enhance *pre-existing* semi-natural habitat. AES participation rates and type of option applied are also linked to land use intensity. Much of the upland area (generally farmed extensively) was in AES and there were many field-scale features. In arable regions (generally farmed intensively) the participation rates were lower, mostly consisting of linear features with some small and dispersed field-scale options. Participation rates were lower in the orchard fruit and strawberry growing areas relative to areas where only OSR and field beans were cultivated (compare exemplar area patterns in c, d of Figure S13, Figure S14 and Figure S15).

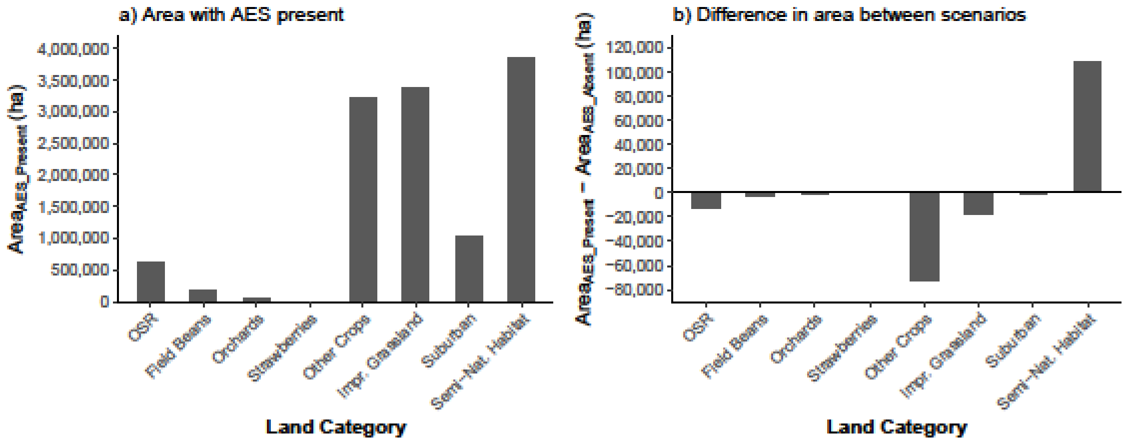

Figure. 1 a) Total area by land category in England for 2016 when Agri-environment scheme (AES) features are present - AES_Present scenario; b) Area change (ha) between scenarios with AES feature present (AES_Present) and absent (AES_Absent). in each land category. The Urban land category is excluded as it is parameterised with no resource value.

3.2 Impact of AES participation on pollinator abundance at national level

Nest productivity (number of new reproductive females produced per cell) is predicted to be significantly higher for ground-nesting guilds when AES management is present (Figure 2 – ‘All land’) with relative increases of 10.4% for ground-nesting bumblebees and 15.4% / 7.8% for spring-active / summer-active ground-nesting solitary bees.

Nest density is also predicted to be significantly higher for ground-nesting guilds when AES management is present (Figure 3, ‘All land’) with increases of 4.6% for ground-nesting bumblebees and 16.2% for spring-active ground-nesting solitary bees. The predicted increase in nest density for summer-active ground-nesting solitary bees is not significant. Semi-natural habitat shows the largest and consistently significant nest density increases (6.6% and 36.9% for the above-mentioned guilds respectively) across the land categories and this drives the change in the ‘All land’ category. Significant nest density increases in crop and improved grassland categories for ground-nesting solitary bees are relatively small (2.8% – 9.0%) while no significant overall increase is predicted for tree-nesting bumblebees or cavity-nesting solitary bees (Figures S4, S5 in Supplementary Material).

AES management is also predicted to have a significant overall positive impact on ground-nesting bumblebee worker production in late spring (increase of 8.15%; Figure 4b ‘All Land’) although semi-natural habitat is the only land category to show a significant increase (11.5% equivalent). Overall increases in worker production are predicted for early spring but these are not significant given current uncertainties, the exception being a small but significant predicted increase in the worker population for nests in orchards during early spring (2.5% equivalent). No significant overall change in tree-nesting bumblebee worker production is predicted, though the results do show a similar significant increase for orchards in early spring (Figure S3 in Supplementary Material.).

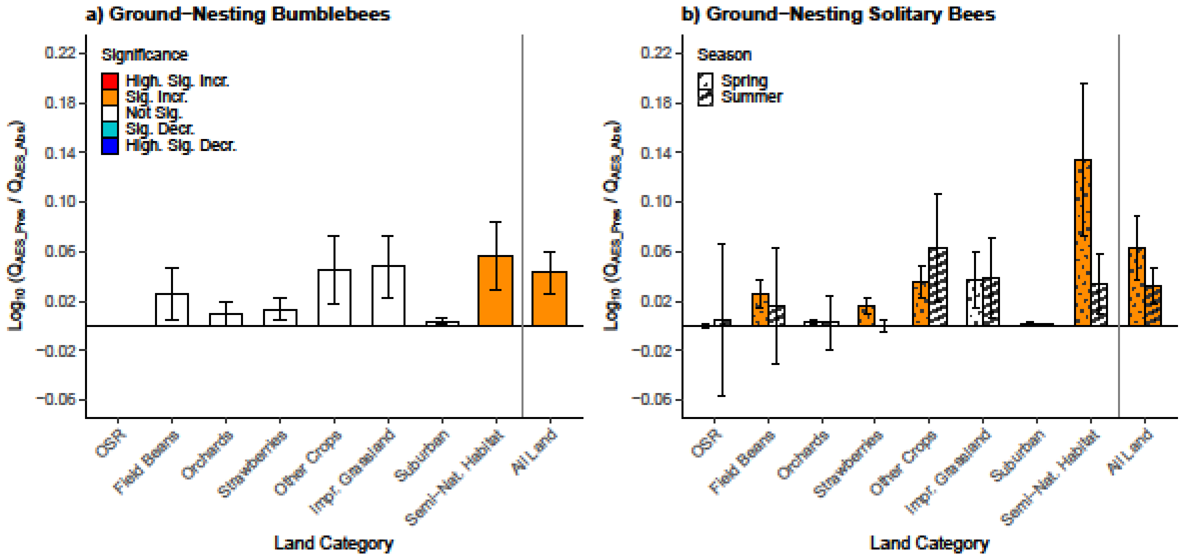

Figure 2. Predicted impact of Agri-environment schemes (AES) on nest productivity (Q; production of new reproductive females per 25 m2) nationally to all land categories and subdivided by land category for (a) ground-nesting bumblebees and b) ground-nesting solitary bees (separated by active season). The impact is measured as the log of the ratio between the scenarios with AES features present and absent. Significance thresholds are number of standard deviations that the log ratio is above (increase) or below (decrease) zero: value > =|3| is highly significant, |2| < = value < |3| is significant. See Supplementary Material for other guilds.

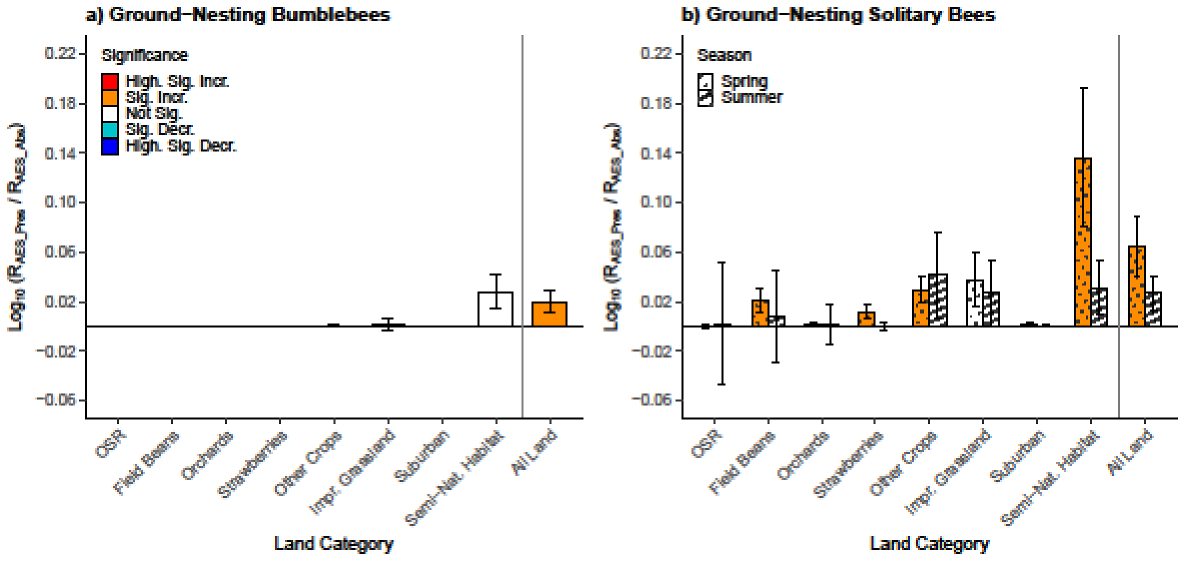

Figure 3. Predicted impact of Agri-environment schemes (AES) on nest density (R; nests per 25 m2 cell) nationally to all land classes and subdivided by land category for (a) ground-nesting bumblebees and b) ground-nesting solitary bees (separated by active season). The impact is measured as the log of the ratio between the scenarios with AES features present and absent. Significance thresholds are number of standard deviations that the log ratio is above (increase) or below (decrease) zero: value > =|3| is highly significant, |2| < = value < |3| is significant. See Supplementary Material for other guilds.

3.3 Impact of AES participation on floral visitation rate at national level

The model predicts significantly higher floral visitation overall (across all land categories) in Early Spring and Summer for ground-nesting bumblebees (+4.6% and +8.2% respectively; Figure 5) and in Early and Late Spring for ground-nesting solitary bees (+16.2% both seasons). Visitation to semi-natural habitat is also predicted to be significantly higher for these guilds in those seasons. Predicted increases for tree-nesting bumblebees and cavity-nesting solitary bees are not significant overall or for semi-natural habitat (see Figure S4 in the Supplementary Material).

Although the model predicts increased visitation rate to OSR and field beans during peak flowering (Late Spring) due to AES management, this increase is only significant for the case of ground-nesting solitary bees to field beans where visitation rises by 6.2% (Figure 5). An increase of similar scale and significance to field beans is also predicted for cavity-nesting solitary bees. The absolute change in both cases is not large and is from a low base (e.g. V_s in *AES_Absent* for field beans is 0.19 for ground-nesting solitary bees compared to 7.9 for ground-nesting bumblebees; Figure S9 in the Supplementary Material).

There are no significant changes to orchard or strawberry visitation at national-level, with the exception of tree-nesting bumblebees where the model predicts a small but significant decrease in visitation in Early Spring (-2.2%; Figure S4, Supplementary Material). Tree-nesting bumblebees are also predicted to show reduced visitation to OSR, Field Beans in Early Spring (-4.5% in both cases) in the presence of AES features. This is not a flowering season for these crops, so the change is relative to a very low absolute visitation rate (V_s in *AES_Absent* is 0.12 and 0.03 for OSR and field beans, respectively).

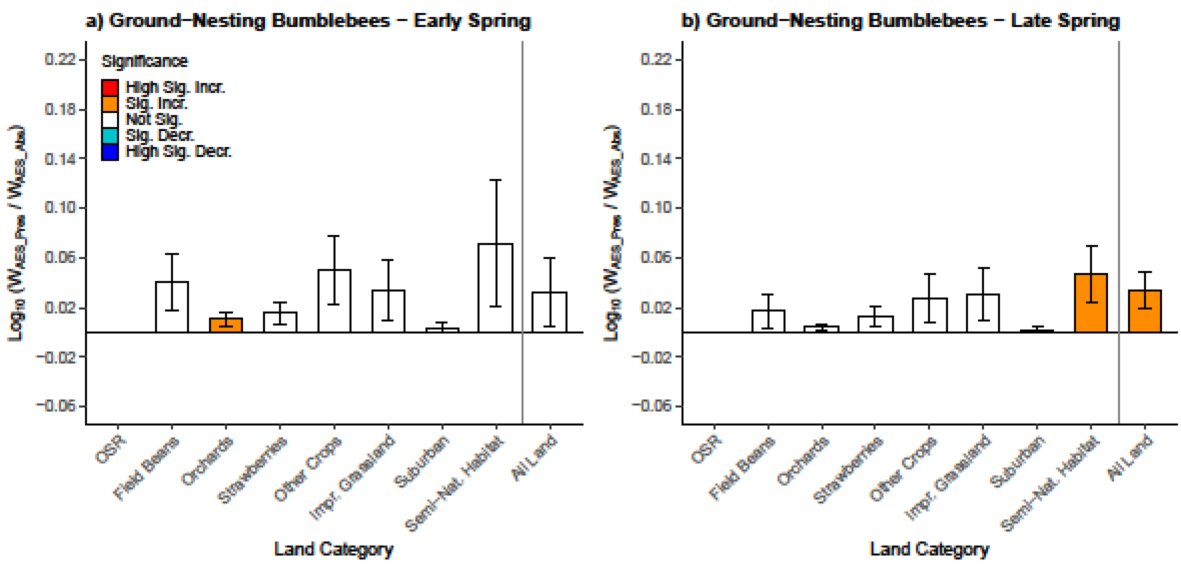

Figure 4. Predicted impact of Agri-environment schemes on ground-nesting bumblebee worker production (W; workers produced per 25 m2 cell) nationally to all land classes and subdivided by land category for (a) Early Spring and (b) Late Spring. The impact is measured as the log ratio between the scenarios with AES feature present and absent. Significance thresholds are number of standard deviations that the log ratio is above (increase) or below (decrease) zero: value > =|3| is highly significant, |2| < = value <|3| is significant. Early spring: early/mid-March – late April/early May. Late spring: late April/early May - early/mid-June. See Supplementary material for tree-nesting bumblebees.

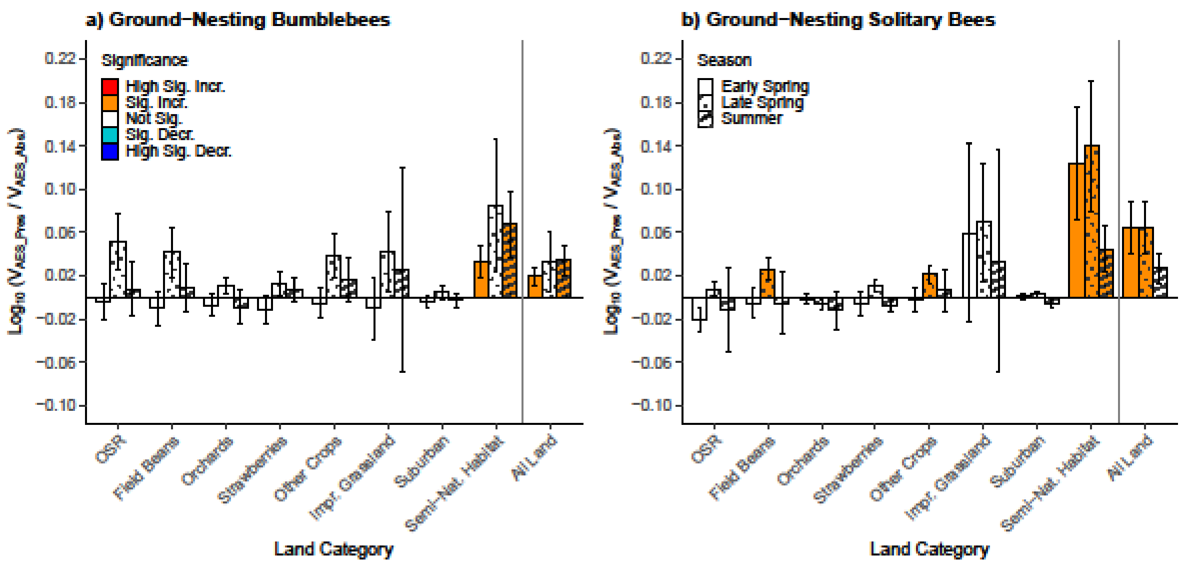

Figure 5. Predicted impact of Agri-environment schemes (AES) on floral visitation rate (V; visits per 25 m2 cell) nationally to all land classes and subdivided by land category for (a) ground-nesting bumblebees and b) ground-nesting solitary bees in each season. The impact is measured as the log ratio between the scenarios with AES feature present and absent. Significance thresholds are number of standard deviations that the log ratio is above (increase) or below (decrease) zero: value > =|3| is highly significant, |2| < = value < |3| is significant. Early spring: early/mid-March – late April/early May. Late spring: late April/early May - early/ mid-June. Summer: early/mid-June – early/mid-September. See Supplementary Material for other guilds.

3.4 Impact of AES participation on floral visitation rate at cell-level

Despite a lack of significant changes at national-level, Figure 7 shows that significant increases are predicted in localised areas for both ground-nesting guilds in late spring. Closer inspection of their distribution within the exemplar area (Figure 7c-d) shows significant increases occurring for cells which correspond to AES management locations. There are also localised areas of significant increase covering a defined neighbourhood around these locations, whose extent is related to bee foraging range. These neighbourhoods are typically narrow for solitary bees (approx. 250-500m radius) and are usually isolated, whilst the neighbourhoods of significant bumblebee visitation increase extend to a wider radius (approx. 1-2km) and often merge with each other. The scale of increase in late spring is generally 0.1 to 2-fold in the neighbourhood and 2 to 10-fold within the AES cells. The effect is less evident in other seasons (see Figure 6 for early spring and Figure S16 in the Supplementary Material for summer).

The presence of a neighbourhood effect has implications for crop pollination services where pollinator-dependent crops form part of this neighbourhood. 46.4% of the national OSR cropping area and 36.1% of the national field bean cropping area is predicted to experience a significant or highly significant increase in ground-nesting bumblebee visitation during what is the peak flowering season for these crops (Figure 8c). 11.5% of the orchard resource is also predicted to benefit from increased late spring ground-nesting bumblebee visitation but this will only be beneficial if those orchards are growing late flowering cultivars. 20% of strawberry cells also experience a significant or highly significant ground-nesting bumblebee visitation increase in Late Spring.

By contrast less than 5% of the resource for any of the pollinator-dependent crops are predicted to receive significantly increased ground-nesting solitary bee visitation during this season (Figure 8d). There is very little neighbourhood effect for pollinator-dependent crops in Early Spring (Figure 8a, b). This is peak flowering season for orchard fruit and only 0.9% and 2.3% of orchard cells are predicted to experience a significant or highly significant increase for ground-nesting bumblebee and ground-nesting solitary bee visitation. Likewise, very few cells are predicted to receive significantly more bee visitation in Summer (Figure S16, Supplementary Material).

Tree-nesting bumblebees show similar trends to the ground-nesting bumblebees, although fewer cells are predicted to receive significantly more visitation (for OSR and Field Beans in Late Spring those proportions are 26.1% and 20.3%, respectively; Figure S11, Supplementary Material), while the percentage of cropland with significant changes in cavity-nesting solitary bees visitation is similar to that for ground-nesting solitary bees.

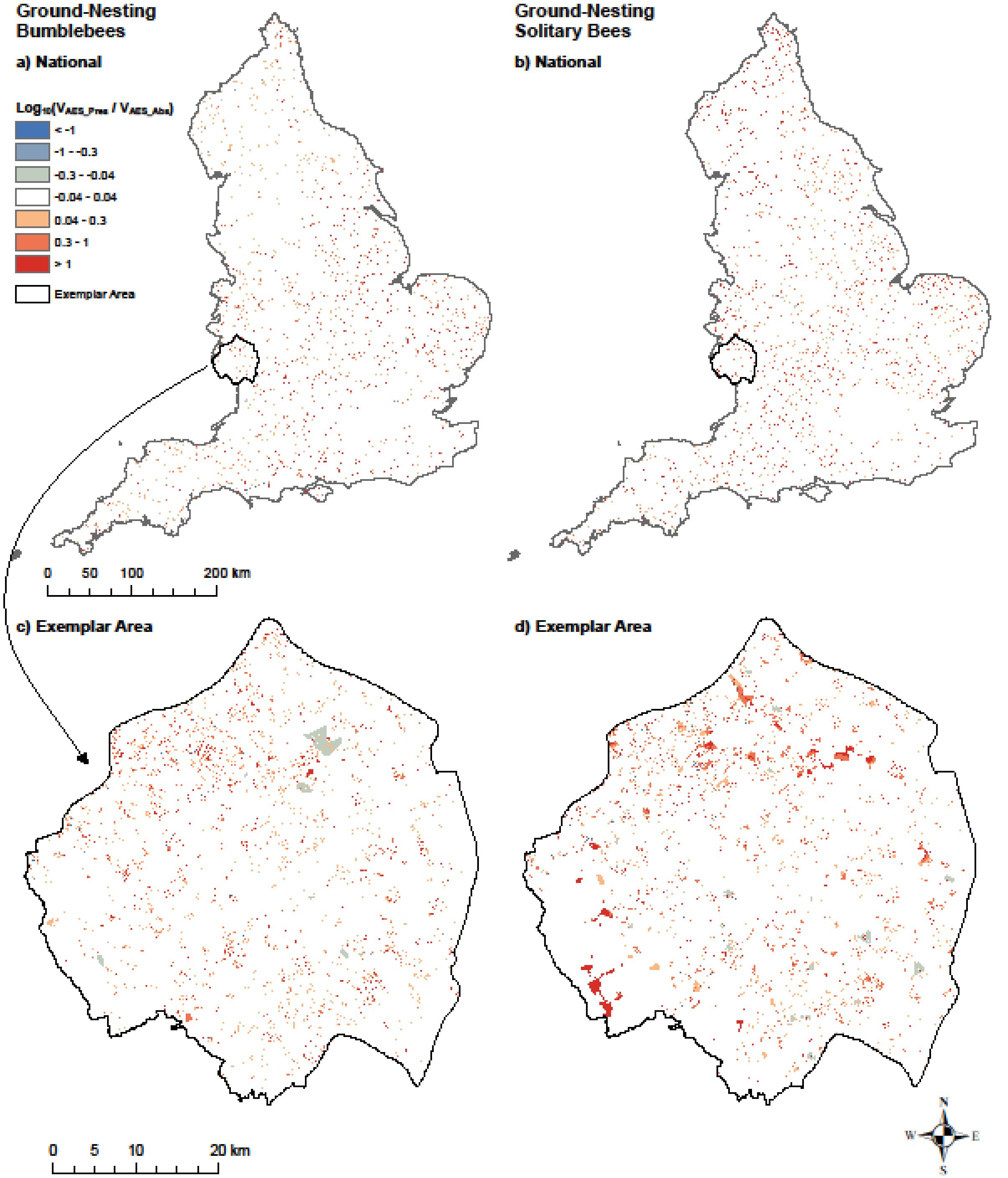

Figure 6. Impact of Agri-environment schemes on floral visitation rate (V) for ground-nesting guilds in England for early spring 2016 at cell-level nationally (a, b) and within an exemplar area (c, d) in western England. The impact is shown as the log of the ratio of V (visitation/25 m2) between the scenarios with AES feature present and absent. Only cells with significant change are shown - where the log ratio is at least 2 standard deviations from zero. Early spring: early/mid-March – late April/early May. See Supplementary material for other guilds.

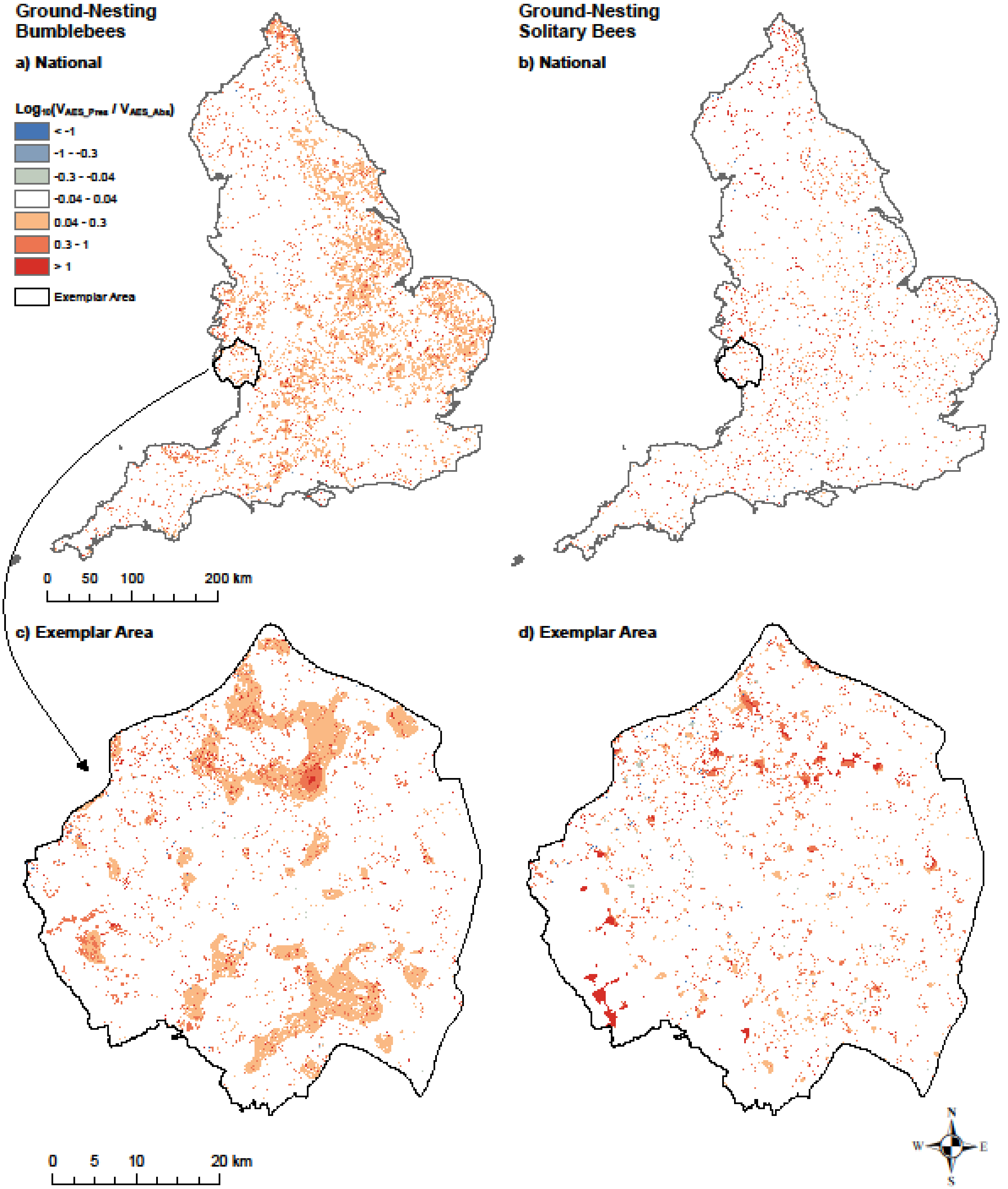

Figure 7. impact of Agri-environment schemes on floral visitation rate (V) for ground-nesting guilds for late spring 2016 at cell-level nationally (a, b) and within an exemplar area (c, d) in western England. The impact is shown as the log of the ratio of V (visitation/25 m2) between the scenarios with AES feature present and absent. Only cells with significant change are shown - where the log ratio is at least 2 standard deviations from zero. Late spring: late April/early May - early/mid-June. See Supplementary Material for other guilds.

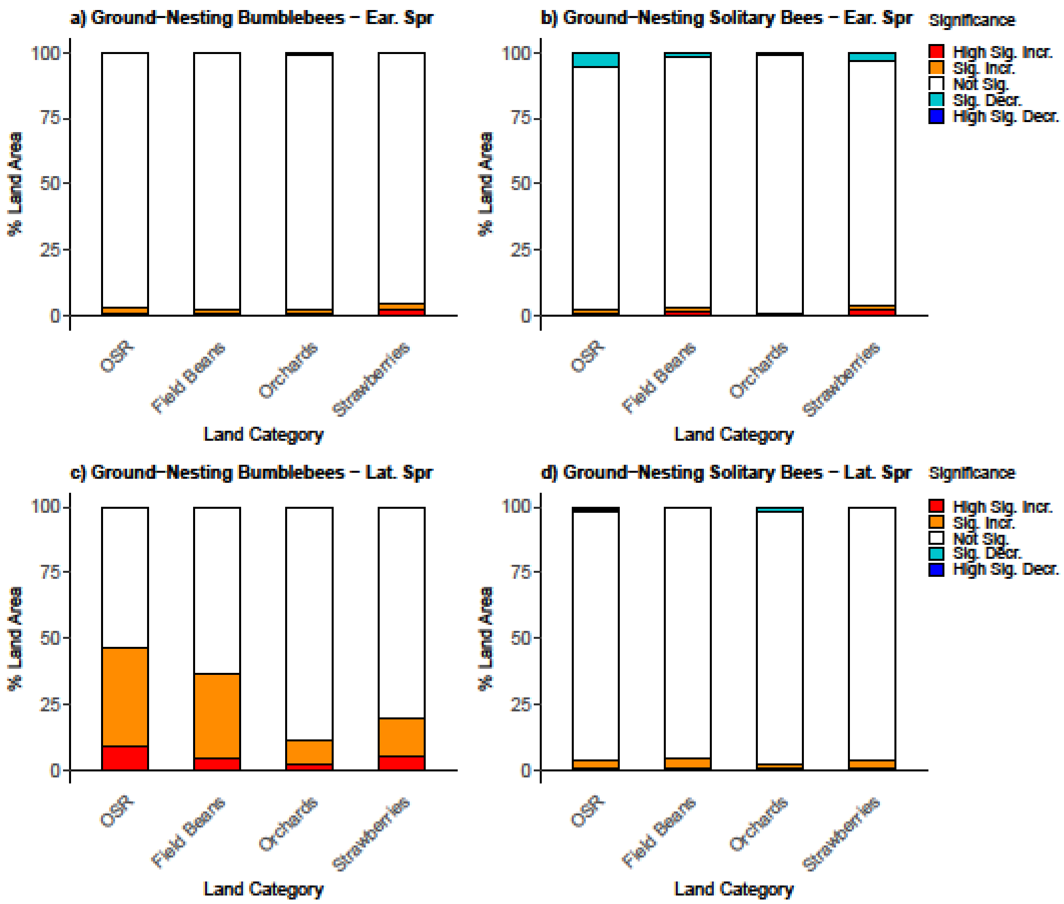

Figure 8. Percentage of cropland area within significance thresholds for predicted impact of Agri-environment schemes (AES) on floral visitation rate (V; visits per 25 m2 cell) for ground-nesting guilds in early (a, b) and late (c, d) spring. The impact is measured as the log ratio between the scenarios with AES feature present and absent. Significance thresholds are number of standard deviations that the log ratio is above (increase) or below (decrease) zero: value > =|3| is highly significant, |2| < = value < |3| is significant. Early spring: early/mid-March - late April/early May; Late spring: late April/early May - early/mid-June. See Supplementary material for other guilds.

4 Discussion

This study applied a validated spatially explicit process-based model (poll4pop) to examine changes in pollinator abundance and pollination service provision due to uptake of agri-environment scheme (AES) options across the whole of England for the year 2016. The model was used to compare bee visitation rates across four guilds in a scenario where the agri-environment features and/or management were present (*AES_Present*) with an alternative scenario where these were absent (*AES_Absent*).

The predictions suggest that participation in AES increased bee abundances, but these increases were only significant nationally for ground-nesting guilds. No significant increase is predicted for tree-nesting bumblebee and cavity-nesting solitary bee populations. We also predict significantly increased floral visitation rates nationally by ground-nesting guilds but only consistently within the semi-natural habitat enhanced by AES management. On average, visitation to pollinator dependent crops did not significantly increase nationally, but our simulations suggest some significant localised increases in visitation to late-spring flowering crops (predominantly OSR and field beans) by bumblebees. We do not predict enhanced crop visitation in other seasons from any guild.

4.1 Impact of AES on pollinator abundance

Predicted significant increases in nest productivity, nest density, and the number of workers for ground nesting guilds align with results of fieldwork in England demonstrating a significant relationship between observed bee abundances and presence of AES management (Crowther and Gilbert, 2020; Wood et al., 2015). The lack of predicted significant increases in the national-level abundance outputs for tree-nesting bumblebees or cavity-nesting solitary bees may be because few AES options provide or increase the quality of their preferred nesting habitat (Crowther et al., 2014; Gresty et al., 2018), as reflected in the expert opinion parameters assigned to these guilds for key AES options (e.g., flower rich margins, semi-improved/unimproved grassland, fallow, hedgerow – see Table S13 in Supplementary Material). The greater benefits of AES to spring-active, rather than summer active, ground nesting solitary bees is likely due to the early season boost in floral resources when there is less alternative floral provision from land outside schemes (Scheper et al., 2015).

Interestingly, our modelling suggests that the significant increases in nest productivity for ground-nesting bumblebees, induced by AES participation, are not matched by significant increases in nest density. This suggests the increased foraging resources provided by AES participation support larger pollinator populations during the active season, but this is not being met with a corresponding increase in the availability of nesting resources for new queens. AES schemes have focused on boosting bee abundances through floral resource provision (Dicks et al., 2015), however our predictions suggest schemes should pay increased attention to nesting resource availability (Requier and Leonhardt, 2020).

Predicted increases in abundance (number of new reproductive females) are predominantly associated with semi-natural habitats, which are typically of higher floral and nesting quality under AES participation. We do also predict an increase in solitary bee nest abundance in some crop fields (Figure 2b, Figure S2b), although abundance in these areas still remains low compared to semi-natural habitats (Figure S6b, d). The experts who provided the model's habitat scores assigned some limited solitary bee nesting value to certain crop types (Tables S9, S10), assumed to represent nesting opportunities in bare but untilled margins/tramlines, etc. The predicted increase in in-crop nests therefore likely reflects the fact that solitary bee reproductive females produced within adjacent AES features face limited availability of their preferred nesting habitat, due to their limited dispersal range (βn = 100m vs 1000m for bumblebees) and the relatively low semi-natural habitat coverage in arable areas (Figure S15).

4.2 Impact of AES on pollination services

The simulations predict significant and often large (2 to 10-fold) increases in visitation at cells under AES management (where floral and nesting values have generally increased relative to their value in *AES_Absent*). There is also a significant but generally smaller "neighbourhood effect" representing 0.1 to 2-fold changes in predicted visitation to surrounding cells outside AES management, where resource value is otherwise unchanged. The magnitude and direction of this neighbourhood effect depends on the guild and season. Where foraging is done by reproductive females (i.e. solitary bees in all seasons and bumblebees in early spring), increased neighbourhood visitation only occurs if the nesting density has increased sufficiently to offset the relative increase in floral value within the AES cell (Zamorano et al., 2020). Otherwise, there will be no change or even potentially sink effects where foragers are drawn away from neighbouring cells (see Figure S17 for tree-nesting bumblebees in early spring). For bumblebees in later seasons, workers do the foraging so floral resource increases support higher worker production rates and thus higher neighbourhood foraging rates without the need for increases in nest density (Riedinger et al., 2014).

The neighbourhood effect extends over a larger area for ground-nesting bumblebees compared to ground-nesting solitary bees due to their larger foraging and dispersal ranges (β_f = 530m vs 191m; β_n = 1000m vs 100m). This enables bumblebee populations to forage and disperse more widely, especially in more fragmented landscapes (Cranmer et al., 2012), so extending their neighbourhood effect. To encourage more solitary bee visitation into crops, schemes would need to provide larger, contiguous habitat features that better account for their limited dispersal range (Martínez-Núñez et al., 2020; Woodcock et al., 2013). In so doing, schemes would also help increase the diversity of pollinators provided thus increasing the resilience of the service.

A contributing factor towards the lack of a significant change in national visitation from ground-nesting bumblebees in late spring (despite significant changes in other seasons) could be the much larger variance in predictions for this guild for this season. This is driven by high uncertainty in the change in floral resource value for the 14,830 ha of semi-natural habitat in *AES_Present* where AES features have replaced (late-spring-flowering) OSR or field beans in *AES_Absent* (Figure 1).

4.2.1 Effect on OSR and field beans

At national scale, 46% of OSR and 36% of field bean area receive increased visitation from ground nesting bumblebees (key pollinators of both crops; Hutchinson et al. (2021)) due to the presence of AES. Flowering OSR and field beans are attractive resources relative to the surrounding landscape (Kovács-Hostyánszki et al., 2013), so additional bees supported by AES are then attracted to this resource. Even a small increase in semi-natural habitat area due to AES can increase populations which would otherwise be constrained by the relatively low floral quality of mass-flowering crops at other times of the year (Holzschuh et al., 2016; Riedinger et al., 2015). In areas where OSR and field bean visitation is not predicted to increase, this may reflect insufficient cover or placement of higher quality AES in general (Krimmer et al., 2019), uptake of AES land classes with higher resource parameter uncertainty (e.g. semi-natural grassland), or nesting limitation (see above) which can constrain the scale of the neighbourhood effect.

AES are predicted to have less impact on mass-flowering crop visitation by solitary bees. Only field beans, where solitary bees are not a common pollinator (Garratt et al., 2014b; Hutchinson et al., 2021; Nayak et al., 2015) show any significant change. This is again due to the shorter foraging and dispersal ranges of solitary bees, with much of the increased visitation stemming from greater nesting within the field bean cells themselves and the apparently substantial fractional change simply due to the very low level of solitary bee visitation predicted to this crop in both scenarios. By contrast, OSR is an attractive floral resource to solitary bees (Knopper et al., 2016), but to promote increased visitation by these guilds, AES management would need to be better distributed to enable these short-range foragers to reach a greater proportion of the crop.

4.2.2 Effect on orchard fruit and strawberries

At national scale, there was no significant increase in visitation to orchard or strawberry cells due to AES during their peak flowering seasons (early spring and summer, respectively). Both crops are predominantly located in areas of England that have relatively low AES participation (Figure S14, S15). Field studies elsewhere in Europe have found significantly lower populations of wild bees in the vicinity of commercial orchards (Eeraerts et al., 2017; Marini et al., 2012). This was attributed to lack of habitat diversity, suggesting that greater targeting of AES towards orchards would be beneficial for visitation, especially in more intensive agricultural landscapes (Holzschuh et al., 2012). Landscape fragmentation and simplification around strawberry crops is also associated with lower wild bee abundance and lower crop visitation rates (Bukovinszky et al. 2017; Castle et al., 2019; Connelly et al., 2015).

However, when wildflower strips have been experimentally introduced to orchards, no significant impact on pollination service is observed (Campbell et al., 2017; McKerchar et al., 2020). Placing wildflower strips alongside strawberries can increase visitation to the crop (Feltham et al., 2015), though the visitation is not always consistent across the field (Ganser et al., 2018). Meanwhile, manually increasing the population of bees through *in situ* nest provision does increase pollination of both crops (Bosch et al., 2006; Horth and Campbell, 2018).

Early spring orchard visitation is dependent on reproductive females, and we do not predict nest density increases in orchards (Figure 3). Although workers are available to forage on strawberry crops, their peak flowering season (summer) coincides with that of many AES interventions, potentially causing competition for pollinators. Significant increases in visitation to both these crops will therefore only be achieved if AES provide a large increase in nest density (which increases the absolute number of foragers) relative to the increase in floral value provided (which decreases the relative attractiveness of the crop). Scheme design may also need to change to increase the financial incentive available to fruit growers as current AES payment rates may not cover the income foregone in more productive agricultural areas where these crops are grown (Lastra-Bravo et al., 2015).

4.3 Caveats

Although the poll4pop model is sophisticated, it currently has limited temporal resolution (three seasons) and does not allow for mortality during ‘hunger gaps’ at the start/end of the active period (Jachuła et al., 2021). Some AES hedgerow options may provide floral resources in early-March (due to tree/shrub flowering) and again in autumn via flowering ivy (*Hedera helix*), while options promoting legume and herb-rich swards may also provide important late resources such as red clover (*Trifolium pratense*). Wild bees in English landscapes are highly dependent on these resources at these critical points for survival of reproductive females (Timberlake et al., 2019). We may therefore have underestimated the value of some AES options due to the relatively coarse temporal resolution of our model.

Our application of the model generalised wild bees into four guilds, but this may overstate the value of AES to bee species. For ground-nesting solitary bees in particular, field data suggests AES only provide beneficial floral resources for a minority of common species (Wood et al., 2017). We also note that an increase in visitation rate for one guild alone does not necessarily mean an increase in pollination service if the level of pollination service in the absence of the intervention is already sufficient to achieve optimal pollination, less pollinator-dependent crop varieties are grown or there are other limiting factors (Garratt et al., 2018). Further work is needed to link model visitation rates to yield in order to examine the impact of schemes on pollination service deficits.

Our study has sought to predict the extent to which participation in AES at scheme level, given current uptake patterns, has changed wild bee guild abundances and flower visitation rates. The geographic variation in magnitude and significance of the effect will depend on the type, quantity, quality (relative resource value-add) and placement of the AES resource with respect to crops or other areas of interest. The relative importance of these factors and the relative importance of individual interventions in driving these predicted scheme-level changes will be investigated in forthcoming work.

5 Conclusions and Recommendations for Policy

This study has demonstrated how a sophisticated process-based model (poll4pop) can be used in conjunction with detailed landcover data to examine the effectiveness of entire agri-environment schemes (AES) at supporting bee populations and the ecosystem services they provide. Our results also demonstrate the potential of this approach to inform selection and targeting of AES incentives to enhance these outcomes.

Our modelling predicts that the pattern of AES participation in 2016 was effective in boosting ground-nesting bee populations compared to a scenario without these features. However, tree-nesting and cavity-nesting bee populations nationally were not predicted to benefit from AES participation. Furthermore, current AES participation was not predicted to significantly increase visitation to pollinator-dependent crops at national level. Significant localised increases were predicted only for late-spring flowering crops (OSR and field beans), and these were delivered by bumblebees. Motivated by our predictions we summarise below our recommendations for future AES design in England:

- **Floral resource provision**. Our predictions for ground-nesting bee populations align with monitoring data suggesting a slowing of the decline in recent years for generalist bee species due to AES (Powney et al., 2019) and with estimates that a 2% land allocation to floral cover options within AES would provide sufficient resource for common wild bee species (Dicks et al., 2015). Schemes should therefore continue to incentivise floral resource provision.

- **Nesting resource provision**. We identified nest site limitation as preventing populations from fully benefiting from the increased floral resource provided by AES features and as a contributing factor in our prediction for lack of significant national increase in crop visitation. Schemes should enhance the uptake and sophistication of options that provide nesting resources, especially in orchard- and strawberry-growing regions. Interspersing larger, more contiguous patches of semi-natural habitat within arable areas may also better support short-range solitary bee populations and their pollination services.

- **Resource diversity**. Tree-nesting and cavity nesting bee species have habitat requirements that are not well-catered for in current AES. To increase populations of these guilds, schemes should increase the range of interventions that provide specialist nesting and floral resources. Although more bespoke and locally specific features may be required to support some species, AES could support these guilds generically through options that create/manage hedgerows, trees, and scrub (in potentially good alignment with current carbon sequestration goals that also favour such options; Summers et al. (2021)).

6 Author contributions

MI conceived the ideas, carried out the research and wrote the manuscript. TB and EG contributed to conceptual development and manuscript revisions. YC and EG provided the poll4pop model and parameters which MI adapted and applied to this context. All other authors provided comments on the manuscript and/or datasets for model validation.

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Supplementary Material

8 Land Classes

Table S1: Land classes. For each land class used in the model, the table indicates how it has been parameterised relative to G2020, and to what land category for purposes of broad analysis. The final column provides additional information about land class development relative to G2020 and other datasets.

Land class	***Parameterisation relative to G2020***	***Land Category***	***Notes***
Beaches, Sand Dunes/Plane	Beaches, Sand Dunes/Plane	Semi-natural Habitat	
Berries (exc. Strawberries & Raspberries)	Berries (exc. Strawberries & Raspberries)	Other Crops	
Broad/Field Beans	Broad/Field Beans	Field Beans	
Buckwheat	Buckwheat	Other Crops	
Cereal	Cereal	Other Crops	
Cereal - Organic	Organic Cereal	Other Crops	
Ditch	Ditch	Semi-natural Habitat	Ditches in AES are 2m wide. Ditches not in AES are 1m wide.
Fallow	Fallow	Semi-natural Habitat	
Flower Rich Margin	Unimproved Meadow	Semi-natural Habitat	Matched to highest floral value class to distinguish from "Grassy Field Edge"
Gardens	Gardens	Suburban	Match to LCM 'Suburban' includes suburban parks, greens as well as domestic gardens
Golf Courses	Golf Courses	Suburban	
Grassland Acid - Improved	Improved Grassland	Improved Grassland	Acid and Neutral grassland both mapped to Improved Grassland in improved state.
Grassland Neutral - Improved	Improved Grassland	Improved Grassland	Acid and Neutral grassland both mapped to Improved Grassland in improved state.
Grassland Calcareous – Improved	Improved Meadow	Improved Grassland	Calcareous grassland mapped to Meadow spectrum
Grassland Acid – Semi-improved	50% Improved Grassland, 50% Moorland	Semi-natural Habitat	No semi-improved category in G2020. Assumed to be halfway between improved and unimproved.
Grassland Neural – Semi-improved	50% Improved Grassland, 50% Unimproved Grassland	Semi-natural Habitat	No semi-improved category in G2020. Assumed to be halfway between improved and unimproved.
Grassland Calcareous – Semi-improved	50% Improved Meadow, 50% Unimproved Meadow	Semi-natural Habitat	No semi-improved category in G2020. Assumed to be halfway between improved and unimproved.
Grassland Acid - Unimproved	Moorland	Semi-natural Habitat	Acid Grassland treated as equivalent to Moorland as often in mosaic.
Grassland Neutral - Unimproved	Unimproved Grassland	Semi-natural Habitat	Unimproved Grassland in G2020 mapped to Neutral Grassland.

Land class	*Parameterisation relative to G2020*	*Land Category*	*Notes*
Grassland Calcareous - Unimproved	Unimproved Meadow	Semi-natural Habitat	Calcareous grassland mapped to Meadow spectrum
Grassy Field Margin	Grassy Field Edge	Semi-natural Habitat	
Hedgerow	Hedgerow	Semi-natural Habitat	Hedgerows in AES are 5m wide. Hedgerows not in AES are 2.5m wide. The 5m width is that specified in EFA rules for hedgerow management. Hedgerow Regulations (1997) mean that hedgerows are unlikely to be absent in *AES_Absent*. Rather, unmanaged hedgerows are thinner and have more gaps.
Ley - Grass and Legume	Grass and Legume Ley	Semi-natural Habitat	
Ley - Grass	Grass Ley	Semi-natural Habitat	
Ley - Organic	Organic Ley	Semi-natural Habitat	
Linseed/Flax	Linseed/Flax	Other Crops	
Maize	Maize	Other Crops	
Moorland	Moorland	Semi-natural Habitat	Includes all Heathland.
Moorland - Degraded	75% Moorland, 25% Improved Grassland	Semi-natural Habitat	Positioned half-way between unimproved and semi-improved condition. This is closest match to baseline condition for ES “Restoration of Moorland” option in BD2302/5007.
Null	Water, Rock	Urban	
Oilseed Rape	Oilseed Rape	Oilseed Rape	
Oilseed Rape - Organic	Organic Oilseed Rape	Oilseed Rape	
Orchards	Orchards	Orchards	No distinction between Orchard and Traditional Orchard as BD2302/5007 does not distinguish between unproductive and productive Traditional Orchards, and not distinguished in G2020 either.
Orchards – Degraded	80% Orchards, 20% Scrub	Semi-natural Habitat	Match to baseline condition for ES “Traditional Orchard” options in BD2302/5007.
Peas	Peas	Other Crops	
Poplar	Poplar	Other Crops	
Potatoes	Potatoes	Other Crops	
Reed Canary Grass	Reed Canary Grass	Other Crops	
Salix	Salix	Other Crops	
Salt Marsh	Salt Marsh	Semi-natural Habitat	
Scrub	Scrub	Semi-natural Habitat	
Scrub – Degraded	50% Scrub, 25% Unimproved Grassland, 25% Improved Grassland	Semi-natural Habitat	Match to baseline condition for ES “Restoration of Scrub” options in BD2302/5007.

Land class	*Parameterisation relative to G2020*	*Land Category*	*Notes*
Strawberry/Raspberry in Polytunnels	Strawberry/Raspberry in Polytunnels	Other Crops	
Strawberry/Raspberry in the open	Strawberry/Raspberry in the open	Strawberries	
Sugar Beet	Sugar Beet	Other Crops	
Urban	Urban	Urban	
Vegetables	Vegetables	Other Crops	
Wetlands	Wetlands	Semi-natural Habitat	
Wetlands – Degraded	90% Wetlands, 10% Scrub	Semi-natural Habitat	Match to baseline condition for ES “Restoration of Reedbed” options in BD2302/5007.
Woodland - Afforestation	Afforestation	Semi-natural Habitat	
Woodland - Coniferous	Coniferous Woodland	Semi-natural Habitat	
Woodland - Deciduous	Deciduous Woodland	Semi-natural Habitat	Assumed that most woodland under AES will be deciduous or aiming to create more deciduous.
Woodland – Degraded	80% Deciduous Woodland, 10% Unimproved Grassland, 10% Improved Grassland.	Semi-natural Habitat	Match to baseline condition for ES “Woodland management/restoration” options in BD2302/5007.
Woodland Edge	Woodland Edge	Semi-natural Habitat	Woodland edges in AES are 5m wide. Woodland edges outside AES are 2.5m wide. Width specified in AES rules for woodland edge options. Woodland edge itself cannot disappear but managed area is smaller.
Wood Pasture	45% Unimproved Grassland, 45% Improved Grassland, 10% Deciduous Woodland	Semi-natural Habitat	No wood pasture in G2020. Match to with-AES condition for ES “Wood Pasture” options in BD2302/5007.
Wood Pasture - Degraded	50% Improved Grassland, 50% Unimproved Grassland	Semi-natural Habitat	No wood pasture in G2020. Match to baseline condition for ES “Wood Pasture” options in BD2302/5007.

9 Land Cover Generation

The Poll4pop model requires a rasterised input where each cell represents a land cover type to which a specific floral and nesting value can be assigned for a given guild. The different scenarios (*AES_Present* and *AES_Absent*) would be represented by generating two separate raster maps covering the same area but with different land cover classes for cells where AES features were present. However, the underlying spatial data sources for non-agricultural, agricultural and AES land cover are in various vector formats (polygon, polyline and point) so the following process was used to combine them and allocate a land class from which the *AES_Present* and *AES_Absent* raster layers could then be built.

Table S2: Datasets used in land cover generation including brief description and license.

Name	Alias	Description	License
Centre for Ecology and Hydrology (CEH) Land Cover Map 2015 (Rowland et al., 2017)	LCM	The standard CEH land cover map as a polygon which breaks Great Britain into 21 land cover classes.	© NERC (CEH) 2011. Contains Ordnance Survey data © Crown Copyright 2007, Licence number 100017572.
Ordnance Survey (OS) MasterMap Orchards 2017	MMOrch	A polygon layer which provides the location of orchards	© Crown Copyright and Database Right 2018. Ordnance Survey (Digimap Licence)
CEH Woody Linear Features Framework (Scholefield et al., 2016)	WLF	A polyline layer which provides the location of woody linear features in Great Britain (hedgerows, shelterbelts etc.)	© NERC (CEH). Contains Ordnance Survey data © Crown Copyright 2007, Licence number 100017572.
Crop Map of England (CROME) 2016	CROME	A polygon layer consisting of hexagonal pixels which represent one of a set of crop types or non-crop features	Open Government License © Crown copyright 2016.
Land Parcel Information System (LPIS) – England polygons 2016	LPIS	A polygon layer representing land parcels in England for which a BPS payment has been claimed	RPA/Ops/LoB2/124
Basic Payment Scheme (BPS) Claims 2016	Claims	A data table showing all the direct payment claims associated with each land parcel in the RPA database. This is used to associate the land parcel with a crop type as well as other features outside ESS or CS (i.e. buffer strips, fallow, catch/cover)	RPA/Ops/LoB2/124
OpenStreetMap	OSM	A polyline layer showing the location of linear infrastructure features including roads, railways, and waterways.	© OpenStreetMap contributors. www.openstreetmap.org/copyright.

Countryside Stewardship Management Options 2016 (shapefile)	CS	Point layer identifying CS options by land parcel code, business id, type, area, payment etc….	Open Government License
Environmental Stewardship Scheme Agreements (shapefile)	ES	Point layer identifying ES options by land parcel code, business id, type, area, payment etc….	Open Government License

9.1 Agricultural Land Cover

The agricultural component of the land cover for England was generated by merging the LPIS parcel and MMOrch layers, after erasing area from MMOrch which overlapped with LPIS. MMOrch parcels in this merged layer were assigned as Orchards. LPIS polygons in this merged layer were assigned a land cover type based on the corresponding BPS claim for that parcel in the Claims layer for that parcel. This information includes productive features: a set of arable crops; a set of leguminous crops; watercress; temporary and permanent grassland; commercially grown trees (permanent crops, short rotation coppice and nursery crops). It also includes claims for eligible non-productive 'crops' (fallow, catch crops, cover crops), non-eligible land cover and land which would normally be non-eligible for BPS but is included because it is under an eligible RDP scheme (typically woodland options). The Claims dataset also contains information about EFA edge features (buffer strips; hedge features) but these are handled in the section on AES land cover generation.

Where there was more than one land cover type associated with a parcel[1], the polygon was assigned the land cover type which had the largest area. The only exception to this rule was to allow for permanent areas of fallow land to occupy parts of the parcel where the total area of productive crop claims was less than the total area of the parcel and where there was also a fallow claim associated with that parcel. In this case the parcel was split into a fallow area (assigned to fallow) and a non-fallow area (assigned to the largest declared area of non-fallow). Fallow areas were not treated as equivalent to AES features as, unlike boundary features now included as EFA, they were not funded as such under the previous AES.

Catch/cover crops areas and temporary fallow (area of fallow claims exceeding the available area of the parcel) were calculated but were not used, again for simplicity reasons. Non-inclusion of catch/cover crops does not matter as the implementation of the Poll4pop model in this case does not include an autumn/winter season when these features would be present. Non-inclusion of temporary fallow understates the potential area of semi-natural habitat available to pollinators in early spring, but this understatement is consistent across both scenarios as fallow claims were not treated as AES.

In some cases, parcels in the LPIS layer did not have a match with a claim in the RPA Claims dataset or had an undefined crop code. Where this occurred, the polygon was intersected with the CROME layer and a crop assigned according to the CROME feature with the largest area within that parcel. If this was not an agricultural land class, then a crop was assigned based on the crop of the nearest matched LPIS polygon.

Where the assignment was to Permanent Crops a check was needed to establish if these would map to orchards or to berries (excl. strawberry/raspberry). Parcels which intersected the MMOrch layer were assigned as Orchards and the remainder were assigned as Berries (excl. Strawberry/Raspberry). Where the assignment was to the RDP code (even after removal of AES features) the land was deemed to under a woodland scheme outside the scope of ES and CS and was assigned as Woodland in AES in both *AES_Present* and *AES_Absent* scenarios.

Where the assignment was to Permanent Grassland, a further process was needed to identify what type of grassland (improved grassland or semi-natural habitat that would have been claimed as

[1] Many parcels have more than one claim associated with them because more than one crop can be grown in a given parcel at any one time and or during the year (including temporary fallow and catch/cover crops) and because boundary features (buffer strips, hedgerows) also coexist with crops or grassland in the main part of the field. For simplicity, it was decided to constrain agricultural land cover to a single crop rather than allowing for multiple crops

permanent grassland). In this case, the polygon was intersected against the LCM layer and a code assigned based on the area of a relevant LCM feature (Improved Grassland, Neutral Grassland, Acid Grassland, Calcareous Grassland, Fen Marsh Swamp, Heather, Heather Grassland, Bog, Saltmarsh) with the largest intersecting area. Where there was no relevant feature interacting, the grassland type of the nearest matched LPIS polygon was assigned.

9.2 Non-Agricultural Land Cover

The remaining area of land cover for England and the 5km Scotland / Wales buffer was created from LCM polygons. In most cases the land cover type was assigned directly from the LCM modal class. However, there were some instances where additional processing was required.

Firstly, due to classification errors and spatial resolution limitations[2] the area not captured by LPIS polygons still included some land indicated as 'Arable and Horticulture' which required a more specific crop assignment. From visual inspection these polygons appeared to fall into two types:

- Larger, field shaped features that are clearly crops missing from the LPIS database or else non-agricultural land cover wrongly misclassified due to spectral quality (e.g. airfields and industrial parks);
- Smaller, linear-shaped features (e.g. verges, hedgerows, in-field trees, boundary trees, gardens), including hardstanding (road, railway) or water features which have been misclassified in the LCM, most likely because of their resolution. This also included small slivers of crop or non-crop where the LCM and LPIS boundaries did not perfectly match.

The non-matched polygons then passed through the following process to determine their land cover class.

- Non-matched polygons in England were split into two groups: a 'probable field' group with area >= 0.5ha and length to area ratio <= 0.05; a 'probable linear feature' group which represented the other polygons. The area and ratio thresholds were chosen based on visual inspection of a polygons from a sample 10km grid.
- Probable field features were matched against the CROME layer and assigned the land cover class with the largest percentage representation from CROME within that polygon. Non-agricultural features were assigned as 'Urban'.
- Probable linear features were matched against the OSM and features which intersected roads or rail were assigned the 'Urban' land cover class and those intersecting water were assigned 'Water'. Remaining features were checked for intersect with the WLF layer and those intersecting were assigned a 'Hedgerow' land cover. Remaining features were then checked against the CROME layer: those corresponding to a crop land cover class (most likely a crop sliver) were assigned the crop given to the closest LPIS polygon (see next phase); those which corresponded to a non-crop land cover (non-crop slivers) were assigned the land cover class of the closest non-agricultural LCM polygon.
- Non-matched polygons in the Wales / Scotland 5km buffer zone were not linked to LPIS as this dataset refers only to England. Instead, an arable or leguminous crop was assigned at random from the Claims dataset, weighted by the proportion of land area associated with that crop. Pollination visitation rates to these polygons are not considered in the results. The allocation was only made so that the poll4pop model could function.

[2] See CEH (2017) for more details on these limitations.

Secondly, in the Scotland / Wales buffer zone the LCM polygons assigned to 'Arable and Horticulture' needed a specific crop assignment but the Claims dataset only covered England. A simpler process was used here as the precise configuration of crop types in the buffer zone is of less importance to the final output as we ignore these cells in calculating summary values. An arable or leguminous crop was therefore assigned at random from the list in the Claims database, with the selection weighted according to the total proportional area of coverage of each crop in the database.

Two polyline layers were also created. One was derived from the WLF layer and marked as Woody Linear Feature. A second was created from the boundary of contiguous woodland features in the land cover and marked as Woodland Edge.

9.3 AES Land Cover

The ES and CS datasets provide information about the option (code), location (parcel or farm), coverage, and level (agreement or parcel), start date and end date, *inter alia*. The Claims dataset provides information about the area of certain types of buffer strip and hedge feature claimed for each parcel.

The first task was to reduce the ES and CS option datasets to only relevant options. After selecting only those features which were live during 2016, the dataset was further reduce to extract only options which created, restored, or maintained habitat likely to be of some floral or nesting value. This was determined with reference to the baseline and with-AES habitat descriptions used for ESS in BD2302/5007 (and CS options by equivalence) and the expert opinion parameters from G2020. If both baseline and with-AES scenarios were arable crops, improved grassland or a land cover associated with low habitat quality (e.g. open water) then the option was excluded. Most management options were included except for some water-related options. Most capital items were excluded except for items relating to hedgerow / tree planting and stone wall / earth bank restoration. Supplement options[3] were excluded to simplify the *AES_Present* vs *AES_Absent* scenarios. These apply primarily to less intensive farm systems and have less bearing on the crop pollination outcomes.

Next, items were separated into 'Agreement' level and 'Parcel' level features. Parcel level features are applicable to one parcel only and could be matched to specific LPIS polygons by matching the parcel references. Agreement level features are rotational options which are associated with arable parcels and can move around the farm to accompany the field rotation pattern in use. These could not be linked to an explicit parcel and required a rule-based allocation.

Features were further split into groups according to their functional unit of measurement as this affected how their coverage was calculated and how they were represented in the land cover map (as polygon or polyline).

- 'Field' options were features measured in hectares, which are typically not linear and are sufficiently large that there would be little information loss upon conversion to a 25m raster. These would be preserved as polygons.
- 'Plot / Tree' options were features found within the field measured in number of units and would potentially be lost upon conversion to a 25m raster due to their small size (e.g. *AB4 - Skylark plots*, in-field tree management options). These would be converted to polylines representing the perimeter of the plot or tree canopy and located randomly within the field subject to rules on plot or tree density.

[3] Options which do not occur in isolation and must be combined with another option.

- 'Margin' options were features measured in hectares, but which are typically linear and occupy land just inside the field boundary. These would potentially be lost in raster conversion if represented as polygons (e.g. field margins). These would be converted to polylines located 10m within the field boundary.
- 'Transect' options are features measured in hectares, but which are typically linear and go across a field rather than around its boundary. These would potentially be lost in raster conversion if represented as polygons (e.g. beetle banks). These would be converted to polylines which cross the field itself.
- 'Perimeter' options were features measured in metres, which are linear and occupy land on the field boundary itself. These would be lost in raster conversion if represented as polygons (e.g. hedgerows). These would be converted to polyline and placed on the field boundary itself.

Allocation was as follows.

Parcel – Field

Many parcels had more than one AES option assigned to them. This was either because the options occupied different parts of the field, or because the options were co-located as management was complementary. For simplicity, an assumption was made that only one option could occupy any given location within the parcel and an algorithm was used to fill the available space as follows:

- The parcel was cut North-South, South-North, East-West, or West-East (chosen at random) to create a slice of area equal to the smallest option by area allocated to that parcel. This was assigned to that option.
- The remaining parcel was then sliced (again in a random orientation) so create a slice of area equal to the next smallest option.
- And so on until all the available area of the parcel allocated to AES was used up.

Any surplus area (a result of rounding error, input error, or co-location of options) was ignored. Where co-location occurred, the larger option was typically a more generic AES option (e.g. UX3 – generic prescriptions for Moorland) whilst the smaller option had more specific habitat value. Because the algorithm assigned from smallest to largest, failure to represent co-location was unlikely to understate of pollinator value.

Agreement – Field

These features have an area in hectares representing the total area covered by that option on that farm, but all agreements for a given farm are assigned to a representative parcel rather than the actual parcels as the locations change from year to year as per that farm's crop rotation.

First, a set of option to crop type assignment rules was created to ensure that these features could only be placed in parcels containing an appropriate crop as per the option description in the ES or CS Manual. This also contained a set of rules indicating how much of the parcel could be filled up, again as per the option description. Then, all the agreements were assigned to a specific farm in the LPIS database. In most cases this was possible by matching the farm associated with the representative parcel but in a few cases where a match could not be found the agreement was assigned to the nearest farm. Parcels which already had a Parcel – Field feature allocation were excluded. This produced a list of suitable parcels from the agricultural land cover database where the feature could be located and a total area of allocation. However, because the actual parcels are not known, a random allocation was made according to an algorithm:

- Starting with the first farm, each agreement is assigned a random parcel from the list of suitable parcels.
- The parcel is filled up (using the random North-South, South-North, East-West, or West-East slicing approach) up to the parcel limit.
- If there is remaining unallocated area for that agreement, the next random parcel was selected and filled, and so on until the area of that agreement was used or all suitable parcels were fully occupied[4].
- The process was repeated for the next agreement (but excluding parcels already assigned) until all the agreements for that farm were assigned.
- The algorithm then moved to the next farm and repeated until all the farms had been assigned.

Parcel – Plot/Tree

This category includes Skylark Plots in CS (AB4) and in-field tree options in ES (EC1, EC2, HC1, HC2, HC5, HC6, OC1, OC2, OHC1, OHC2). Skylark plots have a minimum area of 16m^2 according to option description. Assuming that a typical plot is the minimum area, the typical plot would have a radius of 2.25m. In-field tree options protect an area extending 2m beyond the crown radius. A typical mature tree has a radius of around 3m (Pretzsch et al., 2015) so this would infer a radius of 5m.

The features were deemed too small to be captured in the raster as polygons. So polyline circles of the aforementioned radii for all plots / tree within a given parcel were generated and then randomly allocated to locations within the polygon such that they were still enclosed by the field boundary.

Agreement – Plot/Tree

This category includes Skylark plots in ES (EF8, HF8, OF8, OHF8), which are agreement features and thus can rotate around the farm. Assignment rules were developed as per the option description (winter cereal fields greater than 5ha, and at least 2 plots/ha) and a set of suitable parcels was selected as per the process for the Agreement – Field parcels (avoiding parcels already containing AB4).

A similar allocation algorithm to the Agreement – Field algorithm was used to allocate plots to appropriate parcels (using a density of 2 plots/ha) except that the features created were circular polylines of the same circumference as the AB4 features.

Parcel – Margin

Parcel margin features are those which are located just inside the field boundary, and which are represented in the databases as an area value in hectares. However, due to their shape (typically long, thin strips) they were converted to linear features to minimise information loss upon conversion to raster. This was achieved by converting the area to m^2 and then dividing by a fixed width parameter applicable to each AES type (Table S4**Error! Reference source not found.**). Widths were derived from the option description in the relevant scheme handbook where available. Where not, widths were set to the default width of associated LC class (Margin = 5m). For EFA features (Fallow Buffer Strip, Temporary Grass Buffer, Sown Mixed Cover Buffer, Buffer Strip, and Permanent Grassland Buffer Strips), the width adjustment used was 9m, as per the BPS 2016 rule book (Rural Payments Agency, 2015).

For each parcel, a list of margin features and lengths was produced. A polyline was created 5m inside the parcel boundary for each feature, starting with the shortest feature and continuing with the next

[4] In practice this never occurred. There was always surplus parcel area.

feature and so on until the length of features or the total available length of polyline was used up (which ever occurred first).

Agreement – Margin

Agreement margin features have an area value in hectares but were converted to linear features (m) to minimise information loss upon conversion to raster as per the Parcel – Margin features process set out above. All agreements for a given farm are assigned to a representative parcel rather than the actual parcel as the locations change from year to year as per that farm's crop rotation.

As per the Agreement – Field features a set of rules for parcel type and max length was created and agreements were matched to specific farms. A similar algorithm to the Agreement – Field process was used to assign agreements to specific parcels, but the assignment was to a polyline 5m inside the parcel edge as per the Parcel – Margin features.

Parcel – Perimeter

Parcel perimeter features have a value in metres and so could be converted directly into polylines, except for hedge features in EFA are in hectares and were converted to metres using a width parameter of five[5]. For each parcel, a list of perimeter features and lengths was produced. A polyline was created along the parcel boundary for each feature, starting with the shortest feature and continuing with the next feature and so on until the length of features or the total available length of polyline was used up (which ever occurred first).

Agreement – Perimeter

Agreement - perimeter features have a length in metres so could be converted directly into polylines. All agreements for a given farm are assigned to a representative parcel rather than the actual parcel as the locations change from year to year as per that farm's crop rotation.

As per the Agreement – Field features a set of rules for parcel type and max length was created and agreements were matched to specific farms. A similar algorithm to the Agreement – Field process was used to assign agreements to specific parcels, but the assignment was to a polyline along the parcel edge as per the Parcel – Perimeter features.

Parcel – Transect

Parcel margin features have an area value in hectares but were converted to linear features to minimise information loss upon conversion to raster. This was achieved by converting the area to m^2 and then dividing by a fixed width parameter applicable to each AES type (Table S4). Widths were derived from the option description in the relevant scheme handbook where available.

For each parcel, a list of transect features and lengths was produced. For each feature, a polyline was created running North-South, South-North, East-West or West-East (at random) across the parcel that would be at least as long as the feature. This was allocated to that feature. If there was still available length of the feature, another line was generated along the same axis until the available length was used up; and so on until the length of features was used up.

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[5] In EFA claims the hedge is deemed to occupy $10m^2$ for every metre of hedge where both sides are under management and $5m^2$ where only one side is. For simplicity, a conservative assumption was made that only one side of the hedge was in management and no adjustments were made to allow for reductions to area that may have been made where hedges were adjacent to fallow land.

Agreement – Transect

There were no Agreement – Transect features.

Areas assigned to Parcel – Field and Agreement – Field features were erased from the agricultural parcels layer and the agricultural, non-agricultural and AES polygon layers were merged to create a single land cover polygon layer providing full coverage for England the 5km buffer into Wales and Scotland. Each polygon in the layer had a field indicating its LC class in the *AES_Present* and *AES_Absent* scenarios.

Lines assigned to the same LC class were merged into polyline layers representing that class. This created lines for Grassy Field Margins, Flower Rich Margins and Fallow buffer features, Hedgerows, Ditches and Woodland Edges. Hedgerow and WLF polylines from the non-agricultural layers which exactly overlaid hedgerow and WLF polylines from the AES layers were removed to avoid duplication.

The single land cover polygon layer was converted to two separate 25m raster layers based, one showing land cover for *AES_Present* and the other for *AES_Absent* using the MAXIMUM_COMBINED_AREA rule in ArcGIS. Cell alignment was matched to the British National Grid.

Each polyline in its respective layer was split into individual lines covering only the area within each 25m raster cell. These lines were then converted to 25m raster based such that the entry for each cell was the total length of that LC class in that 25m cell.

10 Land Class Assignment

Allocation of land class to non-AES features is set out in Table S3. As per the LCM metadata descriptions semi-natural grassland habitat was assigned as semi-improved rather than unimproved status (CEH, 2017). Polylines from the WLF layer were assigned as Hedgerow (unless they were already captured as an AES Hedgerow feature. Woodland edges that form the perimeter of contiguous areas of woodland (and were not already captured as an AES Woodland Edge feature) were allocated to the Woodland Edge land class. Permanent crops were either assigned to Orchard or to Berries (excl. Strawberry/Raspberry) depending on their alignment with the MMOrch layer, as described in the previous section.

Table S3: Land class assignment: non-AES features (non-agricultural, agricultural)

Land cover description	Source	Land class (***AES_Present***)
Broadleaved Woodland	LCM	Woodland - Deciduous
Coniferous Woodland	LCM	Woodland - Coniferous
Improved Grassland	LCM	Grassland – Improved
Neutral Grassland	LCM	Grassland Neutral - Semi-Improved
Calcareous Grassland	LCM	Grassland Calcareous - Semi-Improved
Acid Grassland	LCM	Grassland Acid – Semi-Improved
Fen, Marsh and Swamp	LCM	Wetlands
Heather	LCM	Moorland
Heather Grassland	LCM	Moorland
Bog	LCM	Wetlands
Inland Rock	LCM	Null
Saltwater	LCM	Null
Freshwater	LCM	Null
Supra-littoral Rock	LCM	Null
Supra-littoral Sediment	LCM	Beaches, Sand Dunes/Plane
Littoral Rock	LCM	Null
Littoral Sediment	LCM	Beaches, Sand Dunes/Plane
Saltmarsh	LCM	Salt Marsh
Urban	LCM	Urban
Suburban	LCM	Gardens
Woody linear features	WLF	Hedgerow
Woodland edges	LCM, CROME	Woodland Edge
Barley (Spring)	Claims	Cereal
Basil	Claims	Cereal
Beet	Claims, CROME	Sugar Beet

Land cover description	Source	Land class (*AES_Present*)
Borage	Claims	Linseed/Flax
Buckwheat	Claims	Buckwheat
Canary Seed	Claims	Reed Canary Grass
Carrot	Claims	Vegetables
Celery	Claims	Vegetables
Chicory	Claims	Cereal
Daffodil	Claims	Cereal
Ryegrass	Claims	Reed Canary Grass
Dill	Claims	Cereal
Evening Primrose	Claims	Linseed/Flax
Fennel	Claims	Vegetables
Hemp	Claims	Cereal
Lettuce	Claims	Vegetables
Linseed (Spring)	Claims, CROME	Linseed/Flax
Maize	Claims, CROME	Maize
Millet	Claims	Cereal
Oats (Spring)	Claims	Cereal
Onion	Claims	Vegetables
Oregano	Claims	Cereal
Parsley	Claims	Cereal
Parsnip	Claims	Vegetables
Rye (Spring)	Claims	Cereal
Sage	Claims	Cereal
Spinach	Claims	Vegetables
Strawberry	Claims	Strawberry / Raspberry in the open
Sweet Potato	Claims	Vegetables
Thyme	Claims	Cereal
Triticale (Spring)	Claims	Cereal
Tulip	Claims	Cereal
Wheat (Spring)	Claims	Cereal
Yam	Claims	Vegetables
Cabbage (Spring)	Claims	Vegetables
Turnip	Claims	Vegetables
Oilseed (Spring)	Claims, CROME	OSR
Brown Mustard	Claims	OSR
Mustard	Claims	OSR

Land cover description	Source	Land class (*AES_Present*)
Crambe	Claims	OSR
Rocket	Claims	Cereal
Radish	Claims	Vegetables
Horseradish	Claims	Vegetables
Tobacco	Claims	Cereal
Potato	Claims, CROME	Potatoes
Tomato	Claims	Null
Aubergine	Claims	Vegetables
Pepper	Claims	Vegetables
Chilli	Claims	Vegetables
Tree Chilli	Claims	Vegetables
Squash	Claims	Vegetables
Japanese Pie Squash	Claims	Vegetables
Siam Pumpkin	Claims	Vegetables
Banana Squash	Claims	Vegetables
Butternut Squash	Claims	Vegetables
Watermelon	Claims	Null
Cucumber	Claims	Null
Melon	Claims	Null
Mixed Arable	Claims	Cereal
Barley (Winter)	Claims	Cereal
Linseed (Winter)	Claims, CROME	Linseed/Flax
Oats (Winter)	Claims	Cereal
Wheat (Winter)	Claims	Cereal
Oilseed (Winter)	Claims, CROME	OSR
Rye (Winter)	Claims	Cereal
Triticale (Winter)	Claims	Cereal
Cabbage (Winter)	Claims	Vegetables
Coriander	Claims	Cereal
Corn Gromwell	Claims	Linseed/Flax
Camelina	Claims	Cereal
Phacelia	Claims	Linseed/Flax
Oca	Claims	Vegetables
German Chamomile	Claims	Linseed/Flax
Corn Chamomile	Claims	Linseed/Flax
Corn Cockle	Claims	Linseed/Flax

Land cover description	Source	Land class (*AES_Present*)
Corn Flower	Claims	Linseed/Flax
Corn Marigold	Claims	Linseed/Flax
Poppy	Claims	Linseed/Flax
Field Forgetmenot	Claims	Linseed/Flax
Foxglove	Claims	Linseed/Flax
Hay Rattle	Claims	Linseed/Flax
Hedge Bedstraw	Claims	Linseed/Flax
Teasel	Claims	Cereal
Quinoa	Claims	Cereal
Sunflower	Claims	OSR
Cress	Claims	Vegetables
Gladioli	Claims	Linseed/Flax
Echium	Claims	Linseed/Flax
Sorghum	Claims	Cereal
Sticky Nightshade	Claims	Linseed/Flax
Sweet William	Claims	Linseed/Flax
Wallflower	Claims	Cereal
Samphire	Claims	Vegetables
Aster	Claims	Linseed/Flax
Larkspur	Claims	Linseed/Flax
Nigella	Claims	Linseed/Flax
Catch Crop	Claims	Not used
Cover Crop	Claims	Not used
Watercress	Claims	Vegetables
Fallow	Claims, CROME	Fallow
Chickpea	Claims	Peas
Fenugreek	Claims	Peas
Field Beans (Spring)	Claims	Broad/Field Beans
Green Beans	Claims	Broad/Field Beans
Lentil	Claims	Peas
Lupin	Claims	Peas
Pea (Spring)	Claims, CROME	Peas
Soya	Claims	Broad/Field Beans
Cowpea	Claims	Peas
Birds Foot Trefoil	Claims	Linseed/Flax
Lucerne	Claims	Cereal

Land cover description	Source	Land class (***AES_Present***)
Sweet Clover	Claims	Linseed/Flax
Sainfoin	Claims	Linseed/Flax
Clover	Claims	Linseed/Flax
Mixed Legumes	Claims	Broad/Field Beans
Field Beans (Winter)	Claims	Broad/Field Beans
Pea (Winter)	Claims, CROME	Peas
Ineligible Area	Claims	Null
Nursery Crops	Claims	Woodland - Deciduous
Permanent Grassland	Claims, CROME	Grassland – see text for assignment process
Short Rotation Coppice	Claims	Woodland - Deciduous
Permanent Crops	Claims	Orchards or Berries (excl. Strawberry/Raspberry). See text.
Temporary Grassland	Claims	Ley - Grass
Beans	CROME	Field Beans
Berries	CROME	Berries (excl. Strawberry/Raspberry)
Cereal	CROME	Cereal
Non-Agricultural	CROME	Urban
Vegetables	CROME	Vegetables
Water	CROME	Null
Wood	CROME	Woodland - Deciduous
Orchards	MMOrch	Orchards
Road	OSM	Urban
Rail	OSM	Urban
Water	OSM	Null

Assignment of specific AES options to land classes is set out in Table S4. The broad process is already described in the previous section. A brief rationale is provided for each option as required. The width column indicates the width parameter used to assign correct lengths to perimeter, margin or transect feature types. AES options from the CS and ES schemes that do not appear here have been excluded either because they are not relevant to pollinators or because there were no options of that type taken up during 2016. In some cases, there is no difference in land class assignment between *AES_Present* and *AES_Absent* scenarios because BD2302/5007 indicates as such. These options have not been excluded from the dataset as the BD2302/5007 information was useful to distinguish land class and maintain consistency in categorisation. Capital items (one-off land use change such as hedgerow planting, hedgerow coppicing, scrub removal) were not included as the datasets are not precise on whether management took place within the calendar year 2016. In any case the number of capital items is very small: there are just 2273 items in the potentially relevant ES agreement dataset (0.32%) prior to allocation and no items in the relevant CS agreement dataset. The list of management options not included in the analysis including reasons for exclusion is provided in Table S5.

Table S4: Land class assignment - AES features. Underlying LC means land class for non-AES feature underlying the AES feature.

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (*AES_Present*)	Land Class (*AES_Absent*)	Width (*AES_Present*) (m)	Notes
AB1	Nectar flower mix	CS	Parcel	Field	Flower Rich Margin	Underlying LC		
AB10	Unharvested cereal headland	CS	Parcel	Margin	Fallow	No feature	15	
AB11	Cultivated areas for arable plants	CS	Parcel	Field	Fallow	Underlying LC		
AB15	Two-year sown legume fallow	CS	Parcel	Field	Ley – Legume and Grass	Underlying LC		
AB16	Autumn sown bumblebird mix	CS	Parcel	Field	Flower Rich Margin	Underlying LC		
AB3	Beetle banks	CS	Parcel	Transect	Ditch	No feature	3	
AB4	Skylark plots	CS	Parcel	Plot/Tree	Fallow	No feature		
AB5	Nesting plots for lapwing and stone curlew	CS	Parcel	Field	Fallow	Underlying LC		
AB8	Flower-rich margins and plots	CS	Parcel	Field	Flower Rich Margin	Underlying LC		
ABS01	Temporary Grass Buffer Strip	EFA	Parcel	Margin	Grassy Field Margin	No feature	9	
ABS02	Sown Mixed Cover Buffer Strip	EFA	Parcel	Margin	Grassy Field Margin	No feature	9	
ABS03	Fallow Buffer Strip	EFA	Parcel	Margin	Fallow	No feature	9	
BE1	Protection of in-field trees on arable land	CS	Parcel	Plot/Tree	Hedgerow	Hedgerow (half)		Treat as short hedgerow
BE2	Protection of in-field trees on intensive grassland	CS	Parcel	Plot/Tree	Hedgerow	Hedgerow (half)		Treat as short hedgerow
BE3	Management of hedgerows	CS	Parcel	Perimeter	Hedgerow	Hedgerow (half)	5	
BE4	Management of traditional orchards	CS	Parcel	Field	Orchard	Orchard - Degraded		Equivalent to HC18
BE5	Creation of traditional orchards	CS	Parcel	Field	Orchard	Grassland Neutral – Semi-Improved		Equivalent to HC21
BF11	Half Hedge	EFA	Parcel	Perimeter	Hedgerow	Hedgerow (half)		Adjustment for half-hedge already implicit in declared area

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (*AES_Present*)	Land Class (*AES_Absent*)	Width (*AES_Present*) (m)	Notes
BF12	Adjacent Hedge	EFA	Parcel	Perimeter	Hedgerow	Hedgerow (half)		
BF15	Buffer Strip	EFA	Parcel	Margin	Grassy Field Margin	No feature	9	
CT1	Management of coastal sand dunes and vegetated shingle	CS	Parcel	Field	Beaches, Sand Dunes/Plane	Beaches, Sand Dunes/Plane		Equivalent to HP1
CT2	Creation of coastal sand dunes and vegetated shingle on arable land and improved grassland	CS	Parcel	Field	Beaches, Sand Dunes/Plane	Grassland Neutral – Improved		Equivalent to HP4
CT3	Management of coastal saltmarsh	CS	Parcel	Field	Saltmarsh	Saltmarsh		Equivalent to HP5
CT4	Creation of inter-tidal and saline habitat on arable land	CS	Parcel	Field	Saltmarsh	Nearest arable crop		Equivalent to HP7
CT5	Creation of inter-tidal and saline habitat by non-intervention	CS	Parcel	Field	Saltmarsh	Grassland Neutral – Semi-Improved		Equivalent to HP9
CT7	Creation of inter-tidal and saline habitat on intensive grassland	CS	Parcel	Field	Saltmarsh	Grassland Neutral – Improved		Equivalent to HP8
EB1	Hedgerow management for landscape (on both sides of a hedge)	ES	Agreement	Perimeter	Hedgerow	Hedgerow (half)	5	
EB10	Combined hedge and ditch management (incorporating EB3)	ES	Agreement	Perimeter	Hedgerow	Hedgerow (half)	5	
EB11	Stone wall protection and maintenance	ES	Agreement	Perimeter	Ditch	Ditch (half)	2	Closest match in G2020
EB12	Earth bank management (on both sides)	ES	Agreement	Perimeter	Ditch	Ditch (half)	2	Closest match in G2020
EB13	Earth bank management (on one side)	ES	Agreement	Perimeter	Ditch	Ditch (half)	1	Closest match in G2020
EB14	Hedgerow restoration	ES	Agreement	Perimeter	Hedgerow	Hedgerow (half)	5	
EB2	Hedgerow management for landscape (on one side of a hedge)	ES	Agreement	Perimeter	Hedgerow	Hedgerow (half)	2.5	

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (*AES_Present*)	Land Class (*AES_Absent*)	Width (*AES_Present*) (m)	Notes
EB3	Hedgerow management for landscape and wildlife	ES	Agreement	Perimeter	Hedgerow	Hedgerow (half)	5	
EB4	Stone faced hedge bank management on both sides	ES	Agreement	Perimeter	Ditch	Ditch (half)	2	Closest match in G2020
EB5	Stone faced hedge bank management on one side	ES	Agreement	Perimeter	Ditch	Ditch (half)	2	Closest match in G2020
EB6	Ditch management	ES	Agreement	Perimeter	Ditch	Ditch (half)	2	
EB7	Half ditch management	ES	Agreement	Perimeter	Ditch	Ditch (half)	1	
EB8	Combined hedge and ditch management (incorporating EB1)	ES	Agreement	Perimeter	Hedgerow	Hedgerow (half)	5	
EB9	Combined hedge and ditch management (incorporating EB2)	ES	Agreement	Perimeter	Hedgerow	Hedgerow (half)	2.5	
EC1	Protection of in-field trees (arable)	ES	Parcel	Plot/Tree	Hedgerow	Hedgerow (half)	5	
EC2	Protection of in-field trees (grassland)	ES	Parcel	Plot/Tree	Hedgerow	Hedgerow (half)	5	
EC24	Hedgerow tree buffer strips on cultivated land	ES	Parcel	Margin	Hedgerow	Hedgerow (half)	6	
EC25	Hedgerow tree buffer strips on grassland	ES	Parcel	Margin	Hedgerow	Hedgerow (half)	6	
EC3	Maintenance of woodland fences	ES	Agreement	Perimeter	Woodland Edge	Woodland Edge (half)	5	Creates a woodland edge
EC4	Management of woodland edges	ES	Parcel	Perimeter	Woodland Edge	Woodland Edge (half)	5	
ED2	Take archaeological features out of cultivation	ES	Parcel	Field	Grassland Neutral – Semi-Improved	Underlying LC		Option description
EE1	2m buffer strips on cultivated land	ES	Parcel	Margin	Grassy Field Margin	No feature	2	
EE10	6m buffer strips on intensive grassland next to a watercourse	ES	Parcel	Margin	Grassy Field Margin	No feature	6	
EE2	4m buffer strips on cultivated land	ES	Parcel	Margin	Grassy Field Margin	No feature	4	

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (*AES_Present*)	Land Class (*AES_Absent*)	Width (*AES_Present*) (m)	Notes
EE3	6m buffer strips on cultivated land	ES	Parcel	Margin	Grassy Field Margin	No feature	6	
EE4	2m buffer strips on intensive grassland	ES	Parcel	Margin	Grassy Field Margin	No feature	2	
EE5	4m buffer strips on intensive grassland	ES	Parcel	Margin	Grassy Field Margin	No feature	4	
EE6	6m buffer strips on intensive grassland	ES	Parcel	Margin	Grassy Field Margin	No feature	6	
EE7	Buffering in-field ponds in improved grassland	ES	Parcel	Margin	Grassy Field Margin	No feature	10	
EE8	Buffering in-field ponds in arable land	ES	Parcel	Margin	Grassy Field Margin	No feature	10	
EE9	6m buffer strips on cultivated land next to a watercourse	ES	Parcel	Margin	Grassy Field Margin	No feature	6	
EF1	Field corner management	ES	Parcel	Field	Grassy Field Margin	Underlying LC		Option description
EF10	Unharvested cereal headlands for birds and rare arable plants	ES	Agreement	Margin	Fallow	No feature	15	Option description
EF11	Uncropped, cultivated margins for rare plants on arable land	ES	Parcel	Margin	Fallow	No feature	4.5	Option description
EF13	Uncropped cultivated areas for ground-nesting birds - arable	ES	Agreement	Field	Fallow	No feature		Option description
EF4	Nectar Flower mixture	ES	Agreement	Field	Grassland Calcareous - Unimproved	Underlying LC		
EF4NR	Nectar Flower mixture (Non-rotational)	ES	Parcel	Field	Grassland Calcareous - Unimproved	Underlying LC		
EF7	Beetle banks	ES	Parcel	Transect	Ditch	Ditch (half)	3	Closest match in G2020
EF8	Skylark plots	ES	Agreement	Plot/Tree	Fallow	No feature		Option description
EF9	Cereal headlands for birds	ES	Agreement	Margin	Fallow	No feature	15	Option description
EG3	ASD to Jan 2010 Nectar flower mixture in grassland areas	ES	Parcel	Field	Grassland Calcareous - Unimproved	Underlying LC		

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (*AES_Present*)	Land Class (*AES_Absent*)	Width (*AES_Present*) (m)	Notes
EJ11	Maintenance of watercourse fencing	ES	Parcel	Perimeter	Grassy Field Margin	No feature	1	Creates grass strip
EJ5	In-field grass areas	ES	Parcel	Field	Grassy Field Margin	Underlying LC		Option description
EJ9	12m buffer strips for watercourses on cultivated land	ES	Parcel	Margin	Grassy Field Margin	No feature	12	
EK1	Take field corners out of management: outside SDA & ML	ES	Parcel	Field	Grassy Field Margin	Underlying LC		Option description
EK2	Permanent grassland with low inputs: outside SDA & ML	ES	Parcel	Field	Grassland Neutral – Unimproved	Grassland Neutral – Semi-improved		BD2302/5007
EK21	Legume- and herb-rich swards	ES	Agreement	Field	Ley - Grass and Legume	Underlying LC		Option description
EK3	Permanent grassland with very low inputs: outside SDA & ML	ES	Parcel	Field	Grassland Neutral – Unimproved	Grassland Neutral – Semi-improved		BD2302/5007
EK4	Manage rush pastures: outside SDA & ML	ES	Parcel	Field	Grassland Acid – Semi-improved	Grassland Acid – Semi-improved		BD2302/5007
EL1	Field corner management: SDA land	ES	Parcel	Field	Grassy Field Margin	Underlying LC		
EL2	Permanent in-bye grassland with low inputs: SDA land	ES	Parcel	Field	Grassland Acid – Unimproved	Grassland Acid – Semi-improved		BD2302/5007
EL3	In-bye pasture & meadows with very low inputs: SDA land	ES	Parcel	Field	Grassland Acid – Unimproved	Grassland Acid – Semi-improved		BD2302/5007
EL4	Manage rush pastures: SDA land & ML parcels under 15ha	ES	Parcel	Field	Grassland Acid – Semi-improved	Grassland Acid – Semi-improved		BD2302/5007
EL5	Enclosed rough grazing: SDA land & ML parcels under 15ha	ES	Parcel	Field	Moorland	Moorland		BD2302/5007
EL6	Moorland and rough grazing: ML land only	ES	Parcel	Field	Moorland	Moorland		BD2302/5007
GS1	Take field corners out of management	CS	Parcel	Field	Grassy Field Margin	Underlying LC		Option description
GS10	Management of wet grassland for wintering waders and wildfowl	CS	Parcel	Field	Wetland	Wetland		Equivalent to HK10

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (*AES_Present*)	Land Class (*AES_Absent*)	Width (*AES_Present*) (m)	Notes
GS11	Creation of wet grassland for breeding waders	CS	Parcel	Field	Wetland	Nearest arable crop		Equivalent to HK11
GS12	Creation of wet grassland for wintering waders and wildfowl	CS	Parcel	Field	Wetland	Nearest arable crop		Equivalent to HK12
GS13	Management of grassland for target features	CS	Parcel	Field	Grassland Calcareous – Semi-improved	Grassland Calcareous – Semi-improved		Equivalent to HK15
GS14	Creation of grassland for target features	CS	Parcel	Field	Grassland Calcareous – Semi-improved	Nearest arable crop		Equivalent to HK17
GS2	Permanent grassland with very low inputs (outside SDAs)	CS	Parcel	Field	Grassland Neutral – Unimproved	Grassland Neutral – Semi-improved		Equivalent to HK2
GS4	Legume and herb-rich swards	CS	Parcel	Field	Ley - Grass and Legume	Underlying LC		Equivalent to HK21
GS5	Permanent grassland with very low inputs in SDAs	CS	Parcel	Field	Grassland Acid – Unimproved	Grassland Acid – Semi-improved		Equivalent to HL3
GS6	Management of species-rich grassland	CS	Parcel	Field	Grassland Calcareous – Unimproved	Grassland Calcareous – Unimproved		Equivalent to HK6
GS7	Restoration towards species-rich grassland	CS	Parcel	Field	Grassland Calcareous – Semi-improved	Grassland Calcareous –Improved		Option description (not equivalent to HK7)
GS8	Creation of species-rich grassland	CS	Parcel	Field	Grassland Calcareous – Unimproved	Nearest arable crop		Equivalent to HK8
GS9	Management of wet grassland for breeding waders	CS	Parcel	Field	Wetland	Wetland		Equivalent to HK9
HAE1	Hedge	EFA	Parcel	Perimeter	Hedgerow	Hedgerow (half)	5	
HAE2	Hedge	EFA	Parcel	Perimeter	Hedgerow	Hedgerow (half)	5	
HPE1	Hedge	EFA	Parcel	Perimeter	Hedgerow	Hedgerow (half)	5	
HPE2	Hedge	EFA	Parcel	Perimeter	Hedgerow	Hedgerow (half)	5	

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (*AES_Present*)	Land Class (*AES_Absent*)	Width (*AES_Present*) (m)	Notes
HB11	Maintenance of hedges of very high environmental value (2 sides)	ES	Parcel	Perimeter	Hedgerow	Hedgerow (half)	5	
HB12	Maintenance of hedges of very high environmental value (1 side)	ES	Parcel	Perimeter	Hedgerow	Hedgerow (half)	2.5	
HB14	Management of ditches of very high environmental value	ES	Parcel	Perimeter	Ditch	Ditch (half)	2	
HC1	Protection of in-field trees on arable land	ES	Parcel	Plot/Tree	Hedgerow	Hedgerow (half)	5	
HC10	Creation of woodland outside of the SDA & ML	ES	Parcel	Field	Woodland - Afforestation	Grassland Neutral – Semi-improved		BD2302/5007
HC12	Maintenance of wood pasture and parkland	ES	Parcel	Field	Wood Pasture	Wood Pasture		BD2302/5007
HC13	Restoration of wood pasture and parkland	ES	Parcel	Field	Wood Pasture	Wood Pasture - Degraded		BD2302/5007
HC14	Creation of wood pasture	ES	Parcel	Field	Wood Pasture	Near arable crop		BD2302/5007
HC15	Maintenance of successional areas and scrub	ES	Parcel	Field	Scrub	Scrub		
HC16	Restoration of successional areas and scrub	ES	Parcel	Field	Scrub	Degraded Scrub		BD2302/5007
HC17	Creation of successional areas and scrub	ES	Parcel	Field	Scrub	Grassland Neutral – Semi-improved		BD2302/5007
HC18	Maintenance of high value traditional orchards	ES	Parcel	Field	Orchard	Orchard		BD2302/5007
HC19	Maintenance of traditional orchards in production	ES	Parcel	Field	Orchard	Orchard		BD2302/5007
HC2	Protection of in-field trees on grassland	ES	Parcel	Plot/Tree	Hedgerow	Hedgerow (half)		Treat as short hedgerow
HC20	Restoration of traditional orchards	ES	Parcel	Field	Orchard	Orchard - Degraded		BD2302/5007
HC21	Creation of traditional orchards	ES	Parcel	Field	Orchard	Grassland Neutral – Semi-improved		BD2302/5007
HC24	Hedgerow tree buffer strips on cultivated land	ES	Parcel	Perimeter	Hedgerow	Hedgerow (half)	6	

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (*AES_Present*)	Land Class (*AES_Absent*)	Width (*AES_Present*) (m)	Notes
HC25	Hedgerow tree buffer strips on grassland	ES	Parcel	Perimeter	Hedgerow	Hedgerow (half)	6	
HC4	Management of woodland edges	ES	Parcel	Perimeter	Woodland Edge	Woodland Edge	5	
HC5	Ancient trees in arable fields	ES	Parcel	Plot/Tree	Hedgerow	Hedgerow (half)		Treat as short hedgerow
HC6	Ancient trees in intensively-managed grass fields	ES	Parcel	Plot/Tree	Hedgerow	Hedgerow (half)		Treat as short hedgerow
HC7	Maintenance of woodland	ES	Parcel	Field	Woodland - Deciduous	Woodland – Deciduous		BD2302/5007
HC8	Restoration of woodland	ES	Parcel	Field	Woodland - Deciduous	Woodland – Degraded		BD2302/5007
HC9	Creation of woodland in the SDA	ES	Parcel	Field	Woodland - Deciduous	Grassland Acid – Semi-improved		BD2302/5007
HD10	Maintenance of traditional water meadows	ES	Parcel	Field	Wetland	Wetland		BD2302/5007
HD11	Restoration of traditional water meadows	ES	Parcel	Field	Wetland	Scrub		BD2302/5007
HD2	Take archaeological features out of cultivation	ES	Parcel	Field	Grassland Neutral – Semi-improved	Underlying LC		Option description
HD7	Arable reversion by natural regeneration	ES	Parcel	Field	Grassland Neutral – Semi-improved	Near arable crop		Option description
HE1	2 m buffer strips on cultivated land	ES	Parcel	Margin	Grassy Field Margin	No feature	2	
HE10	Floristically enhanced grass margin	ES	Parcel	Margin	Flower Rich Margin	No feature	6	
HE11	Enhanced strips for target species on intensive grassland	ES	Parcel	Margin	Flower Rich Margin	No feature	2	
HE2	4 m buffer strips on cultivated land	ES	Parcel	Margin	Grassy Field Margin	No feature	4	
HE3	6 m buffer strips on cultivated land	ES	Parcel	Margin	Grassy Field Margin	No feature	6	
HE4	2 m buffer strips on intensive grassland	ES	Parcel	Margin	Grassy Field Margin	No feature	2	
HE5	4 m buffer strips on intensive grassland	ES	Parcel	Margin	Grassy Field Margin	No feature	4	

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (*AES_Present*)	Land Class (*AES_Absent*)	Width (*AES_Present*) (m)	Notes
HE6	6 m buffer strips on intensive grassland	ES	Parcel	Margin	Grassy Field Margin	No feature	6	
HE7	Buffering in-field ponds in improved permanent grassland	ES	Parcel	Margin	Grassy Field Margin	No feature	10	
HE8	Buffering in-field ponds in arable land	ES	Parcel	Margin	Grassy Field Margin	No feature	10	
HF1	Management of field corners	ES	Parcel	Field	Grassy Field Margin	Underlying LC		Option description
HF10	Unharvested cereal headlands for birds and rare arable plants	ES	Agreement	Margin	Fallow	No feature	15	
HF10NR	Unharvested cereal headlands for birds and rare arable plants (Non-Rotational)	ES	Parcel	Margin	Fallow	No feature	15	
HF11	Uncropped, cultivated margins for rare plants	ES	Parcel	Margin	Fallow	No feature	4.5	
HF13	Uncropped cultivated areas for ground-nesting birds - arable	ES	Agreement	Field	Fallow	No feature		
HF13NR	Uncropped cultivated areas for ground-nesting birds - arable	ES	Parcel	Field	Fallow	No feature		
HF14	Unharvested, fertiliser-free conservation headland	ES	Agreement	Margin	Fallow	No feature	15	
HF14NR	Unharvested, fertiliser-free conservation headland	ES	Parcel	Margin	Fallow	No feature	15	
HF17	ASD to Dec 2008 Fallow plots for ground-nesting birds (setaside)	ES	Agreement	Field	Fallow	No feature		
HF19	ASD to Dec 2008 Unharvested conservation headland with setaside	ES	Agreement	Margin	Fallow	No feature	15	
HF20	Cultivated fallow plots or margins for arable plants	ES	Agreement	Margin	Fallow	No feature	4	
HF20NR	Cultivated fallow plots or margins for arable plants	ES	Parcel	Margin	Fallow	No feature	4	

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (*AES_Present*)	Land Class (*AES_Absent*)	Width (*AES_Present*) (m)	Notes
HF4	Nectar flower mixture	ES	Agreement	Field	Flower Rich Margin	No feature		
HF4NR	Nectar flower mixture	ES	Parcel	Field	Flower Rich Margin	No feature		
HF7	Beetle banks	ES	Parcel	Transect	Ditch	No feature	3	Closest match in G2020
HF8	Skylark plots	ES	Agreement	Plot/Tree	Fallow	No feature		
HF9	Cereal headlands for birds	ES	Agreement	Margin	Fallow	No feature	15	
HF9NR	Cereal headlands for birds	ES	Parcel	Margin	Fallow	No feature	15	
HG3	ASD to Jan 2010 Nectar flower mixture in grassland areas	ES	Parcel	Field	Flower Rich Margin	Underlying LC		Option description
HJ11	Maintenance of watercourse fencing	ES	Parcel	Perimeter	Grassy Field Margin	No feature	1	
HJ3	Reversion to unfertilised grassland to prevent erosion/run-off	ES	Parcel	Field	Grassland Neutral – Unimproved	Nearest arable crop		BD2302/5007
HJ4	Reversion to low input grassland to prevent erosion/run-off	ES	Parcel	Field	Grassland Neutral – Semi-improved	Nearest arable crop		BD2302/5007
HJ5	In-field grass areas to prevent erosion or run-off	ES	Parcel	Field	Grassy Field Margin	Underlying LC		Option description
HJ9	12 m buffer strips for watercourses on cultivated land	ES	Parcel	Margin	Grassy Field Margin	No feature	12	
HK1	Take field corners out of management	ES	Parcel	Field	Grassy Field Margin	Underlying LC		Option description
HK10	Maintenance of wet grassland for wintering waders and wildfowl	ES	Parcel	Field	Wetland	Wetland		BD2302/5007
HK11	Restoration of wet grassland for breeding waders	ES	Parcel	Field	Wetland	Grassland Neutral – Semi-improved		BD2302/5007
HK12	Restoration of wet grassland for wintering waders and wildfowl	ES	Parcel	Field	Wetland	Grassland Neutral – Semi-improved		BD2302/5007
HK13	Creation of wet grassland for breeding waders	ES	Parcel	Field	Wetland	Nearest arable crop		BD2302/5007

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (*AES_Present*)	Land Class (*AES_Absent*)	Width (*AES_Present*) (m)	Notes
HK14	Creation of wet grassland for wintering waders and wildfowl	ES	Parcel	Field	Wetland	Nearest arable crop		BD2302/5007
HK15	Maintenance of grassland for target features	ES	Parcel	Field	Grassland Calcareous – Semi-improved	Grassland Calcareous – Semi-improved		BD2302/5007
HK16	Restoration of grassland for target features	ES	Parcel	Field	Grassland Calcareous – Semi-improved	Grassland Calcareous – Semi-improved		BD2302/5007
HK17	Creation of grassland for target features	ES	Parcel	Field	Grassland Calcareous – Semi-improved	Nearest arable crop		BD2302/5007
HK2	Permanent grassland with low inputs	ES	Parcel	Field	Grassland Neutral – Unimproved	Grassland Neutral – Semi-improved		BD2302/5007
HK21	Legume- and herb-rich swards	ES	Agreement	Field	Ley - Grass and Legume	Underlying LC		Option description
HK3	Permanent grassland with very low inputs	ES	Parcel	Field	Grassland Neutral – Unimproved	Grassland Neutral – Semi-improved		BD2302/5007
HK4	Management of rush pastures	ES	Parcel	Field	Grassland Acid – Semi-improved	Grassland Acid – Semi-improved		BD2302/5007
HK6	Maintenance of species-rich, semi-natural grassland	ES	Parcel	Field	Grassland Calcareous – Unimproved	Grassland Calcareous – Unimproved		BD2302/5007
HK7	Restoration of species-rich, semi-natural grassland	ES	Parcel	Field	Grassland Calcareous – Unimproved	Grassland Calcareous – Semi-improved		BD2302/5007
HK8	Creation of species-rich, semi-natural grassland	ES	Parcel	Field	Grassland Calcareous – Unimproved	Nearest arable crop		BD2302/5007
HK9	Maintenance of wet grassland for breeding waders	ES	Parcel	Field	Wetlands	Wetlands		BD2302/5007
HL1	Take field corners out of management in SDAs	ES	Parcel	Field	Grassy Field Margin	Underlying LC		Option description
HL10	Restoration of moorland	ES	Parcel	Field	Moorland	Moorland - Degraded		BD2302/5007
HL11	Creation of upland heathland	ES	Parcel	Field	Moorland	Moorland - Degraded		BD2302/5007

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (*AES_Present*)	Land Class (*AES_Absent*)	Width (*AES_Present*) (m)	Notes
HL12	Management of heather, gorse and grass	ES	Parcel	Field	Moorland	Moorland		BD2302/5007
HL2	Permanent grassland with low inputs in SDAs	ES	Parcel	Field	Grassland Acid – Unimproved	Grassland Acid – Semi-improved		BD2302/5007
HL3	Permanent grassland with very low inputs in SDAs	ES	Parcel	Field	Grassland Acid – Unimproved	Grassland Acid – Semi-improved		BD2302/5007
HL4	Management of rush pastures in SDAs	ES	Parcel	Field	Grassland Acid – Semi-improved	Grassland Acid – Semi-improved		BD2302/5007
HL5	Enclosed rough grazing	ES	Parcel	Field	Moorland	Moorland		BD2302/5007
HL6	Unenclosed moorland rough grazing	ES	Parcel	Field	Moorland	Moorland		BD2302/5007
HL7	Maintenance of rough grazing for birds	ES	Parcel	Field	Moorland	Moorland		BD2302/5007
HL8	Restoration of rough grazing for birds	ES	Parcel	Field	Moorland	Moorland - Degraded		BD2302/5007
HL9	Maintenance of moorland	ES	Parcel	Field	Moorland	Moorland		BD2302/5007
HO1	Maintenance of lowland heathland	ES	Parcel	Field	Moorland	Moorland		BD2302/5007
HO2	Restoration of lowland heath	ES	Parcel	Field	Moorland	Scrub		BD2302/5007
HO3	Restoration of forestry areas to lowland heathland	ES	Parcel	Field	Moorland	Nearest woodland LC		Option description
HO4	Creation of lowland heathland from arable or improved grassland	ES	Parcel	Field	Moorland	Nearest arable or improved grassland LC		Option description
HO5	Creation of lowland heathland on worked mineral sites	ES	Parcel	Field	Moorland	Urban		Option description
HP1	Maintenance of sand dunes	ES	Parcel	Field	Beaches, Sand Dune/Plane	Beaches, Sand Dune/Plane		BD2302/5007
HP2	Restoration of sand dune systems	ES	Parcel	Field	Beaches, Sand Dune/Plane	Beaches, Sand Dune/Plane		BD2302/5007
HP4	Creation of vegetated shingle and sand dune on grassland	ES	Parcel	Field	Beaches, Sand Dune/Plane	Grassland Neutral – Semi-improved		BD2302/5007

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (*AES_Present*)	Land Class (*AES_Absent*)	Width (*AES_Present*) (m)	Notes
HP5	Maintenance of coastal saltmarsh	ES	Parcel	Field	Saltmarsh	Saltmarsh		BD2302/5007
HP6	Restoration of coastal saltmarsh	ES	Parcel	Field	Saltmarsh	Grassland Neutral – Semi-improved		BD2302/5007
HP7	Creation of inter-tidal and saline habitat on arable land	ES	Parcel	Field	Saltmarsh	Nearest arable LC		BD2302/5007
HP8	Creation of inter-tidal and saline habitat on grassland	ES	Parcel	Field	Saltmarsh	Grassland Neutral – Semi-improved		BD2302/5007
HP9	Creation of inter-tidal and saline habitat by non-intervention	ES	Parcel	Field	Saltmarsh	Grassland Neutral – Unimproved		BD2302/5007
HQ10	Restoration of lowland raised bog	ES	Parcel	Field	Wetland	Scrub		BD2302/5007
HQ3	Maintenance of reedbeds	ES	Parcel	Field	Wetland	Wetland		BD2302/5007
HQ4	Restoration of reedbeds	ES	Parcel	Field	Wetland	Wetland - Degraded		BD2302/5007
HQ5	Creation of reedbeds	ES	Parcel	Field	Wetland	Nearest arable LC		BD2302/5007
HQ6	Maintenance of fen	ES	Parcel	Field	Wetland	Wetland		BD2302/5007
HQ7	Restoration of fen	ES	Parcel	Field	Wetland	Scrub		BD2302/5007
HQ8	Creation of fen	ES	Parcel	Field	Wetland	Nearest arable LC		BD2302/5007
HQ9	Maintenance of lowland raised bog	ES	Parcel	Field	Wetland	Wetland		BD2302/5007
HS7	Management of historic water meadows through traditional irrigation	ES	Parcel	Field	Wetland	Wetland		BD2302/5007
LH1	Management of lowland heathland	CS	Parcel	Field	Moorland	Moorland		Equivalent to HO1
LH2	Restoration of forestry and woodland to lowland heathland	CS	Parcel	Field	Moorland	Nearest woodland LC		Equivalent to HO3
LH3	Creation of heathland from arable or improved grassland	CS	Parcel	Field	Moorland	Nearest arable or improved grassland LC		Equivalent to HO4

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (*AES_Present*)	Land Class (*AES_Absent*)	Width (*AES_Present*) (m)	Notes
OB1	Hedgerow management for landscape (on both sides of a hedge)	ES	Agreement	Perimeter	Hedgerow	Hedgerow (half)	5	
OB10	Combined hedge and ditch management (incorporating OB3)	ES	Agreement	Perimeter	Hedgerow	Hedgerow (half)	5	
OB11	Stonewall protection and maintenance	ES	Agreement	Perimeter	Ditch	Ditch (half)	2	Nearest match to G2020
OB12	Earth bank management (on both sides)	ES	Agreement	Perimeter	Ditch	Ditch (half)	2	Nearest match to G2020
OB13	Earth bank management (on one side)	ES	Agreement	Perimeter	Ditch	Ditch (half)	1	Nearest match to G2020
OB14	Hedgerow restoration	ES	Agreement	Perimeter	Hedgerow	Hedgerow (half)	5	
OB2	Hedgerow management for landscape (on one side of a hedge)	ES	Agreement	Perimeter	Hedgerow	Hedgerow (half)	5	
OB3	Hedgerow management for landscape and wildlife	ES	Agreement	Perimeter	Hedgerow	Hedgerow (half)	5	
OB4	Stone faced Hedge bank management on both sides	ES	Agreement	Perimeter	Ditch	Ditch (half)	2	Nearest match to G2020
OB5	Stone faced Hedge bank management on one side	ES	Agreement	Perimeter	Ditch	Ditch (half)	1	Nearest match to G2020
OB6	Ditch management	ES	Agreement	Perimeter	Ditch	Ditch (half)	2	
OB7	Half ditch management	ES	Agreement	Perimeter	Ditch	Ditch (half)	2	
OB8	Combined hedge and ditch management (incorporating OB1)	ES	Agreement	Perimeter	Hedgerow	Hedgerow (half)	5	
OB9	Combined hedge and ditch management (incorporating OB2)	ES	Agreement	Perimeter	Hedgerow	Hedgerow (half)	2.5	
OC1	Protection of in field trees - rotational land	ES	Parcel	Plot/Tree	Hedgerow	Hedgerow (half)		

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (*AES_Present*)	Land Class (*AES_Absent*)	Width (*AES_Present*) (m)	Notes
OC2	Protection of in field trees - grassland	ES	Parcel	Plot/Tree	Hedgerow	Hedgerow (half)		
OC24	Hedgerow tree buffer strips on rotational land	ES	Parcel	Margin	Hedgerow	Hedgerow (half)	6	Option description
OC25	Hedgerow tree buffer strips on organic grassland	ES	Parcel	Margin	Hedgerow	Hedgerow (half)	6	Option description
OC3	Maintenance of woodland fences	ES	Agreement	Perimeter	Woodland Edge	Woodland Edge (half)		Creates an un-grazed woodland edge
OC4	Management of wood edges	ES	Parcel	Perimeter	Woodland Edge	Woodland Edge (half)	5	
OD2	Take archaeological features out of cultivation	ES	Parcel	Field	Grassland Neutral – Semi-improved	Underlying LC		Option description
OE1	2m buffer strips on rotational land	ES	Parcel	Margin	Grassy Field Margin	No feature	2	
OE10	6m buffer strip on organic grassland next to a watercourse	ES	Parcel	Margin	Grassy Field Margin	No feature	6	
OE2	4m buffer strips on rotational land	ES	Parcel	Margin	Grassy Field Margin	No feature	4	
OE3	6m buffer strips on rotational land	ES	Parcel	Margin	Grassy Field Margin	No feature	6	
OE4	2m buffer strip on organic grassland	ES	Parcel	Margin	Grassy Field Margin	No feature	2	
OE5	4m buffer strip on organic grassland	ES	Parcel	Margin	Grassy Field Margin	No feature	4	
OE6	6m buffer strip on organic grassland	ES	Parcel	Margin	Grassy Field Margin	No feature	6	
OE7	Buffering in-field ponds in organic grassland	ES	Parcel	Margin	Grassy Field Margin	No feature	10	Option description
OE8	Buffering in-field ponds in rotational land	ES	Parcel	Margin	Grassy Field Margin	No feature	10	Option description
OE9	6m buffer strips on rotational land next to a watercourse	ES	Parcel	Margin	Grassy Field Margin	No feature	6	
OF1	Field corner management	ES	Parcel	Field	Grassy Field Margin	Underlying LC		Option description
OF11	Uncropped, cultivated margins for rare plants on arable land	ES	Parcel	Margin	Fallow	No feature	4.5	Option description

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (*AES_Present*)	Land Class (*AES_Absent*)	Width (*AES_Present*) (m)	Notes
OF13	Uncropped cultivated areas for ground-nesting birds - rotational	ES	Agreement	Field	Fallow	No feature		Option description
OF4	Nectar Flower mixture	ES	Agreement	Field	Flower Rich Margin	Underlying LC		Option description
OF4NR	Nectar Flower mixture	ES	Parcel	Field	Flower Rich Margin	Underlying LC		Option description
OF7	Beetle banks	ES	Parcel	Transect	Ditch	No feature	3	Closest match in G2020
OF8	Skylark plots	ES	Agreement	Plot/Tree	Fallow	No feature		Option description
OG3	ASD to Jan 2010 Nectar flower mixture in grassland areas	ES	Parcel	Field	Flower Rich Margin	Underlying LC		Option description
OHC1	Protection of in-field trees on rotational land	ES	Parcel	Plot/Tree	Hedgerow	Hedgerow (half)		
OHC2	Protection of in-field trees on organic grassland	ES	Parcel	Plot/Tree	Hedgerow	Hedgerow (half)		
OHC24	Hedgerow tree buffer strips on rotational land	ES	Parcel	Margin	Hedgerow	Hedgerow (half)	6	
OHC4	Management of woodland edges	ES	Parcel	Perimeter	Woodland Edge	Woodland Edge (half)	5	
OHD2	Take archaeological features out of cultivation (Org)	ES	Parcel	Field	Grassland Neutral – Semi-improved	Underlying LC		Option description
OHE1	2m buffer strips on rotational land	ES	Parcel	Margin	Grassy Field Margin	No feature	2	
OHE2	4m buffer strips on rotational land	ES	Parcel	Margin	Grassy Field Margin	No feature	4	
OHE3	6m buffer strips on rotational land	ES	Parcel	Margin	Grassy Field Margin	No feature	6	
OHE4	2m buffer strip on organic grassland	ES	Parcel	Margin	Grassy Field Margin	No feature	2	
OHE5	4m buffer strip on organic grassland	ES	Parcel	Margin	Grassy Field Margin	No feature	4	
OHE6	6m buffer strip on organic grassland	ES	Parcel	Margin	Grassy Field Margin	No feature	6	
OHE7	Buffering in-field ponds in organic grassland	ES	Parcel	Margin	Grassy Field Margin	No feature	10	
OHE8	Buffering in-field ponds in rotational land	ES	Parcel	Margin	Grassy Field Margin	No feature	10	

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (*AES_Present*)	Land Class (*AES_Absent*)	Width (*AES_Present*) (m)	Notes
OHF1	Management of field corners	ES	Parcel	Field	Grassy Field Margin	Underlying LC		Option description
OHF11	Uncropped, cultivated margins for rare plants	ES	Parcel	Margin	Fallow	No feature	4.5	Option description
OHF13	Uncropped, cultivated areas for ground-nesting birds	ES	Agreement	Field	Fallow	No feature		Option description
OHF13NR	Uncropped, cultivated areas for ground-nesting birds	ES	Parcel	Field	Fallow	No feature		Option description
OHF4	Nectar Flower mixture	ES	Agreement	Field	Flower Rich Margin	Underlying LC		Option description
OHF4NR	Nectar Flower mixture	ES	Parcel	Field	Flower Rich Margin	Underlying LC		Option description
OHF7	Beetle banks	ES	Parcel	Transect	Ditch	No feature	3	Closest match in G2020
OHF8	Skylark plots	ES	Agreement	Plot/Tree	Fallow	No feature		Option description
OHG3	ASD to Jan 2010 Nectar flower mixture in grassland areas	ES	Parcel	Field	Flower Rich Margin	Underlying LC		Option description
OHJ11	Maintenance of watercourse fencing	ES	Parcel	Perimeter	Grassy Field Margin	No feature	1	Narrow strip
OHJ5	In-field grass areas to prevent erosion and run-off	ES	Parcel	Field	Grassy Field Margin	Underlying LC		Option description
OHJ9	12 m buffer strips for watercourses on rotational land	ES	Parcel	Margin	Grassy Field Margin	No feature	12	
OHK1	Take field corners out of management	ES	Parcel	Field	Grassy Field Margin	Underlying LC		Option description
OHK2	Permanent grassland with low inputs	ES	Parcel	Field	Grassland Neutral – Unimproved	Grassland Neutral – Semi-improved		BD2302/5007
OHK21	Legume- and herb-rich swards	ES	Agreement	Field	Ley - Grass and Legume	Underlying LC		Option description
OHK3	Permanent grassland with very low inputs	ES	Parcel	Field	Grassland Neutral – Unimproved	Grassland Neutral – Semi-improved		BD2302/5007
OHK4	Management of rush pastures	ES	Parcel	Field	Grassland Acid – Semi-improved	Grassland Acid – Semi-improved		BD2302/5007

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (*AES_Present*)	Land Class (*AES_Absent*)	Width (*AES_Present*) (m)	Notes
OHL2	Permanent grassland with low inputs in SDAs	ES	Parcel	Field	Grassland Acid – Unimproved	Grassland Acid – Semi-improved		BD2302/5007
OHL3	Permanent grassland with very low inputs in SDAs	ES	Parcel	Field	Grassland Acid – Unimproved	Grassland Acid – Semi-improved		BD2302/5007
OHL4	Management of rush pastures in SDAs	ES	Parcel	Field	Grassland Acid – Semi-improved	Grassland Acid – Semi-improved		BD2302/5007
OHL5	Enclosed rough grazing	ES	Parcel	Field	Moorland	Moorland		BD2302/5007
OJ11	Maintenance of watercourse fencing	ES	Agreement	Margin	Grassy Field Margin	No feature	1	Narrow strip
OJ5	In-field grass areas to prevent erosion and run-off	ES	Parcel	Field	Grassy Field Margin	No feature		
OJ9	12m buffer strips for watercourses on cultivated land	ES	Parcel	Field	Grassy Field Margin	No feature	12	
OK1	Take field corners out of management: outside SDA & ML (organic)	ES	Parcel	Field	Grassy Field Margin	No feature		
OK2	Permanent grassland with low inputs: outside SDA & ML (organic)	ES	Parcel	Field	Grassland Neutral – Unimproved	Grassland Neutral – Semi-improved		BD2302/5007
OK21	Legume- and herb-rich swards	ES	Agreement	Field	Ley - Grass and Legume	Underlying LC		Option description
OK3	Permanent grassland with very low inputs:outside SDA&ML (organic)	ES	Parcel	Field	Grassland Neutral – Unimproved	Grassland Neutral – Semi-improved		BD2302/5007
OK4	Manage rush pastures: outside SDA & ML (organic)	ES	Parcel	Field	Grassland Acid – Semi-improved	Grassland Acid – Semi-improved		BD2302/5007
OL1	Field corner management: SDA land (organic)	ES	Parcel	Field	Grassy Field Margin	Underlying LC		Option description
OL2	Permanent in-bye grassland with low inputs: SDA land (organic)	ES	Parcel	Field	Grassland Acid – Unimproved	Grassland Acid – Semi-improved		BD2302/5007
OL3	In-bye pasture & meadows with very low inputs: SDA land (organic)	ES	Parcel	Field	Grassland Acid – Unimproved	Grassland Acid – Semi-improved		BD2302/5007

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (***AES_Present***)	Land Class (***AES_Absent***)	Width (***AES_Present***) (m)	Notes
OL4	Manage rush pastures: SDA land & ML parcels under 15ha (organic)	ES	Parcel	Field	Grassland Acid – Semi-improved	Grassland Acid – Semi-improved		BD2302/5007
OL5	Enclosed rough grazing:SDA land & ML parcels under 15ha (organic)	ES	Parcel	Field	Moorland	Moorland		BD2302/5007
OP4	Multi species ley	CS	Parcel	Field	Ley – Organic	Underlying LC		Option description
OR1	Organic conversion - improved permanent grassland	CS	Parcel	Field	Grassland Neutral – Improved	Grassland Neutral – Improved		Option description
OR2	Organic conversion - unimproved permanent grassland	CS	Parcel	Field	Grassland Neutral – Unimproved	Grassland Neutral – Unimproved		Option description
OR3	Organic conversion - rotational land	CS	Parcel	Field	Cereal – Organic	Cereal		Option description
OT3	Organic land management - rotational land	CS	Agreement	Field	Cereal – Organic	Cereal		Option description
PG02	Permanent grassland buffer strip	EFA	Parcel	Margin	Grassy Field Margin	No feature		
RD01	Non-Agricultural Land Under Rural Development Programme	Other	Parcel	Field	Woodland - Deciduous	Woodland - Deciduous		Assumed to be woodland in other equivalent schemes (see text)
SW1	4 - 6 m buffer strip on cultivated land	CS	Parcel	Margin	Grassy Field Margin	No feature	5	
SW11	Riparian management strip	CS	Parcel	Margin	Grassy Field Margin	No feature	8	
SW2	4 - 6 m buffer strip on intensive grassland	CS	Parcel	Margin	Grassy Field Margin	No feature	5	
SW3	In-field grass strips	CS	Parcel	Field	Grassy Field Margin	No feature		
SW4	12 - 24m watercourse buffer strip on cultivated land	CS	Parcel	Margin	Grassy Field Margin	No feature	18	
SW7	Arable reversion to grassland with low fertiliser input	CS	Parcel	Field	Grassland Neutral – Semi-improved	Near arable LC		Option description
UB11	Stone wall protection and maintenance on/above the moorland line	ES	Agreement	Perimeter	Ditch	Ditch (half)	2	Nearest match to G2020

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (*AES_Present*)	Land Class (*AES_Absent*)	Width (*AES_Present*) (m)	Notes
UB12	Earth bank management (both sides) on/above the moorland line	ES	Agreement	Perimeter	Ditch	Ditch (half)	2	Nearest match to G2020
UB13	Earth bank management (one side) on/above the moorland line	ES	Agreement	Perimeter	Ditch	Ditch (half)	1	Nearest match to G2020
UB14	Hedgerow restoration	ES	Agreement	Perimeter	Hedgerow	Hedgerow (half)	5	
UB15	Stone-faced hedgebank restoration	ES	Agreement	Perimeter	Ditch	Ditch (half)	2	Nearest match to G2020
UB16	Earth bank restoration	ES	Agreement	Perimeter	Ditch	Ditch (half)	2	Nearest match to G2020
UB17	Stone wall restoration	ES	Agreement	Perimeter	Ditch	Ditch (half)	2	Nearest match to G2020
UB4	Stone-faced hedgebank management (both sides) on/above ML	ES	Agreement	Perimeter	Ditch	Ditch (half)	2	Nearest match to G2020
UB5	Stone-faced hedgebank management (one side) on/above ML	ES	Agreement	Perimeter	Ditch	Ditch (half)	1	Nearest match to G2020
UC5	Sheep fencing around small woodlands	ES	Agreement	Perimeter	Woodland Edge	Woodland Edge (half)	5	Creates un-grazed woodland edge
UHL21	No cutting strip within meadows	ES	Parcel	Field	Grassy Field Margin			
UHL23	Management of upland grassland for birds	ES	Parcel	Field	Grassland Acid – Unimproved	Grassland Acid – Unimproved		Option description
UL21	No cutting strip within meadows	ES	Parcel	Field	Grassy Field Margin	Underlying LC		Option description
UL22	Management of enclosed rough grazing for birds	ES	Parcel	Field	Moorland	Moorland		Option description
UL23	Management of upland grassland for birds	ES	Parcel	Field	Grassland Acid – Unimproved	Grassland Acid – Unimproved		Option description
UOB11	Stone wall protection and maintenance on/above the moorland line	ES	Agreement	Perimeter	Ditch	Ditch (half)	2	Nearest match to G2020

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (*AES_Present*)	Land Class (*AES_Absent*)	Width (*AES_Present*) (m)	Notes
UOB12	Earth bank management (both sides) on/above the moorland line	ES	Agreement	Perimeter	Ditch	Ditch (half)	2	Nearest match to G2020
UOB14	Hedgerow restoration	ES	Agreement	Perimeter	Hedgerow	Hedgerow (half)	5	
UOB15	Stone-faced hedgebank restoration	ES	Agreement	Perimeter	Ditch	Ditch (half)	2	Nearest match to G2020
UOB16	Earth bank restoration	ES	Agreement	Perimeter	Ditch	Ditch (half)	2	Nearest match to G2020
UOB17	Stone wall restoration	ES	Agreement	Perimeter	Ditch	Ditch (half)	2	Nearest match to G2020
UOB4	Stone-faced hedgebank management (both sides) on/above ML	ES	Agreement	Perimeter	Ditch	Ditch (half)	2	Nearest match to G2020r
UOB5	Stone-faced hedgebank management (one side) on/above ML	ES	Agreement	Perimeter	Ditch	Ditch (half)	1	Nearest match to G2020
UOC5	Sheep fencing around small woodlands	ES	Agreement	Perimeter	Woodland Edge	Woodland Edge (half)	5	Creates un-grazed woodland edge
UOJ3	Post and wire fencing along watercourses	ES	Agreement	Perimeter	Grassy Field Margin	No feature	1	Creates un-grazed strip
UOL21	No cutting strip within meadows	ES	Parcel	Field	Grassy Field Margin	Underlying LC		Option description
UOL22	Management of enclosed rough grazing for birds	ES	Parcel	Field	Moorland	Moorland		Option description
UOL23	Management of upland grassland for birds	ES	Parcel	Field	Grassland Acid – Unimproved	Grassland Acid – Unimproved		Option description
UOX2	Grassland and arable	ES	Parcel	Field	Grassland Acid – Unimproved	Grassland Acid – Unimproved		Option description
UOX3	Moorland	ES	Parcel	Field	Moorland	Moorland		Option description
UP1	Enclosed rough grazing	ES	Parcel	Field	Moorland	Moorland		Option description

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (*AES_Present*)	Land Class (*AES_Absent*)	Width (*AES_Present*) (m)	Notes
UP2	Management of rough grazing for birds	ES	Parcel	Field	Moorland	Moorland		Option description
UP3	Management of moorland	ES	Parcel	Field	Moorland	Moorland		Option description
UX2	Grassland and arable	ES	Parcel	Field	Grassland Acid – Unimproved	Grassland Acid – Unimproved		Option description
UX3	Moorland	ES	Parcel	Field	Moorland	Moorland		Option description
WD1	Woodland creation – maintenance payments	CS	Parcel	Field	Afforestation	Grassland Neutral – Semi-improved		Equivalent to HC10
WD2	Woodland improvement	CS	Parcel	Field	Woodland – Deciduous	Woodland - Degraded		Equivalent to HC8
WD3	Woodland edges on arable land	CS	Parcel	Perimeter	Woodland Edge	Woodland Edge (half)	5	Option description
WD4	Management of wood pasture and parkland	CS	Parcel	Field	Wood Pasture	Wood Pasture		Equivalent to HC12
WD5	Restoration of wood pasture and parkland	CS	Parcel	Field	Wood Pasture	Wood Pasture - Degraded		Equivalent to HC13
WD6	Creation of wood pasture	CS	Parcel	Field	Wood Pasture	Near arable LC		Equivalent to HC14
WD7	Management of successional areas and scrub	CS	Parcel	Field	Scrub	Scrub		Equivalent to HC15
WD8	Creation of successional areas and scrub	CS	Parcel	Field	Scrub	Grassland Neutral – Semi-improved		Equivalent to HC17
WT1	Buffering in-field ponds and ditches in improved grassland	CS	Parcel	Margin	Grassy Field Margin	No feature	15	
WT10	Management of lowland raised bog	CS	Parcel	Field	Wetland	Wetland		Equivalent to HQ9
WT2	Buffering in-field ponds and ditches in arable land	CS	Parcel	Margin	Grassy Field Margin	No feature	15	
WT3	Management of ditches of high environmental value	CS	Parcel	Perimeter	Ditch	Ditch (half)	2	Nearest match to G2020
WT6	Management of reedbed	CS	Parcel	Field	Wetland	Wetland		Equivalent to HQ3
WT7	Creation of reedbed	CS	Parcel	Field	Wetland	Near arable LC		Equivalent to HQ5

Option Code	Option Description	Scheme	Option Level	Feature Type	Land Class (*AES_Present*)	Land Class (*AES_Absent*)	Width (*AES_Present*) (m)	Notes
WT8	Management of fen	CS	Parcel	Field	Wetland	Wetland		Equivalent to HQ6
WT9	Creation of fen	CS	Parcel	Field	Wetland	Near arable LC		Equivalent to HQ8

Table S5: Management Options Excluded from Analysis

Option Code	Option Description	Scheme	Reason for exclusion
A13	Non payment option - permanent grassland for Article 13	ES	No impact on land use
AB2	Basic overwinter stubble	CS	Impact on land cover outside season considered in model
AB6	Enhanced overwinter stubble	CS	Impact on land cover outside season considered in model
AB7	Wholecrop cereals	CS	No impact on floral or nesting resources
AB9	Winter bird food	CS	Impact on land cover outside season considered in model
AB12	Supplementary winter feeding for farmland birds	CS	Impact on land cover outside season considered in model
AB13	Brassica fodder crop	CS	No impact on floral or nesting resources
AB14	Harvested low input cereal	CS	No impact on floral or nesting resources
EA1	Farm Environment Record (FER)	ES	No impact on land use
ED1	Educational Access	CS	No impact on floral or nesting resources
ED1	Maintenance of traditional farm buildings	ES	No impact on floral or nesting resources

Option Code	Option Description	Scheme	Reason for exclusion
ED3	Low depth, non-inversion cultivation on archaeological features	ES	No impact on floral or nesting resources
ED4	Management of scrub on archaeological features	ES	No impact on floral or nesting resources
ED5	Management of archaeological features on grassland	ES	No impact on floral or nesting resources
EF2	Wild bird seed mixture	ES	Impact on land cover outside season considered in model
EF2NR	Wild bird seed mixture (Non-Rotational)	ES	Impact on land cover outside season considered in model
EF3	ASD to Dec 2008 Wild bird seed mixture on set-aside land	ES	Impact on land cover outside season considered in model
EF6	Over-wintered stubbles	ES	Impact on land cover outside season considered in model
EG2	ASD to Jan 2010 Wild bird seed mixture in grassland areas	ES	Impact on land cover outside season considered in model
EG2NR	ASD to Jan 2010 Wild bird seed mixture in grassland areas (Non-Rotational)	ES	Impact on land cover outside season considered in model
EJ1	Management of high erosion risk cultivated land	ES	Impact on land cover outside season considered in model
EK5	Mixed stocking	ES	Impact on land cover outside season considered in model
GS15	Haymaking supplement	CS	Supplements were excluded
GS16	Rush infestation control supplement	CS	Supplements were excluded
GS17	Lenient grazing supplement	CS	Supplements were excluded
HD1	Maintenance of weatherproof traditional farm buildings	ES	No impact on floral or nesting resources
HD3	Low depth, non-inversion cultivation on archaeological features	ES	No impact on floral or nesting resources
HD4	Management of scrub on archaeological features	ES	No impact on floral or nesting resources
HD5	Management of archaeological features on grassland	ES	No impact on floral or nesting resources
HD6	Crop establishment by direct drilling (non-rotational)	ES	No impact on floral or nesting resources
HD8	Maintaining high water levels to protect archaeology	ES	No impact on floral or nesting resources
HD9	Maintenance of designed/engineered water bodies	ES	No impact on floral or nesting resources

Option Code	Option Description	Scheme	Reason for exclusion
HF12	Enhanced wild bird seed mix plots	ES	Impact on land cover outside season considered in model
HF12NR	Enhanced wild bird seed mix plots (Non-Rotational)	ES	Impact on land cover outside season considered in model
HF2	Wild bird seed mixture	ES	Impact on land cover outside season considered in model
HF2NR	Wild bird seed mixture	ES	Impact on land cover outside season considered in model
HF3	ASD to Dec 2008 Wild bird seed mixture on set-aside land	ES	Impact on land cover outside season considered in model
HF6	Overwintered stubble	ES	Impact on land cover outside season considered in model
HG2	ASD to Jan 2010 Wild bird seed mixture	ES	Impact on land cover outside season considered in model
HG2NR	ASD to Jan 2010 Wild bird seed mixture	ES	Impact on land cover outside season considered in model
HG6	Fodder crop management to retain or re-create an arable mosaic	ES	No impact on floral or nesting resources
HG6NR	Fodder crop management to retain or re-create an arable mosaic	ES	No impact on floral or nesting resources
HIOS1	Landscape management	ES	Applicable only to Isles of Scilly
HIOS2	Management of rare arable bulb/flora	ES	Applicable only to Isles of Scilly
HIOS3	Reintroduction of conservation grazing to St Mary's	ES	Applicable only to Isles of Scilly
HIOS4	Reintroduction of conservation grazing other than St Mary's	ES	Applicable only to Isles of Scilly
HJ1	Cropping restrictions on high erosion risk fields	ES	No impact on floral or nesting resources
HJ8	Nil fertiliser supplement	ES	Supplements were excluded
HK19	Raised water levels supplement	ES	Supplements were excluded
HK5	Mixed stocking	ES	No impact on floral or nesting resources
HL13	Moorland re-wetting supplement	ES	Supplements were excluded
HL16	Shepherding supplement	ES	Supplements were excluded
HN1	ASD to Nov 2010 Linear and open access base payment	ES	No impact on floral or nesting resources
HN2	ASD to Nov 2010 Permissive open access	ES	No impact on floral or nesting resources

Option Code	Option Description	Scheme	Reason for exclusion
HN3	ASD to Nov 2010 Permissive footpath access	ES	No impact on floral or nesting resources
HN4	ASD to Nov 2010 Permissive bridleway / cycle path access	ES	No impact on floral or nesting resources
HN5	ASD to Nov 2010 Access for people with reduced mobility	ES	No impact on floral or nesting resources
HN6	ASD to Nov 2010 Upgrading access for cyclists/horses	ES	No impact on floral or nesting resources
HN7	ASD to Nov 2010 Upgrading access - people with reduced mobility	ES	No impact on floral or nesting resources
HN8	Educational access - base payment	ES	No impact on floral or nesting resources
HN8CW	Educational access - base payment	ES	No impact on floral or nesting resources
HN9	Educational access - payment per visit	ES	No impact on floral or nesting resources
HN9CW	Educational access - payment per visit	ES	No impact on floral or nesting resources
HR1	Grazing supplement for cattle	ES	Supplements were excluded
HR2	Grazing supplement for native breeds at risk	ES	Supplements were excluded
HR4	Supplement for control of invasive plant species	ES	Supplements were excluded
HR5	Bracken control supplement	ES	Supplements were excluded
HR6	Supplement for small fields	ES	Supplements were excluded
HR7	Supplement for difficult sites	ES	Supplements were excluded
HR8	Supplement for group applications	ES	Supplements were excluded
HR8WF	Supplement for group applications	ES	Supplements were excluded
HS1	Maintenance of weatherproof traditional farm buildings	CS	No impact on floral or nesting resources
HS3	Reduced-depth, non-inversion cultivation on historic and archaeological features	CS	No impact on floral or nesting resources
HS4	Scrub control on historic and archaeological features	CS	No impact on floral or nesting resources
HS5	Management of historic and archaeological features on grassland	CS	No impact on floral or nesting resources

Option Code	Option Description	Scheme	Reason for exclusion
HS6	Maintenance of designed/engineered water bodies	CS	No impact on floral or nesting resources
HS7	Management of historic water meadows through traditional irrigation	CS	No impact on floral or nesting resources
HS8	Maintenance of weatherproof traditional farm buildings in remote areas	CS	No impact on floral or nesting resources
HS9	Restricted depth crop establishment to protect archaeology under an arable rotation	CS	No impact on floral or nesting resources
OA1	Farm Environment Record (FER)	ES	No impact on land use
OD1	Maintenance of traditional farm buildings	ES	No impact on floral or nesting resources
OD3	Low depth, non-inversion cultivation on archaeological features	ES	No impact on floral or nesting resources
OD4	Management of scrub on archaeological features	ES	No impact on floral or nesting resources
OD5	Management of archaeological features on grassland	ES	No impact on floral or nesting resources
OF2	Wild bird seed mixture	ES	Impact on land cover outside season considered in model
OF2NR	Wild bird seed mixture	ES	Impact on land cover outside season considered in model
OF6	Over-wintered stubbles	ES	Impact on land cover outside season considered in model
OH1	Otter holt - log construction	ES	No impact on floral or nesting resources
OH2	Otter holt - concrete pipe & chamber construction	ES	No impact on floral or nesting resources
OHD1	Maintenance of weatherproof traditional farm buildings	ES	No impact on floral or nesting resources
OHD3	Low depth, non-inversion cultivation on archaeological features	ES	No impact on floral or nesting resources
OHD4	Management of scrub on archaeological features	ES	No impact on floral or nesting resources
OHD5	Management of archaeological features on grassland	ES	No impact on floral or nesting resources
OHF2	Wild bird seed mixture	ES	Impact on land cover outside season considered in model
OHF2NR	Wild bird seed mixture	ES	Impact on land cover outside season considered in model

Option Code	Option Description	Scheme	Reason for exclusion
OHF6	Overwintered stubble	ES	Impact on land cover outside season considered in model
OHG2NR	ASD to Jan 2010 Wild bird seed mix in grassland areas (organic)	ES	Impact on land cover outside season considered in model
OHK5	Mixed stocking	ES	No impact on floral or nesting resources
OJ1	Management of high erosion risk cultivated land	ES	No impact on floral or nesting resources
OK5	Mixed stocking	ES	No impact on floral or nesting resources
OP1	Overwintered stubble	CS	Impact on land cover outside season considered in model
OP2	Wild bird seed mixture	CS	Impact on land cover outside season considered in model
OP3	Supplementary feeding for farmland birds	CS	Impact on land cover outside season considered in model
OR1	Organic conversion - improved permanent grassland	CS	No impact on land class
OT1	Organic land management - improved permanent grassland	CS	No impact on land class
OT4	Organic land management - horticulture	CS	No impact on land class
OT5	Organic land management - top fruit	CS	No impact on land class
OT6	Organic land management - enclosed rough grazing	CS	No impact on land class
OU1	Organic Management	ES	No change in management
SW12	Making space for water	CS	No impact on floral or nesting resources
SW13	Very low nitrogen inputs to groundwater	CS	No impact on floral or nesting resources
SW14	Nil fertiliser supplement	CS	Supplements were excluded
SW5	Enhanced management of maize crops	CS	No impact on floral or nesting resources
SP1	Difficult sites supplement	CS	Supplements were excluded
SP2	Raised water level supplement	CS	Supplements were excluded
SP3	Bracken control supplement	CS	Supplements were excluded
SP4	Control of invasive plant species supplement	CS	Supplements were excluded
SP5	Shepherding supplement	CS	Supplements were excluded

Option Code	Option Description	Scheme	Reason for exclusion
SP6	Cattle grazing supplement	CS	Supplements were excluded
SP7	Introduction of cattle grazing on the Isles of Scilly	CS	Applicable of Isles of Scilly only
SP8	Native breeds at risk supplement	CS	Supplements were excluded
SP9	Threatened species supplement	CS	Supplements were excluded
SP10	Administration of group managed agreements supplement	CS	No impact on land cover
UD12	Maintenance of remote weatherproof traditional farm buildings	ES	Negligible impact on floral or nesting resources
UD13	Maintaining visibility of archaeological features on moorland	ES	Negligible impact on floral or nesting resources
UHD12	Maintenance of remote weatherproof traditional farm buildings	ES	Negligible impact on floral or nesting resources
UHD13	Maintaining visibility of archaeological features on moorland	ES	Negligible impact on floral or nesting resources
UJ12	Winter livestock removal next to streams, rivers and lakes	ES	No impact on floral or nesting resources
UOD12	Maintenance of remote weatherproof traditional farm buildings	ES	No impact on floral or nesting resources
UOD13	Maintaining visibility of archaeological features on moorland	ES	Negligible impact on floral or nesting resources
UOJ12	Winter livestock removal next to streams, rivers and lakes	ES	No impact on floral or nesting resources

11 Parameters

Parameters for nest density, dispersal distance, population growth rates and proportion of foraging workers are taken from literature data showing values adapted for bumblebees - Häussler et al (2017) and solitary bees – G2020.

Table S6: Fixed parameters used to populate poll4pop model

Parameter	***Description***	***Unit***	***Bumblebee***	***Solitary***
n_{max}	Number of nests per unit area of maximum nesting quality	nests/ha	19	20
β_f	Mean dispersal distance for foraging	m	530	191
β_n	Mean dispersal distance to new nesting sites	m	1000	100
a_w	Median of the growth rate for workers	-	100	-
b_w	Steepness of the growth rate for workers	-	200	-
a_q	Median of the growth rate for reproductive females	-	15000	42
b_q	Steepness of the growth rate for reproductive females	-	30000	12
w_{max}	Max. number of workers produced by a reproductive female	-	600	-
q_{max}	Max. number of new reproductive females produced	-	160	2
p_w	Fraction of foraging workers	-	0.5	-

The parameterisation approach for nesting attractiveness, floral attractiveness for the four guilds for each land class and floral cover for the three seasons for each land cover class has already been set out in the main document.

To estimate the uncertainty in the log ratio caused by uncertainty in the underlying parameter values, 100 simulations were run where the nesting attractiveness, floral attractiveness and floral cover score for each land class were randomly drawn from a beta distribution ($B(a, b)$) with mean ($\mu = a / (a + b)$) and variance ($\sigma^2 = \mu(1 - \mu) / (a + b + 1)$) equal to the mean and variance of the G2020 expert opinion scores for that parameter. A beta distribution was used as the scores are bounded and, since $B(a, b)$ is only defined on the interval (0,1), the randomly drawn scores are rescaled to the appropriate scale for that parameter. For land classes where means and variances were both close to zero, the variances were adjusted upwards to slightly higher than the minimum value required to generate a solution for *a* and *b.* For new land classes where the mean value was generated by blending the scores of two existing classes, the variances were calculated by means of propagation (Hughes and Hase, 2010).

To calculate variance of a floral or nesting attractiveness parameter of blended land cover class C ($\sigma^2_{C\_att}$) Equation 1 was used:

$$\sigma^2_{C\_att} = a^2\sigma^2_{A\_att} + b^2\sigma^2_{B\_att} \quad (1)$$

Where the mean parameter for blended land class C is weighted sum of the parameters for land classes A and B with blend weights *a* and *b*, respectively, and $\sigma^2_{A\_att}$ and $\sigma^2_{B\_att}$ are their respective variances.

In the case of floral cover, the parameter is the product of abundance and duration parameters provided by the experts. The variance of the blended land cover class abundance ($\sigma^2_{C\_abu}$) and duration

($\sigma^2_{C\_dur}$) was first calculated as per Equation 1 using the component blend weights and variances, then the variance of the floral cover ($\sigma^2_{C\_cov}$) were propagated according to Equation 2.

$$\sigma^2{}_{C\_cov} = C\_cov^2 \left[\left(\frac{\sigma^2{}_{C\_abu}}{C\_abu^2} \right) + \left(\frac{\sigma^2{}_{C\_dur}}{C\_dur^2} \right) \right] \quad 2$$

Where *C_cov* is the mean blended floral cover, *C_abu* is the mean abundance, and *C_dur* is the mean duration. The final parameter values (mean, *a*, *b*) used for the draws are provided in Table S7 to Table_S11 below.

Draws for land classes parameterised directly from G2020 were constrained to within a quantile range (0.075, 0.925), i.e., 85% of the distribution. This excluded extreme draws from the distribution and ensured that draws did not unreasonably exceed the range of scores provided by the experts. The range of 85% was chosen after trials of 95% and 90% were found to be insufficient to exclude outliers. Blended land classes were also constrained by limiting draws to the distribution bounded by the lowest and highest values of the component land class draws. This maintained the relative parameterisation between *AES_Present* and *AES_Absent* scenarios whilst still allowing them to vary independently. For example, the values for semi-improved grassland land classes will always be in between the values for improved grassland and unimproved grassland, but not necessarily half-way. Hedgerow, ditch and woodland edge land classes have the same mean, *a* and *b* values in *AES_Present* and *AES_Absent* but are twice the width in the former. To simulate the variance of improved management on 50% of the width, the draw for these land classes in the *AES_Present* scenario was set at 50% of the draw in *AES_Absent* plus 50% of a draw from a distribution between this value and the upper quantile (0.925) of the distribution.

Table S7: Ground Nesting Bumblebee - Floral (scale 0 - 20) and nesting (scale 0 - 1) mean attractiveness and associated beta distribution parameters (a,b)

	Floral			**Nesting**		
Land Class	***mean***	***a***	***b***	***mean***	***a***	***b***
Beaches, Sand Dunes/Plane	9.18	0.8316	0.98	0.26	0.3751	1.09
Berries (exc. Strawberries & Raspberries)	14.21	5.2152	2.12	0.00	0.0000	0.01
Broad/Field Beans	15.72	6.8012	1.85	0.20	0.2518	1.01
Buckwheat	0.77	0.1364	3.41	0.06	0.2500	3.75
Cereal	0.26	0.3266	25.20	0.06	0.3875	6.36
Cereal - Organic	5.19	0.0695	0.20	0.04	0.4110	9.71
Ditch	8.81	2.2009	2.80	0.58	2.3981	1.77
Fallow	10.28	1.7224	1.63	0.46	1.2470	1.46
Flower Rich Margin	14.47	1.4130	0.54	0.57	1.0523	0.79
Gardens	16.54	5.5358	1.16	0.72	20.5357	8.04
Golf Courses	6.63	0.7373	1.49	0.32	1.2731	2.72
Grassland Acid - Improved	2.29	0.8813	6.80	0.14	1.0669	6.48
Grassland Neutral - Improved	2.29	0.8813	6.80	0.14	1.0669	6.48
Grassland Calcareous - Improved	5.30	0.5593	1.55	0.27	0.7187	1.96
Grassland Acid - Semi-Improved	7.77	4.5995	7.24	0.27	6.8200	18.71

	Floral			*Nesting*		
Land Class	***mean***	***a***	***b***	***mean***	***a***	***b***
Grassland Neutral - Semi-Improved	7.37	2.9388	5.04	0.29	2.6371	6.43
Grassland Calcareous - Semi-Improved	9.88	3.2988	3.38	0.42	2.5111	3.47
Grassland Acid - Unimproved	13.25	1.7135	0.87	0.39	5.7292	8.85
Grassland Neutral - Unimproved	12.44	0.9675	0.59	0.44	1.1618	1.48
Grassland Calcareous - Unimproved	14.47	1.4130	0.54	0.57	1.0523	0.79
Grassy Field Margin	10.63	1.8288	1.61	0.70	2.2479	0.97
Hedgerow	15.95	3.6910	0.94	0.77	8.0500	2.45
Ley - Grass and Legume	16.07	5.4250	1.33	0.28	0.9741	2.47
Ley - Grass	2.57	1.0973	7.46	0.24	0.8253	2.65
Ley - Organic	11.95	1.7730	1.19	0.21	5.5257	20.55
Linseed/Flax	9.62	26.5625	28.69	0.14	0.2659	1.66
Maize	1.14	0.4000	6.60	0.01	0.2969	24.64
Moorland	13.25	1.7135	0.87	0.39	5.7292	8.85
Moorland - Degraded	10.51	3.1350	2.83	0.33	7.3520	14.93
Null	0.00	-	-	0.00	-	-
Oilseed Rape	16.33	12.9391	2.90	0.00	-	-
Oilseed Rape - Organic	16.50	11.8800	2.52	0.22	0.1494	0.53
Orchard	15.69	22.5693	6.21	0.46	3.3971	4.01
Orchard - Degraded	15.31	22.0471	6.76	0.48	5.3592	5.80
Peas	14.25	4.6426	1.87	0.18	0.1081	0.48
Poplar	9.00	1.4063	1.72	0.15	1.1250	6.38
Potatoes	7.14	1.2500	2.25	0.09	0.1849	1.81
Reed Canary Grass	0.86	5.7000	127.30	0.17	2.3286	11.37
Salix	15.94	6.3494	1.62	0.17	0.6176	3.09
Salt Marsh	7.00	2.6833	4.98	0.06	0.2416	3.99
Scrub	13.79	1.7820	0.80	0.57	2.8257	2.15
Scrub - Degraded	10.58	5.6274	5.01	0.43	2.8257	8.51
Strawberry/Raspberry in Polytunnels	10.09	0.4957	0.49	0.00	-	-
Strawberry/Raspberry in the open	15.13	8.3710	2.70	0.32	0.4218	0.89
Sugar Beet	0.00	-	-	0.00	-	-
Urban	0.00	-	-	0.00	-	-
Vegetables	4.38	0.5203	1.86	0.10	0.5000	4.50
Wetland	8.08	6.1688	9.11	0.14	0.3454	2.11
Wetland - Degraded	8.65	8.0045	10.51	0.18	0.7729	3.44
Wood Pasture	12.21	6.7340	0.85	0.45	1.1576	1.92

	Floral			Nesting		
Land Class	***mean***	***a***	***b***	***mean***	***a***	***b***
Wood Pasture - Degraded	7.37	2.7091	5.04	0.29	1.0975	6.43
Woodland - Afforestation	5.93	1.3273	2.17	0.40	1.5559	5.32
Woodland - Coniferous	1.76	1.3273	6.53	0.23	1.5559	3.43
Woodland - Deciduous	10.08	0.9128	2.68	0.51	3.5202	2.72
Woodland - Degraded	9.54	0.6316	4.50	0.47	1.0276	4.73
Woodland Edge	13.97	2.7265	2.17	0.73	2.8619	2.83

Table S8: Tree Nesting Bumblebees - Floral (scale 0 - 20) and nesting (scale 0 - 1) mean attractiveness and associated beta distribution parameters (a,b)

	Floral			Nesting		
Land Class	***mean***	***a***	***b***	***mean***	***a***	***b***
Beaches, Sand Dunes/Plane	0.50	0.9500	37.05	0.00	-	-
Berries (exc. Strawberries & Raspberries)	16.00	2.0444	0.51	0.00	-	-
Broad/Field Beans	15.40	2.0359	0.61	0.00	-	-
Buckwheat	0.00	-	-	0.00	-	-
Cereal	0.25	0.3167	25.02	0.00	-	-
Cereal - Organic	0.00	-	-	0.00	-	-
Ditch	7.86	5.7292	8.85	0.02	0.6333	31.03
Fallow	10.71	1.6406	1.42	0.02	0.4750	28.03
Flower Rich Margin	19.00	17.1000	0.90	0.02	0.6333	31.03
Gardens	19.00	17.1000	0.90	0.95	17.1000	0.90
Golf Courses	2.50	0.7500	5.25	0.08	0.3750	4.13
Grassland Acid - Improved	2.86	1.0000	6.00	0.01	0.1583	22.01
Grassland Neutral - Improved	2.86	1.0000	6.00	0.01	0.1583	22.01
Grassland Calcareous - Improved	0.57	1.2667	43.07	0.00	-	-
Grassland Acid - Semi-Improved	9.13	6.6315	7.90	0.09	0.4069	4.28
Grassland Neutral - Semi-Improved	10.13	19.8237	19.32	0.004	0.0145	4.06
Grassland Calcareous - Semi-Improved	9.79	156.6516	163.51	0.01	0.1177	11.66
Grassland Acid - Unimproved	15.40	2.0359	0.61	0.17	0.2500	1.25
Grassland Neutral - Unimproved	17.40	9.3797	1.40	0.00	-	-
Grassland Calcareous - Unimproved	19.00	17.1000	0.90	0.02	0.6333	31.03
Grassy Field Margin	12.50	8.7500	5.25	0.00	-	-
Hedgerow	17.40	9.3797	1.40	0.20	0.3333	1.33
Ley - Grass and Legume	16.00	2.0444	0.51	0.00	-	-
Ley - Grass	2.14	0.5625	4.69	0.00	-	-

	Floral			Nesting		
Land Class	***mean***	***a***	***b***	***mean***	***a***	***b***
Ley - Organic	5.00	2.7500	8.25	0.02	0.6333	31.03
Linseed/Flax	10.00	7.5000	7.50	0.00	-	-
Maize	0.00	-	-	0.00	-	-
Moorland	15.40	2.0359	0.61	0.17	0.2500	1.25
Moorland - Degraded	12.26	2.0359	2.86	0.13	0.3221	2.22
Null	0.00	-	-	0.00	-	-
Oilseed Rape	19.00	17.1000	0.90	0.00	-	-
Oilseed Rape - Organic	17.40	9.3797	1.40	0.00	-	-
Orchard	19.00	17.1000	0.90	0.50	7.5000	7.50
Orchard - Degraded	18.20	19.7925	1.96	0.42	9.2321	12.75
Peas	14.33	0.6198	0.25	0.00	-	-
Poplar	0.00	-	-	0.00	-	-
Potatoes	0.00	-	-	0.00	-	-
Reed Canary Grass	0.00	-	-	0.00	-	-
Salix	19.00	-	-	0.02	0.6333	31.03
Salt Marsh	0.00	-	-	0.00	-	-
Scrub	15.00	2.0625	0.69	0.10	0.5000	4.50
Scrub - Degraded	12.56	9.8100	5.81	0.05	0.5960	10.91
Strawberry/Raspberry in Polytunnels	16.00	2.0444	0.51	0.00	-	-
Strawberry/Raspberry in the open	17.67	9.3578	1.24	0.00	-	-
Sugar Beet	0.00	-	-	0.00	-	-
Urban	0.00	-	-	0.00	-	-
Vegetables	10.00	49.5000	49.50	0.00	-	-
Wetland	1.00	0.1020	1.94	0.00	-	-
Wetland - Degraded	2.40	0.8432	6.18	0.01	0.0355	3.52
Wood Pasture	17.16	36.1893	2.08	0.08	2.1024	25.20
Wood Pasture - Degraded	10.13	31.9901	19.32	0.004	0.0145	4.06
Woodland - Afforestation	3.33	12.5422	1.25	0.33	5.0000	10.00
Woodland - Coniferous	0.33	12.5422	28.03	0.42	6.8750	9.63
Woodland - Deciduous	15.00	0.2500	18.50	0.77	2.0359	0.61
Woodland - Degraded	14.03	0.4750	33.54	0.62	4.0658	2.53
Woodland Edge	19.00	55.5000	0.90	0.77	2.0359	0.61

Table S9: Ground Nesting Solitary Bees - Floral (scale 0 - 20) and nesting (scale 0 - 1) mean attractiveness and associated beta distribution parameters (a,b)

	Floral			***Nesting***		
Land Class	***mean***	***a***	***b***	***mean***	***a***	***b***
Beaches, Sand Dunes/Plane	11.19	3.3639	2.65	0.54	2.0461	1.76
Berries (exc. Strawberries & Raspberries)	10.96	4.1430	3.42	0.21	0.3637	1.35
Broad/Field Beans	6.65	1.1025	2.22	0.28	0.5813	1.50
Buckwheat	5.00	1.8333	5.50	0.25	1.8333	5.50
Cereal	0.46	0.8000	34.20	0.29	0.5787	1.42
Cereal - Organic	6.33	0.5903	1.27	0.27	0.4682	1.25
Ditch	8.45	1.2238	1.67	0.49	0.8500	0.88
Fallow	10.19	3.0315	2.92	0.54	2.0647	1.77
Flower Rich Margin	14.88	2.5946	0.89	0.46	3.7297	4.35
Gardens	14.81	3.4137	1.20	0.68	11.4700	5.30
Golf Courses	5.86	2.4975	6.03	0.50	2.3750	2.38
Grassland Acid - Improved	2.00	0.8458	7.61	0.25	0.4471	1.34
Grassland Neutral - Improved	2.00	0.8458	7.61	0.25	0.4471	1.34
Grassland Calcareous - Improved	6.36	1.3329	2.86	0.27	0.9115	2.41
Grassland Acid - Semi-Improved	6.11	4.8619	11.06	0.41	3.7011	5.22
Grassland Neutral - Semi-Improved	7.23	3.8896	6.86	0.39	2.0798	3.29
Grassland Calcareous - Semi-Improved	10.62	5.7473	5.08	0.37	4.2954	7.38
Grassland Acid - Unimproved	10.22	2.6301	2.52	0.58	4.0348	2.93
Grassland Neutral - Unimproved	12.47	1.4959	0.90	0.52	1.0768	0.98
Grassland Calcareous - Unimproved	14.88	2.5946	0.89	0.46	3.7297	4.35
Grassy Field Margin	8.15	1.7720	2.58	0.36	2.4919	4.48
Hedgerow	15.91	17.5432	4.50	0.57	1.7854	1.35
Ley - Grass and Legume	9.21	2.8438	3.33	0.21	0.7471	2.81
Ley - Grass	4.88	2.6981	8.37	0.21	0.6412	2.40
Ley - Organic	6.77	1.8231	3.56	0.32	5.1750	10.93
Linseed/Flax	10.00	2.1000	2.10	0.12	0.8924	6.84
Maize	0.56	1.2091	41.97	0.23	0.5941	2.03
Moorland	10.22	2.6301	2.52	0.58	4.0348	2.93
Moorland - Degraded	8.16	3.7952	5.50	0.50	5.3058	5.37
Null	0.00	-	-	0.00	-	-
Oilseed Rape	14.89	3.1509	1.08	0.30	1.3407	3.10
Oilseed Rape - Organic	16.06	3.5914	0.88	0.26	2.0391	5.78
Orchard	16.43	3.9495	0.86	0.65	9.1477	4.97

	Floral			Nesting		
Land Class	***mean***	***a***	***b***	***mean***	***a***	***b***
Orchard - Degraded	15.19	7.3384	2.33	0.59	12.5409	8.57
Peas	5.00	18.5000	55.50	0.30	1.8549	4.40
Poplar	3.00	1.7625	9.99	0.13	1.3333	9.33
Potatoes	5.00	18.5000	55.50	0.18	2.5200	11.88
Reed Canary Grass	1.00	0.9000	17.10	0.05	0.9000	17.10
Salix	11.25	11.2500	8.75	0.28	0.9574	2.45
Salt Marsh	8.20	2.6511	3.81	0.21	5.2336	19.69
Scrub	10.22	4.7342	4.53	0.38	2.4669	4.05
Scrub - Degraded	8.73	9.3224	12.04	0.38	4.8967	7.90
Strawberry/Raspberry in Polytunnels	7.68	0.6821	1.09	0.11	0.2326	1.98
Strawberry/Raspberry in the open	11.60	9.8088	7.10	0.30	1.2253	2.86
Sugar Beet	0.00	-	-	0.00	-	-
Urban	0.00	-	-	0.00	-	-
Vegetables	5.00	0.7917	2.38	0.15	1.7625	9.99
Wetland	5.00	18.5000	55.50	0.17	2.3286	11.37
Wetland - Degraded	5.52	24.0494	63.06	0.19	3.4520	14.64
Wood Pasture	12.27	4.4750	1.24	0.51	2.5947	1.34
Wood Pasture - Degraded	7.23	3.9926	6.86	0.39	2.3305	3.29
Woodland - Afforestation in AES	6.43	1.9737	1.57	0.37	1.4169	1.18
Woodland - Coniferous not in AES	1.54	1.9737	10.74	0.13	1.4169	9.43
Woodland - Deciduous not in AES	10.47	0.7448	3.66	0.42	0.7019	3.46
Woodland - Degraded	9.82	0.8947	6.12	0.42	1.4514	5.37
Woodland Edge	12.24	4.0186	5.57	0.54	2.5282	13.14

Table S10: Cavity Nesting Solitary Bees - Floral (scale 0 - 20) and nesting (scale 0 - 1) mean attractiveness and associated beta distribution parameters (a,b)

	Floral			Nesting		
Land Class	***mean***	***a***	***b***	***mean***	***a***	***b***
Beaches, Sand Dunes/Plane	7.22	0.3275	0.58	0.25	18.5000	55.50
Berries (exc. Strawberries & Raspberries)	7.62	0.6019	0.98	0.16	2.0436	10.64
Broad/Field Beans	10.38	0.5984	0.55	0.15	1.0500	6.15
Buckwheat	5.00	1.8333	5.50	0.25	1.8333	5.50
Cereal	0.60	1.4250	46.08	0.03	1.5200	47.88
Cereal - Organic	3.18	1.9870	10.50	0.06	0.4224	6.34

	Floral			Nesting		
Land Class	***mean***	***a***	***b***	***mean***	***a***	***b***
Ditch	8.18	6.4286	9.29	0.25	18.5000	55.50
Fallow	6.82	4.9554	9.58	0.25	18.5000	55.50
Flower Rich Margin	11.33	1.0921	0.84	0.32	5.2500	11.25
Gardens	14.71	4.1832	1.50	0.68	10.9250	5.18
Golf Courses	6.67	5.0000	10.00	0.42	6.8750	9.63
Grassland Acid - Improved	3.77	3.1944	13.76	0.15	1.2000	6.60
Grassland Neutral - Improved	3.77	3.1944	13.76	0.15	1.2000	6.60
Grassland Calcareous - Improved	5.31	1.3875	3.84	0.23	0.7241	2.41
Grassland Acid - Semi-Improved	6.20	3.6889	8.21	0.29	3.0217	7.57
Grassland Neutral - Semi-Improved	7.23	1.9014	3.36	0.20	2.5527	10.23
Grassland Calcareous - Semi-Improved	8.32	3.0937	4.34	0.27	3.6794	9.73
Grassland Acid - Unimproved	8.64	1.3996	1.84	0.42	1.4063	1.97
Grassland Neutral - Unimproved	10.69	0.4224	0.37	0.25	1.1945	3.67
Grassland Calcareous - Unimproved	11.33	1.0921	0.84	0.32	5.2500	11.25
Grassy Field Margin	9.55	2.5559	2.80	0.42	6.8750	9.63
Hedgerow	13.57	10.9250	5.18	0.81	14.5841	3.48
Ley - Grass and Legume	10.00	49.5000	49.50	0.23	1.0416	3.50
Ley - Grass	5.00	18.5000	55.50	0.17	2.2143	11.07
Ley - Organic	5.00	18.5000	55.50	0.18	2.6160	12.14
Linseed/Flax	10.38	2.5022	2.32	0.17	0.3158	1.55
Maize	0.60	1.4250	46.08	0.03	1.7100	51.49
Moorland	8.64	1.3996	1.84	0.42	1.4063	1.97
Moorland - Degraded	7.42	2.2465	3.81	0.35	2.1338	3.95
Null	0.00	-	-	0.00	-	-
Oilseed Rape	13.00	2.6361	1.42	0.18	0.3596	1.60
Oilseed Rape - Organic	11.67	9.6250	6.88	0.18	0.3596	1.60
Orchard	16.43	12.2986	2.67	0.48	0.2642	0.28
Orchard - Degraded	15.48	20.2796	5.93	0.52	0.7295	0.68
Peas	7.50	5.2500	8.75	0.28	0.8080	2.13
Poplar	3.00	1.7625	9.99	0.25	18.5000	55.50
Potatoes	5.00	18.5000	55.50	0.13	1.4016	9.38
Reed Canary Grass	1.00	0.9000	17.10	0.39	2.0300	3.22
Salix	5.00	18.5000	55.50	0.38	5.2500	8.75
Salt Marsh	4.20	5.2336	19.69	0.21	5.2336	19.69
Scrub	11.67	9.6250	6.88	0.67	10.0000	5.00

	Floral			Nesting		
Land Class	***mean***	***a***	***b***	***mean***	***a***	***b***
Scrub - Degraded	9.45	8.8051	9.83	0.43	16.2632	21.28
Strawberry/Raspberry in Polytunnels	8.85	0.6752	0.85	0.07	0.3000	3.90
Strawberry/Raspberry in the open	10.83	2.8261	2.39	0.45	10.6875	13.06
Sugar Beet	0.00	-	-	0.00	-	-
Urban	0.00	-	-	0.00	-	-
Vegetables	5.00	0.7917	2.38	0.11	0.6000	4.80
Wetland	5.00	18.5000	55.50	0.25	18.5000	55.50
Wetland - Degraded	5.67	26.3042	66.53	0.29	27.5552	66.92
Wood Pasture	10.66	5.0285	0.56	0.28	1.2294	4.84
Wood Pasture - Degraded	7.23	5.7745	3.36	0.20	1.3309	10.23
Woodland - Afforestation	7.22	0.6412	0.58	0.31	1.8884	0.60
Woodland - Coniferous	3.67	0.6412	12.94	0.16	1.8884	10.88
Woodland - Deciduous	10.36	0.3275	2.54	0.60	0.2721	1.42
Woodland - Degraded	9.73	2.9047	4.24	0.52	2.1383	3.01
Woodland Edge	15.00	2.7260	18.50	0.75	2.0990	1.10

Table_S11: Floral cover mean by season (scale 0 - 100) and associated beta distribution parameters (a,b)

	Early Spring			Late Spring			Summer		
Land Class	***mean***	***a***	***b***	***mean***	***a***	***b***	***mean***	***a***	***b***
Beaches, Sand Dunes/Plane	2.37	2.0525	84.45	2.37	2.0525	84.45	14.88	1.4273	8.17
Berries (exc. Strawberries & Raspberries)	0.84	1.5582	183.58	7.57	1.3845	16.89	23.31	0.9613	3.16
Broad/Field Beans	0.51	0.9830	192.07	4.58	0.9015	18.78	12.10	1.2793	9.29
Buckwheat	0.00	-	-	0.00	-	-	1.67	0.1372	8.10
Cereal	0.30	0.5100	166.70	0.30	0.5100	166.70	1.63	0.9044	54.49
Cereal - Organic	1.70	1.0801	62.42	1.70	1.0801	62.42	10.41	2.5075	21.58
Ditch	4.66	1.7399	35.58	4.66	1.7399	35.58	15.38	9.4015	51.71
Fallow	4.89	1.5748	30.64	4.89	1.5748	30.64	17.63	2.7875	13.02
Flower Rich Margin	5.75	0.9358	15.34	5.75	0.9358	15.34	42.99	1.3727	1.82
Gardens	11.15	1.8647	14.85	11.15	1.8647	14.85	39.39	3.0986	4.77
Golf Courses	2.98	2.2621	73.58	2.98	2.2621	73.58	12.40	2.9452	20.81
Grassland Acid - Improved	1.59	1.0919	67.72	1.59	1.0919	67.72	6.77	4.5330	62.45
Grassland Neutral - Improved	1.59	1.0919	67.72	1.59	1.0919	67.72	6.77	4.5330	62.45

	Early Spring			Late Spring			Summer		
Land Class	***mean***	***a***	***b***	***mean***	***a***	***b***	***mean***	***a***	***b***
Grassland Calcareous - Improved	2.61	4.0458	150.85	2.61	4.0458	150.85	14.17	6.5425	39.64
Grassland Acid - Semi-Improved	2.03	2.9712	143.48	2.03	2.9712	143.48	15.45	7.3703	40.35
Grassland Neutral - Semi-Improved	2.77	2.3584	82.91	2.77	2.3584	82.91	21.43	1.6779	6.15
Grassland Calcareous - Semi-Improved	4.33	1.7507	38.72	4.33	1.7507	38.72	29.03	3.6318	8.88
Grassland Acid - Unimproved	2.31	2.8904	122.08	2.31	2.8904	122.08	21.42	3.2735	12.01
Grassland Neutral - Unimproved	3.91	1.9248	47.33	3.91	1.9248	47.33	36.93	0.7288	1.24
Grassland Calcareous - Unimproved	5.75	0.9358	15.34	5.75	0.9358	15.34	42.99	1.3727	1.82
Grassy Field Edges	3.48	3.2114	89.18	3.48	3.2114	89.18	13.06	1.2390	8.25
Hedgerow	10.56	4.7317	40.07	10.56	4.7317	40.07	20.60	1.8688	7.20
Ley - Grass and Legume	5.42	1.7726	30.95	5.42	1.7726	30.95	38.00	1.5839	2.58
Ley - Grass	1.19	1.0324	85.69	1.19	1.0324	85.69	6.27	1.2658	18.93
Ley - Organic	4.39	9.2218	200.89	4.39	9.2218	200.89	21.39	4.6787	17.19
Linseed/Flax	0.87	0.7184	81.83	7.83	0.5977	7.03	9.47	2.8302	27.06
Maize	0.00	0.0476	1006.52	0.00	0.0476	1006.52	2.21	1.0265	45.40
Moorland	2.31	2.8904	122.08	2.31	2.8904	122.08	21.42	3.2735	12.01
Moorland - Degraded	2.19	3.6513	163.03	2.19	3.6513	163.03	18.77	5.1396	22.24
Null	0.00	-	-	0.00	-	-	0.00	-	-
Oilseed Rape	2.12	7.0520	326.26	19.04	5.6597	24.06	9.29	0.5698	5.57
Oilseed Rape - Organic	2.21	4.6144	204.41	19.87	3.6004	14.52	13.97	0.9378	5.77
Orchard	20.30	2.9168	11.46	2.26	3.8033	164.86	13.33	0.4206	2.74
Orchard - Degraded	19.51	4.7208	19.47	2.17	5.9536	268.65	14.28	0.7068	4.24
Peas	0.03	0.2000	733.60	0.24	0.1970	80.27	9.97	8.6946	78.47
Poplar	7.98	1.4502	16.73	7.98	1.4502	16.73	0.99	0.3862	38.71
Potatoes	0.00	-	-	0.00	-	-	3.33	0.8535	24.75
Reed Canary Grass	0.00	-	-	0.00	-	-	0.00	0.0000	0.01
Salix	12.10	5.4408	39.53	12.10	5.4408	39.53	3.75	0.8343	21.43
Salt Marsh	0.99	0.9756	97.40	0.99	0.9756	97.40	14.04	0.9498	5.81
Scrub	4.72	1.6452	33.22	4.72	1.6452	33.22	14.46	6.1393	36.32
Scrub - Degraded	3.69	3.4969	91.28	3.69	3.4969	91.28	17.82	4.8715	22.47
Strawberry/Raspberry in Polytunnels	2.61	1.4932	55.74	23.48	0.9589	3.13	38.14	0.9030	1.46
Strawberry/Raspberry in the open	0.23	0.5980	261.10	2.06	0.5690	27.08	38.07	1.1672	1.90
Sugar Beet	0.00	-	-	0.00	-	-	6.67	2.6784	37.50
Urban	0.00	-	-	0.00	-	-	0.00	-	-
Vegetables	0.23	0.2970	126.40	0.23	0.2970	126.40	12.38	2.9611	20.96
Wetland	1.33	6.2261	462.56	1.33	6.2261	462.56	14.44	4.3346	25.67

	Early Spring			Late Spring			Summer		
Land Class	***mean***	***a***	***b***	***mean***	***a***	***b***	***mean***	***a***	***b***
Wetland - Degraded	1.59	7.7310	479.99	1.59	7.7310	479.99	14.45	5.3721	31.81
Wood Pasture	4.08	2.4393	57.34	4.08	2.4393	57.34	34.45	0.8973	1.71
Wood Pasture - Degraded	2.77	2.3584	82.91	2.77	2.3584	82.91	21.43	1.6779	6.15
Woodland - Afforestation	2.27	0.9967	42.84	2.27	0.9967	42.84	9.70	0.6137	5.71
Woodland - Coniferous	0.35	0.3670	105.33	0.35	0.3670	105.33	2.21	0.7134	31.50
Woodland - Deciduous	5.80	2.4867	40.38	5.80	2.4867	40.38	13.44	3.1143	20.05
Woodland - Degraded	5.12	3.2875	60.91	5.12	3.2875	60.91	15.00	4.6276	26.23
Woodland Edge	6.77	1.9809	27.29	6.77	1.9809	27.29	19.07	2.6771	11.36

12 Validation

G2020 validated the Poll4pop model visitation rates against observed pollinator abundances along transects at 239 sites across Great Britain. We repeated this validation process to check our improvements to the model and more detailed mapping data still produced visitation rates that significantly agree with the observed pollinator abundances. Because our model version only applies to England, only the English transect sites (215 of 239) were used which included 9 urban sites, 104 non-crop sites (semi-natural habitat, nature reserves) and 103 crop sites covering the four focal crops.

For each survey site, the visitation rate per m^2 within the survey area for the relevant season (V_s) was calculated in the *AES_Present* scenario. This was then compared to the number of observed bees (N_{obs}) by fitting Equation 3:

$$\log\left(\frac{N_{obs}+1}{L}\right) = \beta \log V_s + \gamma \log W + \begin{pmatrix} \zeta_{S1} \\ \vdots \\ \zeta_{S2} \end{pmatrix} S + \eta(S * logW) + \theta Y + \begin{pmatrix} \alpha_{2011} \\ \vdots \\ \alpha_{2016} \end{pmatrix} Z \qquad 3$$

Where *L* is the total transect length walked during the survey, *W* is week of the year that the survey was carried out, S is a factor representing the season used for visitation rate (S1 = early spring, S2 = late spring), *Y* is the Y coordinate of the British National Grid reference for the survey site, and *Z* is the year in which the survey took place. Early spring visitation rates were used for all sites except for oilseed rape, field beans and strawberries, for which late spring visitation rates were used to match their peak floral cover. Fitting to $N_{obs} + 1$ avoids taking logarithms of zero. Including week and year as covariables accounts for variability of pollinator populations within and between years due to external factors such as weather. Including the Y grid reference accounts for beneficial temperature and weather effects associated with more southerly latitudes. A significant positive value of β indicates significant model-data agreement. As in G2020, the model is fitted with a Gaussian error term as this yields the smallest and most uniform residuals.

All four guilds show significant agreement (statistically significant β > 0) between the predicted visitation rate for the survey area as calculated by the model (*AES_Present* scenario) and the observed number of bees from the survey data. β and R^2 values are comparable to those reported in G2020, with R^2 values for ground nesting guilds slightly higher in this modelling scenario.

*Table S12: **Agreement between model predictions and observed bee numbers** as assessed by fitting equation 3. Statistically significant coefficients are marked with asterisks (* = p <0.05, ** = p < 0.01, *** = p < 0.001). GNBB, TNBB, GNSB and CNSB refer to ground-nesting bumblebees, tree-nesting bumblebees, ground-nesting solitary bees and cavity-nesting solitary bees, respectively.*

Parameter	Coefficient	GNBB	TNBB	GNSB	CNSB
V_s	β	0.14 ± 0.03 ***	0.16 ± 0.02 ***	0.15 ± 0.02 ***	0.10 ± 0.01 ***
log W	γ	0.3 ± 0.2 *	-0.3 ± 0.1 *	-0.70 ± 0.15 ***	-0.40 ± 0.09 ***
S = Late Spring	ζ_{S2}	-2.0 ± 1.0 *	-3.8 ± 0.7 ***	-5.5 ± 0.9 ***	-4.0 ± 0.6 ***

Parameter	**Coefficient**	**GNBB**	**TNBB**	**GNSB**	**CNSB**
$S * \log W$	η	2.4 ± 0.8 **	3.1 ± 0.5 ***	4.5 ± 0.7 **	3.4 ± 0.5 ***
Y	θ	-1.2E-6 ± 1E-7 ***	-5.5E-7 ± 9E-8***	-1.8E-6 ± 1E-7 ***	-6.3E-7 ± 8E-8***
$Z = 2012$	α_{2012}	-0.36 ± 0.04 ***	-0.13 ± 0.03 ***	0.03 ± 0.04	0.06 ± 0.03 *
$Z = 2013$	α_{2013}	-0.28 ± 0.04 ***	-0.17 ± 0.03 ***	0.02 ± 0.04	0.04 ± 0.02
$Z = 2014$	α_{2014}	0.18 ± 0.09 *	0.24 ± 0.06 ***	0.54 ± 0.08 ***	0.42 ± 0.05 ***
$Z = 2015$	α_{2015}	-0.20 ± 0.07 **	0.02 ± 0.05	0.31 ± 0.07 ***	0.17 ± 0.04 ***
$Z = 2016$	α_{2016}	-0.03 ± 0.09	0.29 ± 0.07 ***	0.27 ± 0.09 **	0.45 ± 0.06 ***
R^2		0.416	0.433	0.378	0.445

We have not directly validated abundance outputs (Q, R, W_s) though their validity is implicit in the validation of V_s. Although there is significant model-data agreement, the actual value of V_s in the model is an indicator of visitation rate due to floral and nesting resource availability rather than a number that reflects the absolute number of visits by bees during that season. As such, subsequent analysis focuses on the relative change in abundance and visitation rates between scenarios. We refer to absolute values only to illustrate differences between guilds and land categories, for example to where changes are significant but at relatively low magnitude.

13 Additional Figures

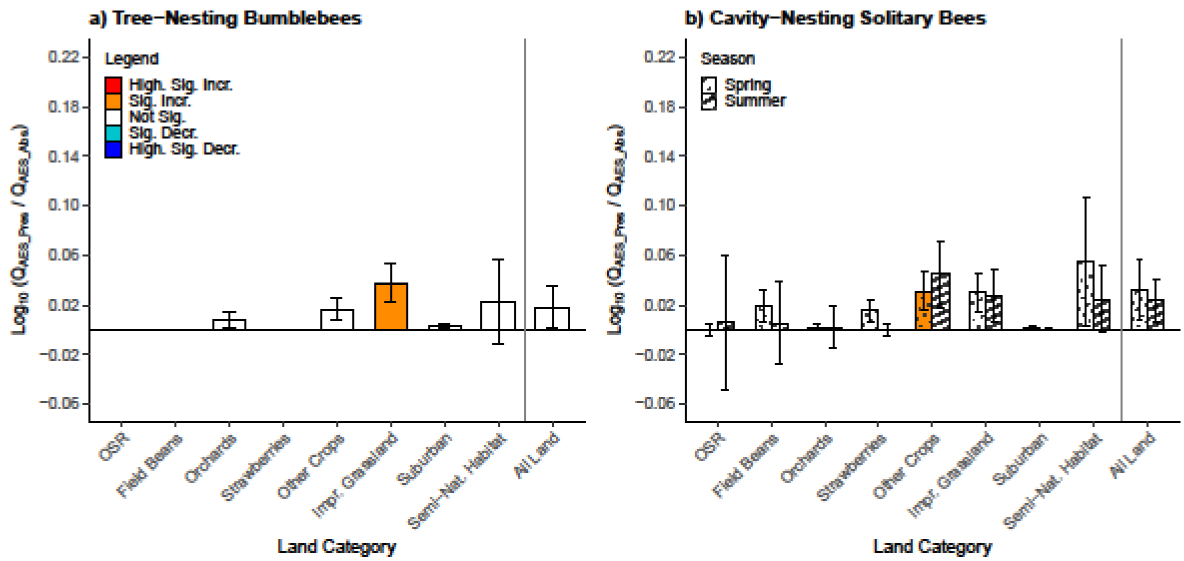

*Figure S1: Predicted impact of Agri-environment schemes (AES) on **nest productivity** (Q; production of new reproductive females per $25m^2$) nationally to all land categories and subdivided by land category for (a) tree-nesting bumblebees and (b) cavity-nesting solitary bees (separated by active season). The impact is measured as the log of the ratio between the scenarios with AES features present and absent. Significance thresholds are number of standard deviations that the log ratio is above (increase) or below (decrease) zero: value >=|3| is highly significant, |2| <= value <|3|is significant.*

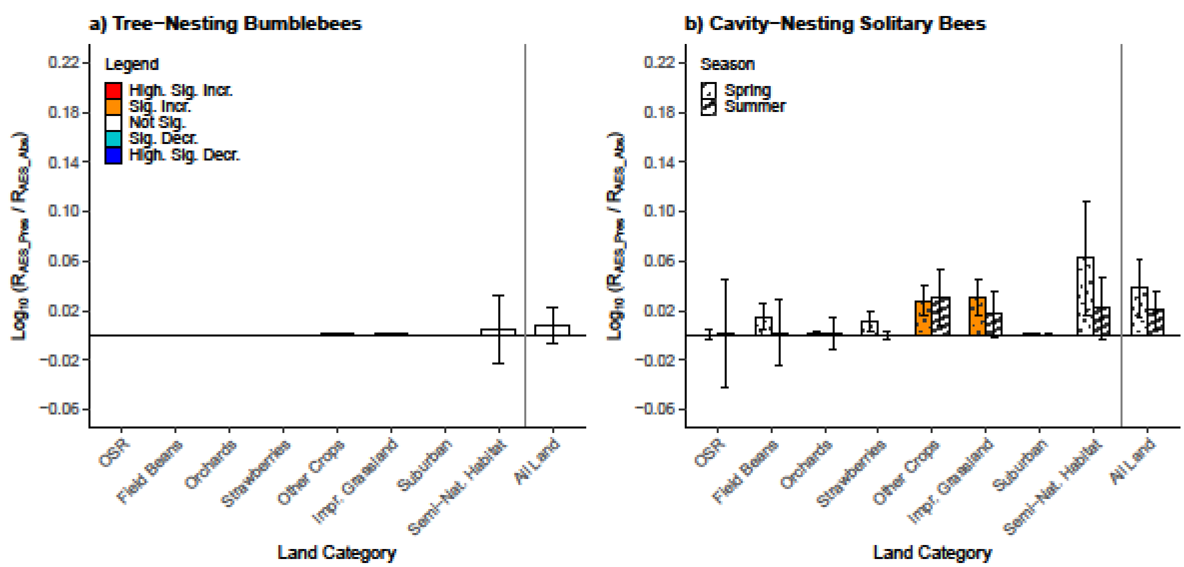

*Figure S2: Predicted impact of Agri-environment schemes (AES) on **nest density** (R; nests per $25m^2$ cell) nationally to all land categories and subdivided by land category for (a) tree-nesting bumblebees and (b) cavity-nesting solitary bees (separated by active season). The impact is measured as the log of the ratio between the scenarios with AES features present and absent. Significance thresholds are number of standard deviations that the log ratio is above (increase) or below (decrease) zero: value >=|3| is highly significant, |2| <= value <|3|is significant.*

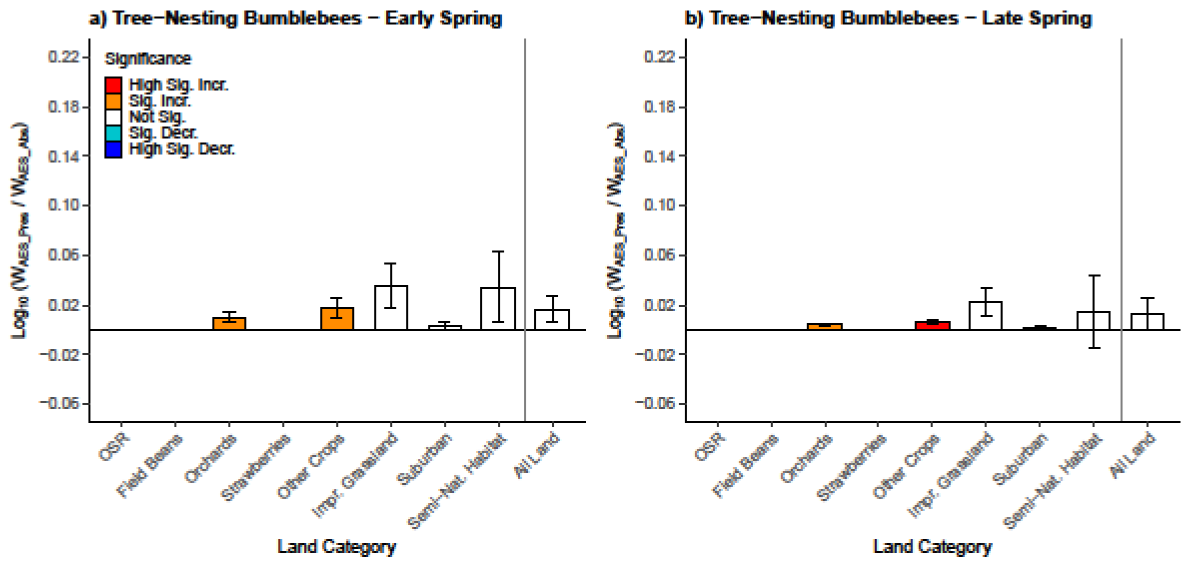

*Figure S3 Predicted impact of Agri-environment schemes on tree-nesting bumblebee **worker production** (W; workers produced per $25m^2$ cell) nationally to all land classes (AL) and subdivided by land category for (a) Early Spring and (b) Late Spring. The impact is measured as the log ratio between the scenarios with AES feature present and absent. Significance thresholds are number of standard deviations that the log ratio is above (increase) or below (decrease) zero: value >=|3| is highly significant, |2| <= value <|3|is significant:*

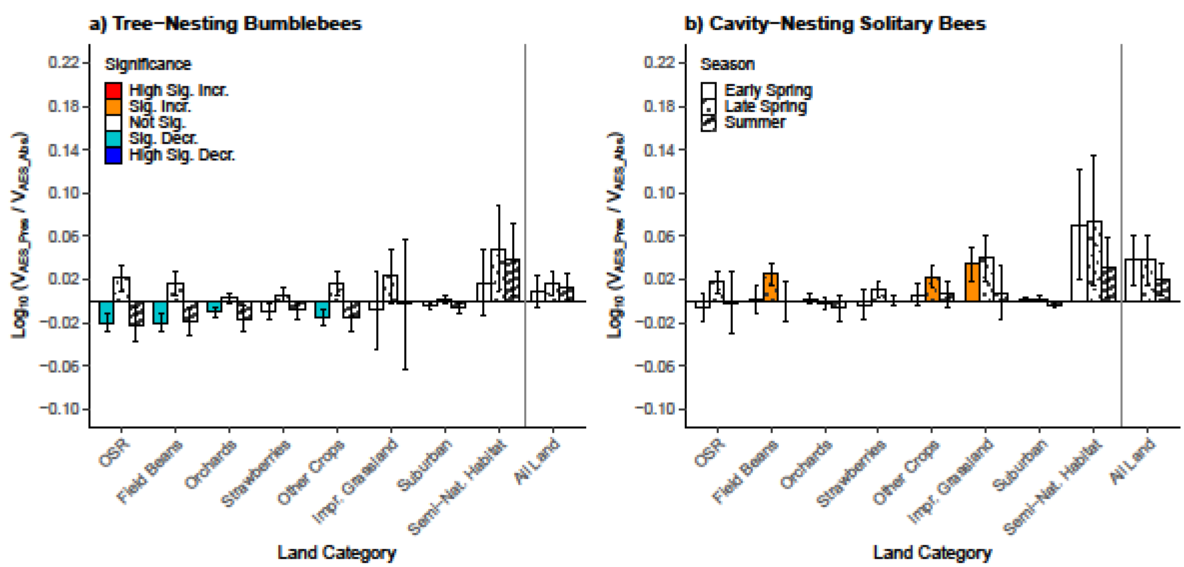

*Figure S4: Predicted impact of Agri-environment schemes (AES) on **floral visitation rate** (V; visits per $25m^2$ cell) nationally to all land classes (ALL) and subdivided by land category for a) tree-nesting bumblebees and b) cavity-nesting solitary bees in each season. The impact is measured as the log ratio between the scenarios with AES feature present and absent. Significance thresholds are number of standard deviations that the log ratio is above (increase) or below (decrease) zero: value >=|3| is highly significant, |2| <= value <|3|is significant*

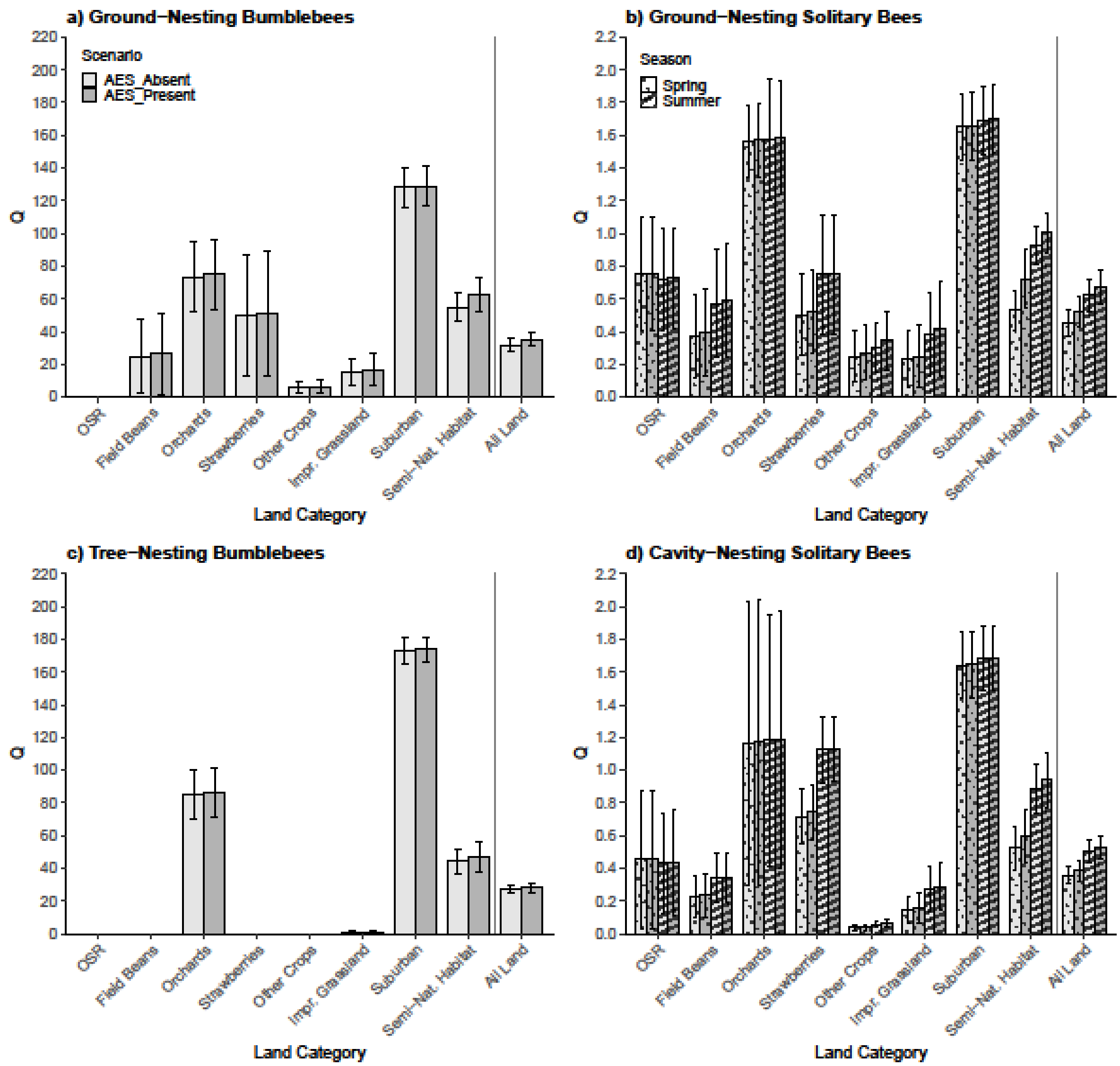

Figure S5: ***Nest productivity*** *(Q) by land category, scenario, and guild. Q represents the number of new reproductive females produced on average per cell (25m²) of that land category in England at the end of the active season for that year.*

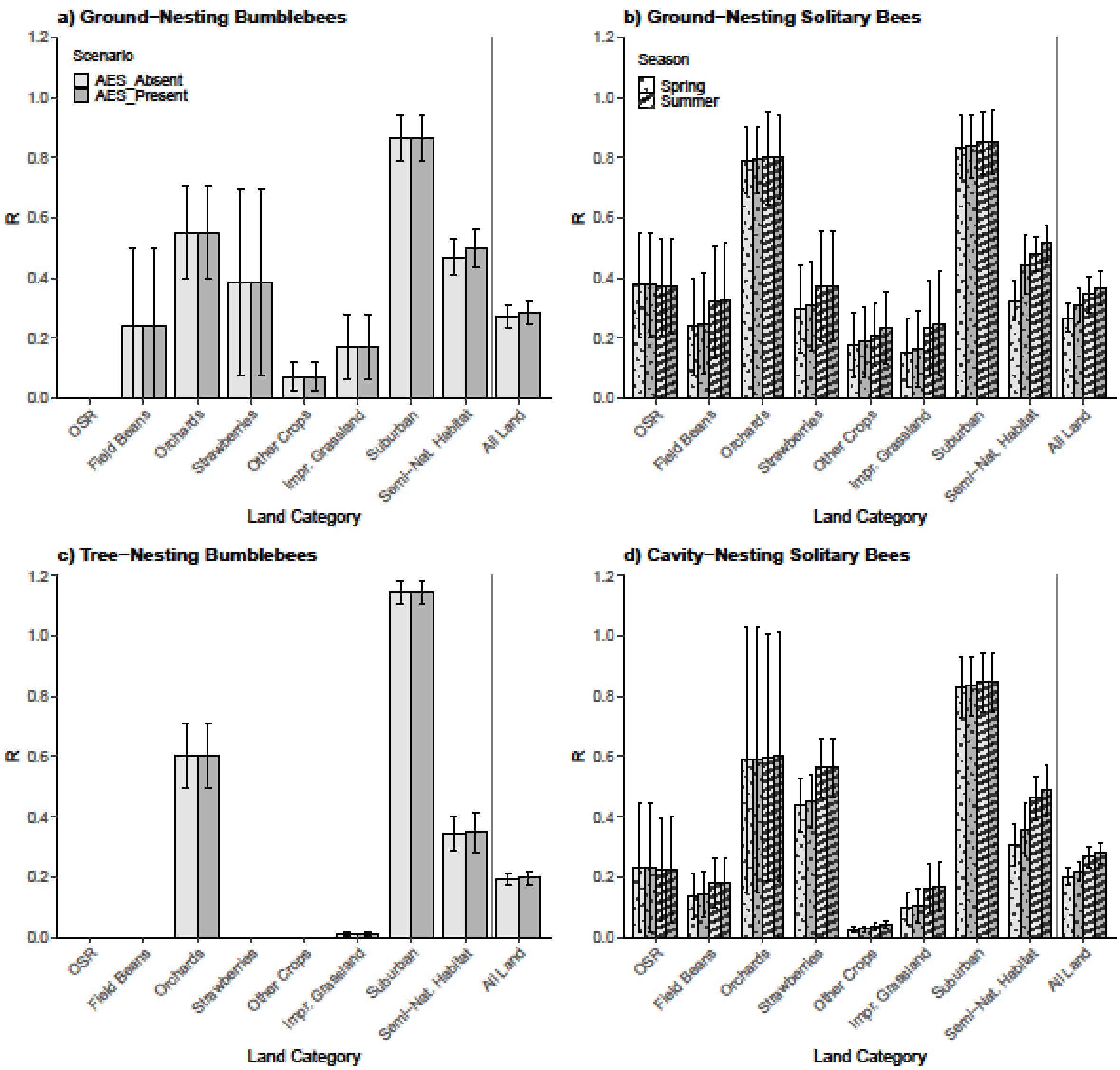

Figure S6: ***Nest density*** *(R) by land category, scenario, and guild. R represents the number of nests found on average per cell (25m²) of that land category in England at the beginning of the active season for the next year.*

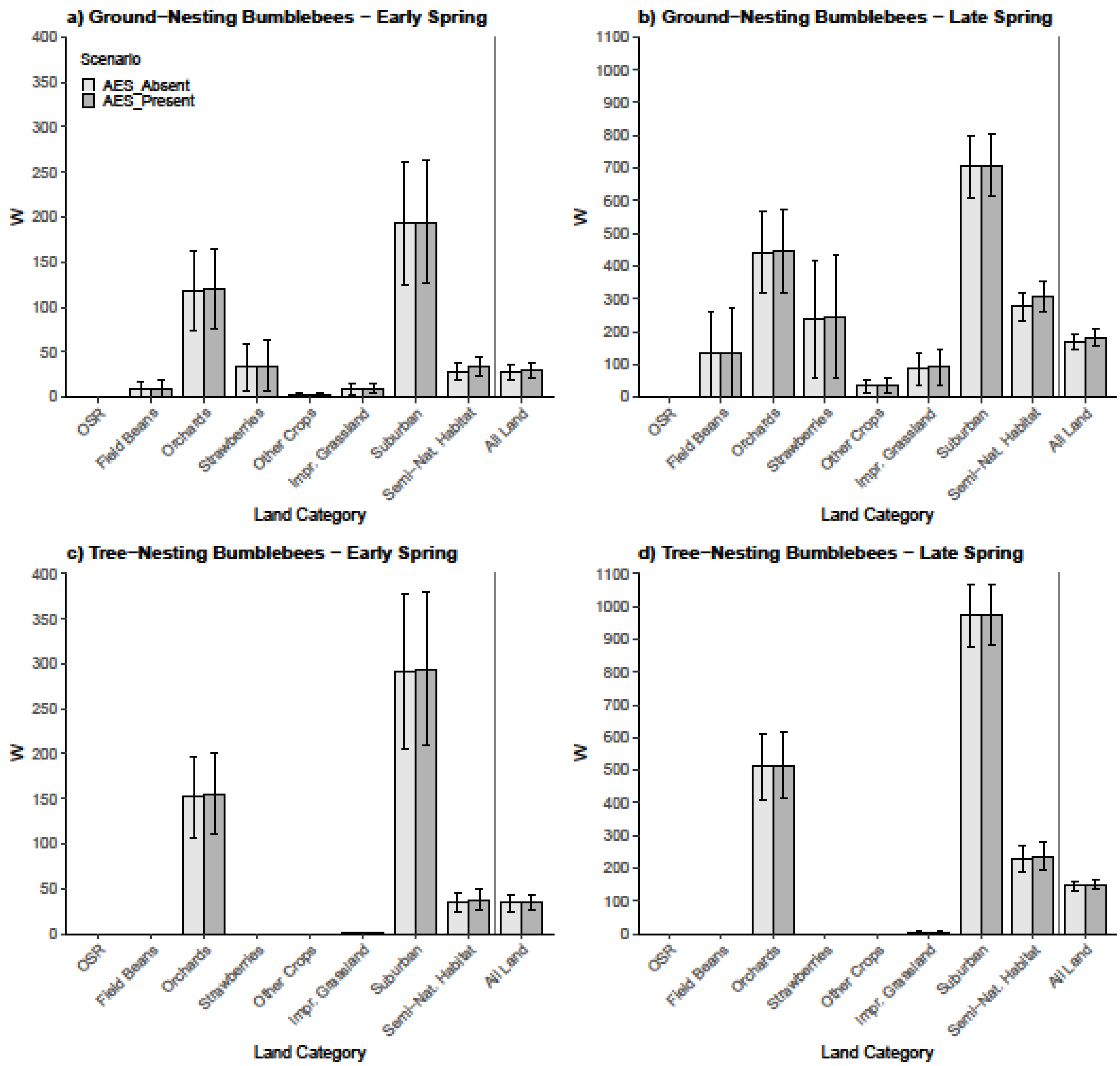

Figure S7: ***Worker generation*** *(W) by land category, scenario, and bumblebee guild. W represents the number of new workers produced on average per cell (25m²) of that land category in England during the captioned season and thus foraging in the next season.*

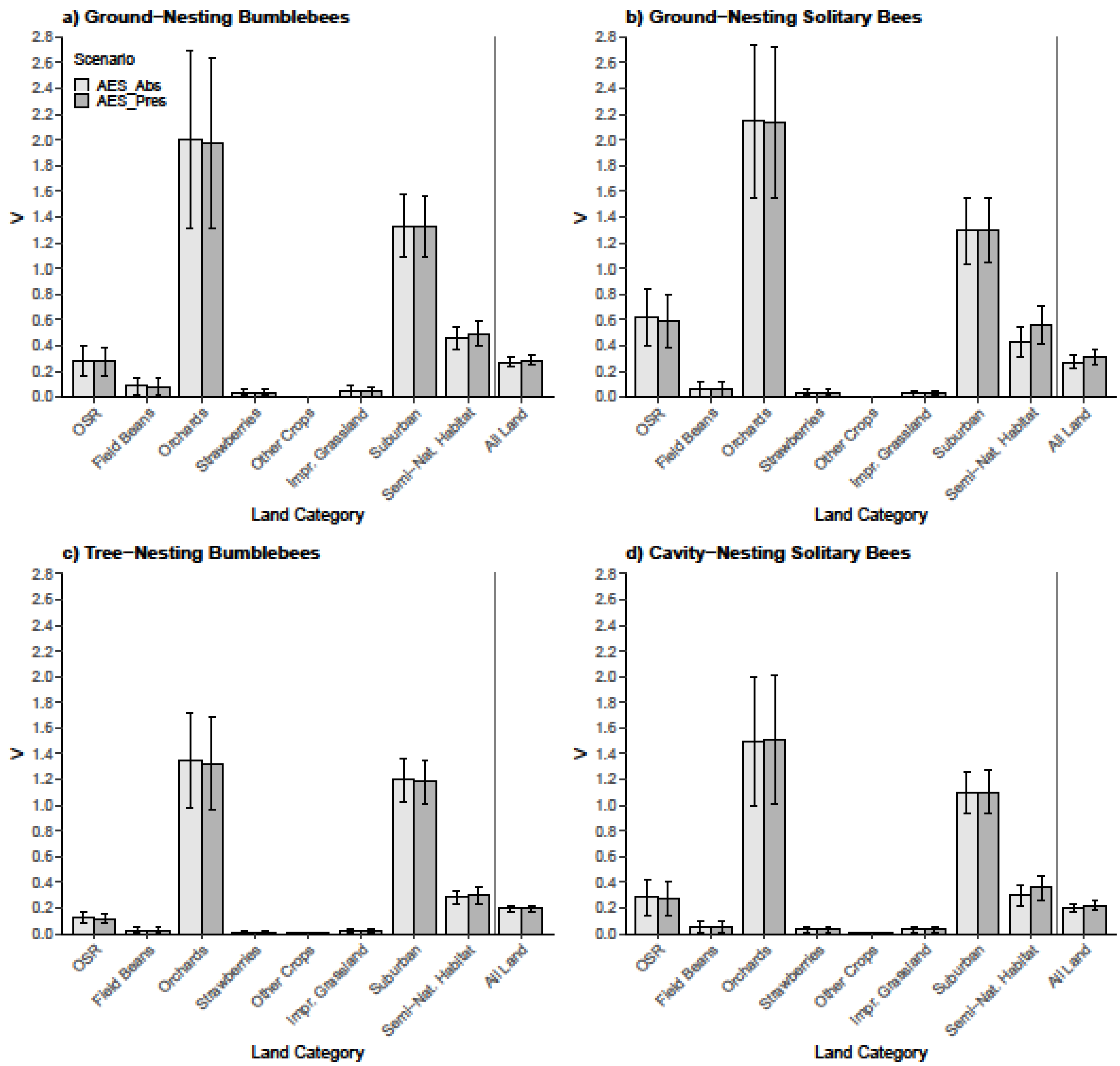

Figure S8: ***Early Spring visitation*** *(V) by land category, scenario, and guild. V represents the number of visits received on average per cell (25m^2) of that land category in England during this season. Early spring: early/mid-March – late April/early May.*

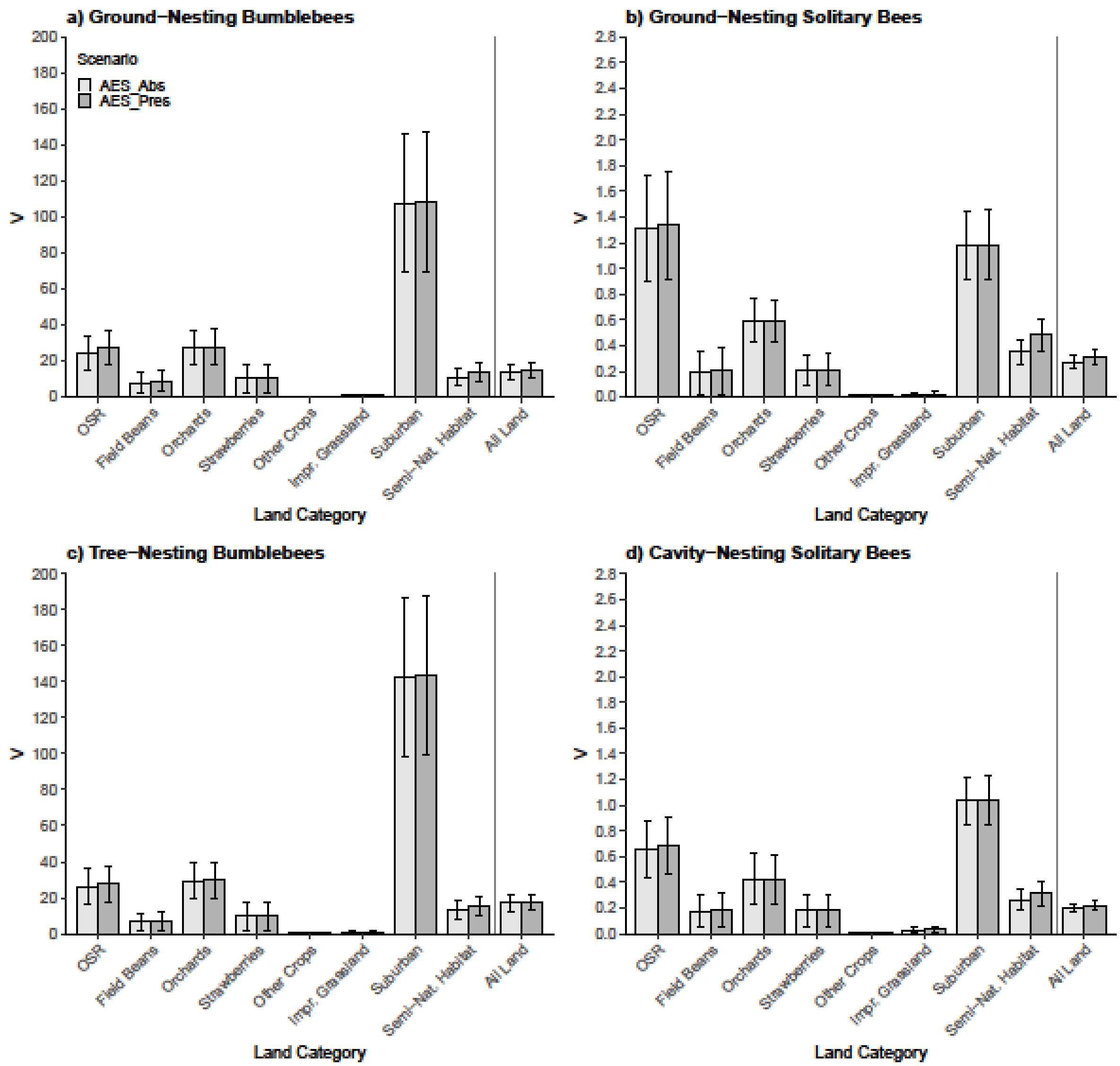

Figure S9: ***Late Spring visitation*** *(V) by land category, scenario, and guild. V represents the number of visits received on average per cell (25m^2) of that land category in England during this season. Late spring: late April/early May - early/mid-June.*

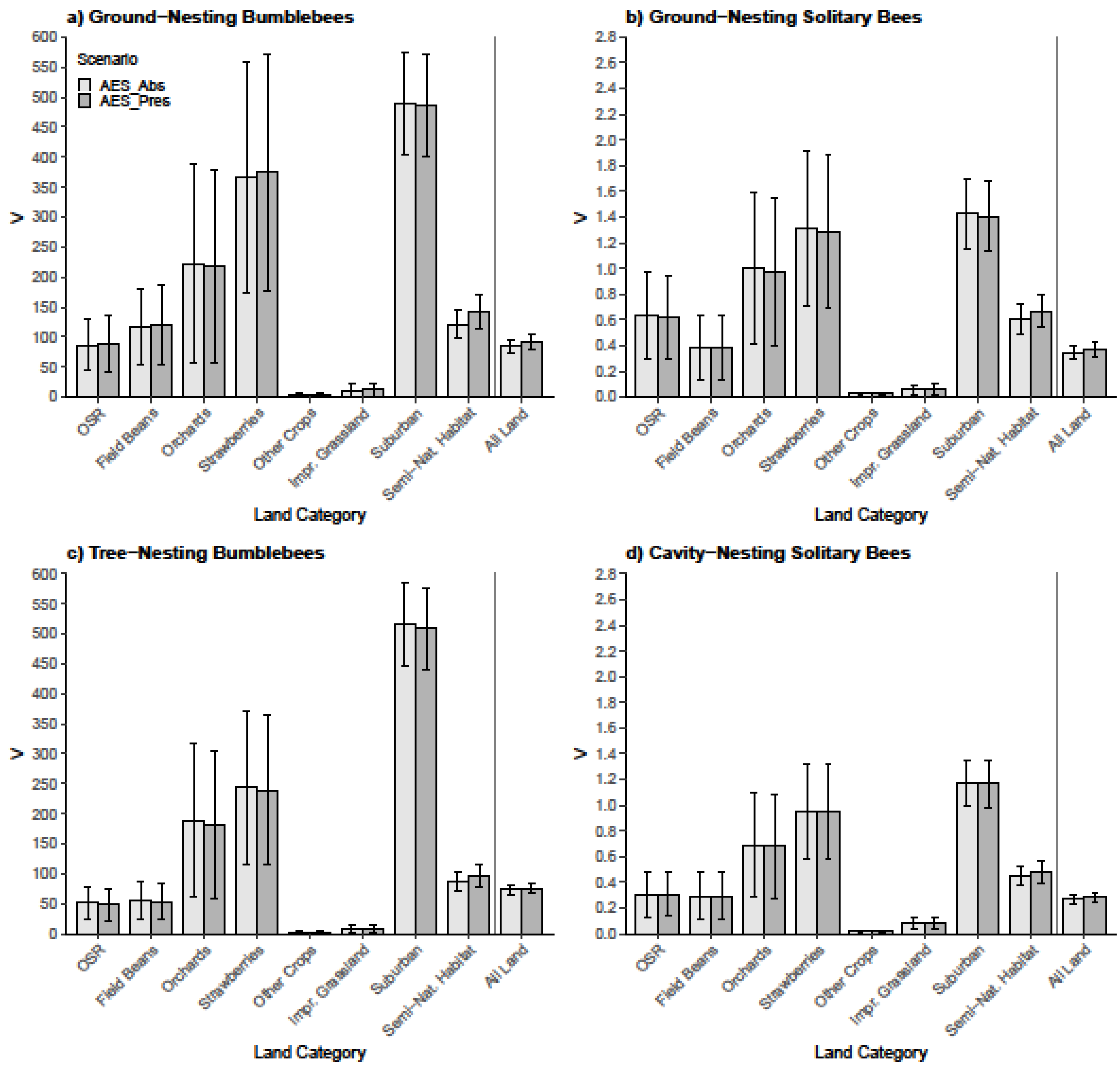

*Figure S10 : **Summer visitation** (V) by land category, scenario, and guild. V represents the number of visits received on average per cell (25m^2) of that land category in England during this season. Summer: early/mid-June – early/mid-September.*

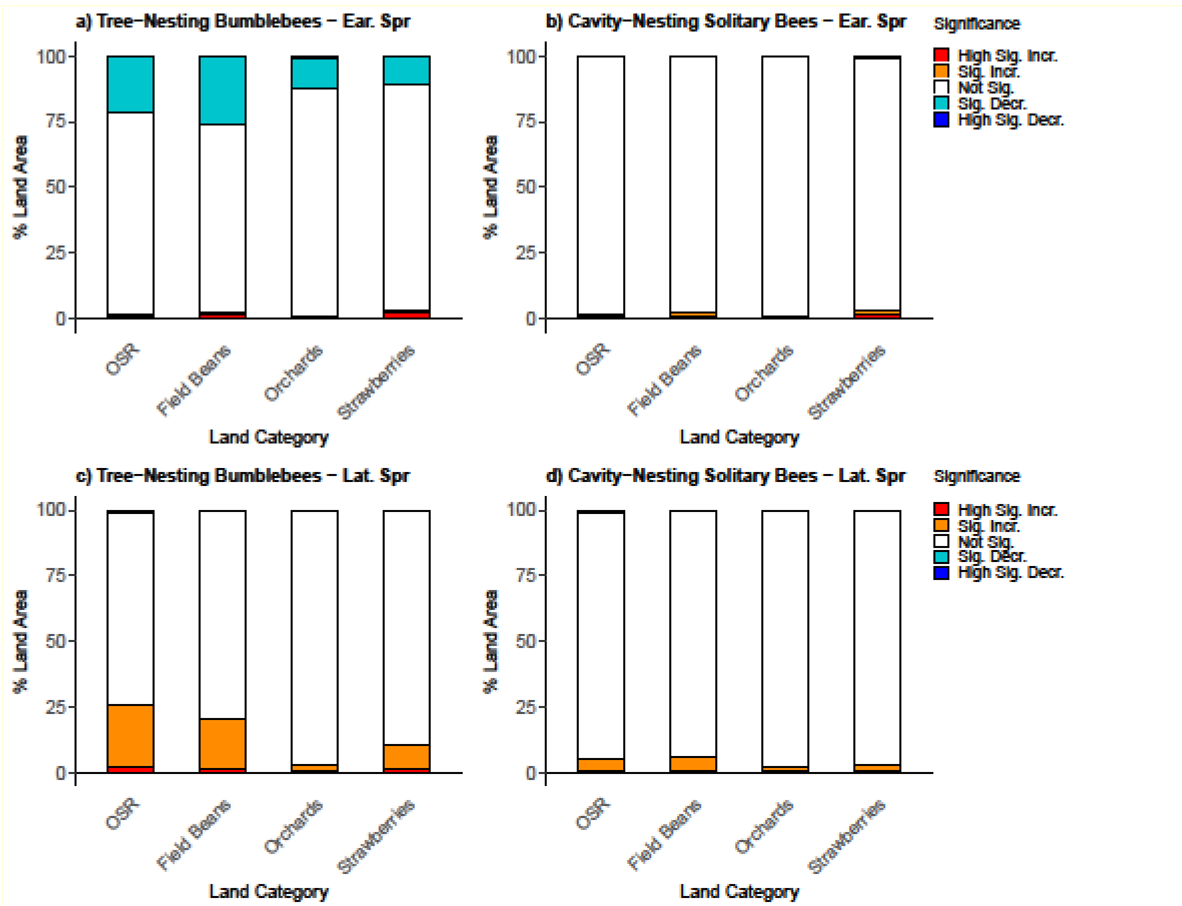

Figure S11: Percentage of land area in significance thresholds for predicted impact of Agri-environment schemes (AES) on floral visitation rate (V; visits per 25m² cell) nationally to selected land categories for tree and cavity-nesting guilds in early (a,b) and late (c,d) spring. The impact is measured as the log ratio between the scenarios with AES feature present and absent. Significance thresholds are number of standard deviations that the log ratio is above (increase) or below (decrease) zero: value >=|3| is highly significant, |2| <= value <|3|is significant. Early spring: early/mid-March - late April/early May; Late spring: late April/early May - early/mid-June.

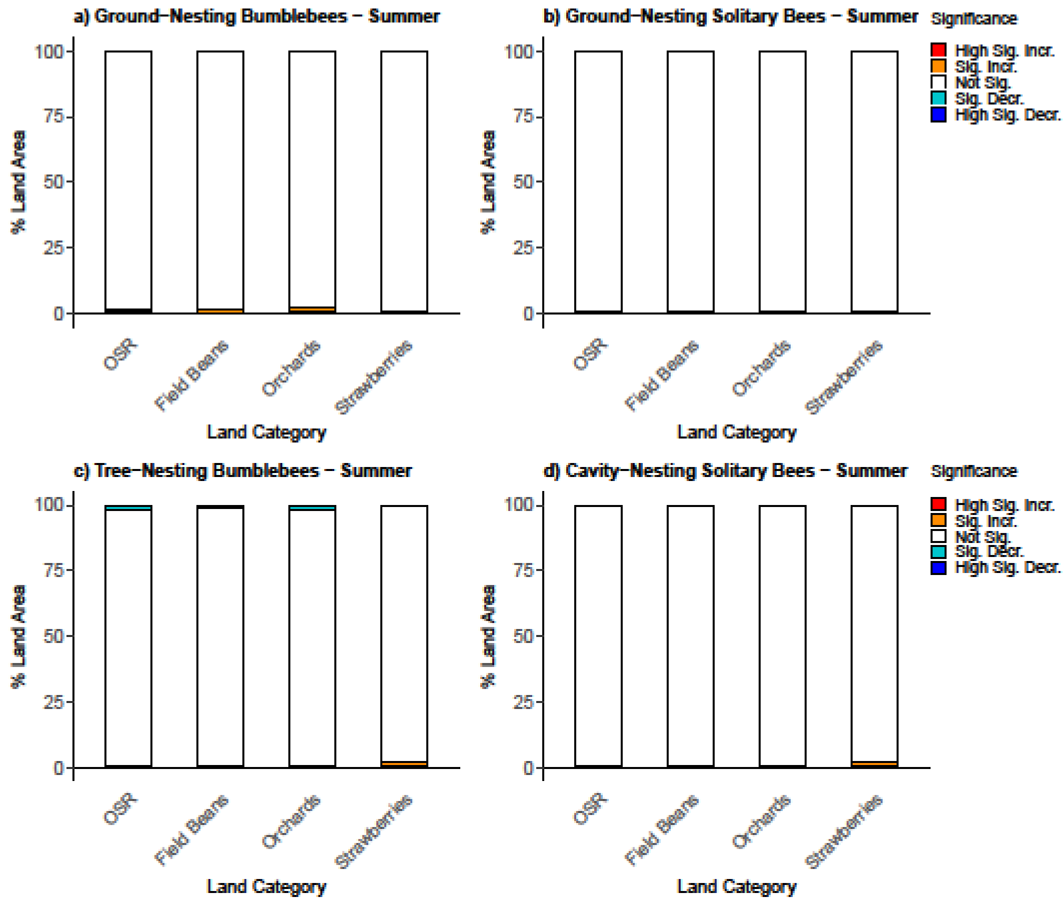

Figure S12: Percentage of land area in significance thresholds for predicted impact of Agri-environment schemes (AES) on floral visitation rate (V; visits per $25m^2$ cell) nationally to all guilds in summer. The impact is measured as the log ratio between the scenarios with AES feature present and absent. Significance thresholds are number of standard deviations that the log ratio is above (increase) or below (decrease) zero: value >=|3| is highly significant, |2| <= value <|3|is significant. Summer: early/mid-June - early/mid-September

14 Additional Map Outputs

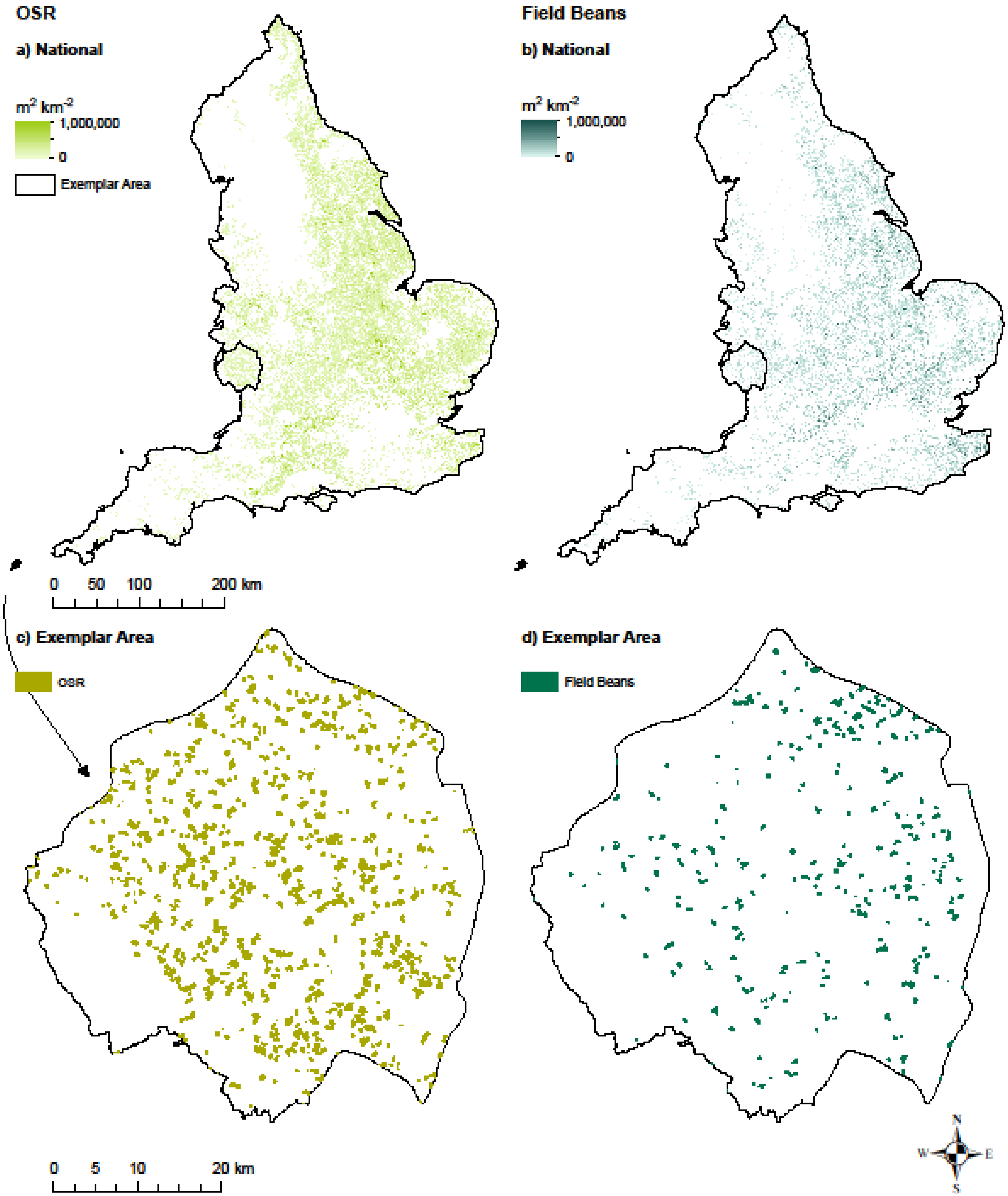

*Figure S13: **Geographical distribution of OSR and field beans** across England (a, b) and an exemplar area (c, d) in 2016. The national maps show crop density (m^2) within a $1km^2$ grid. The exemplar area maps show actual features.*

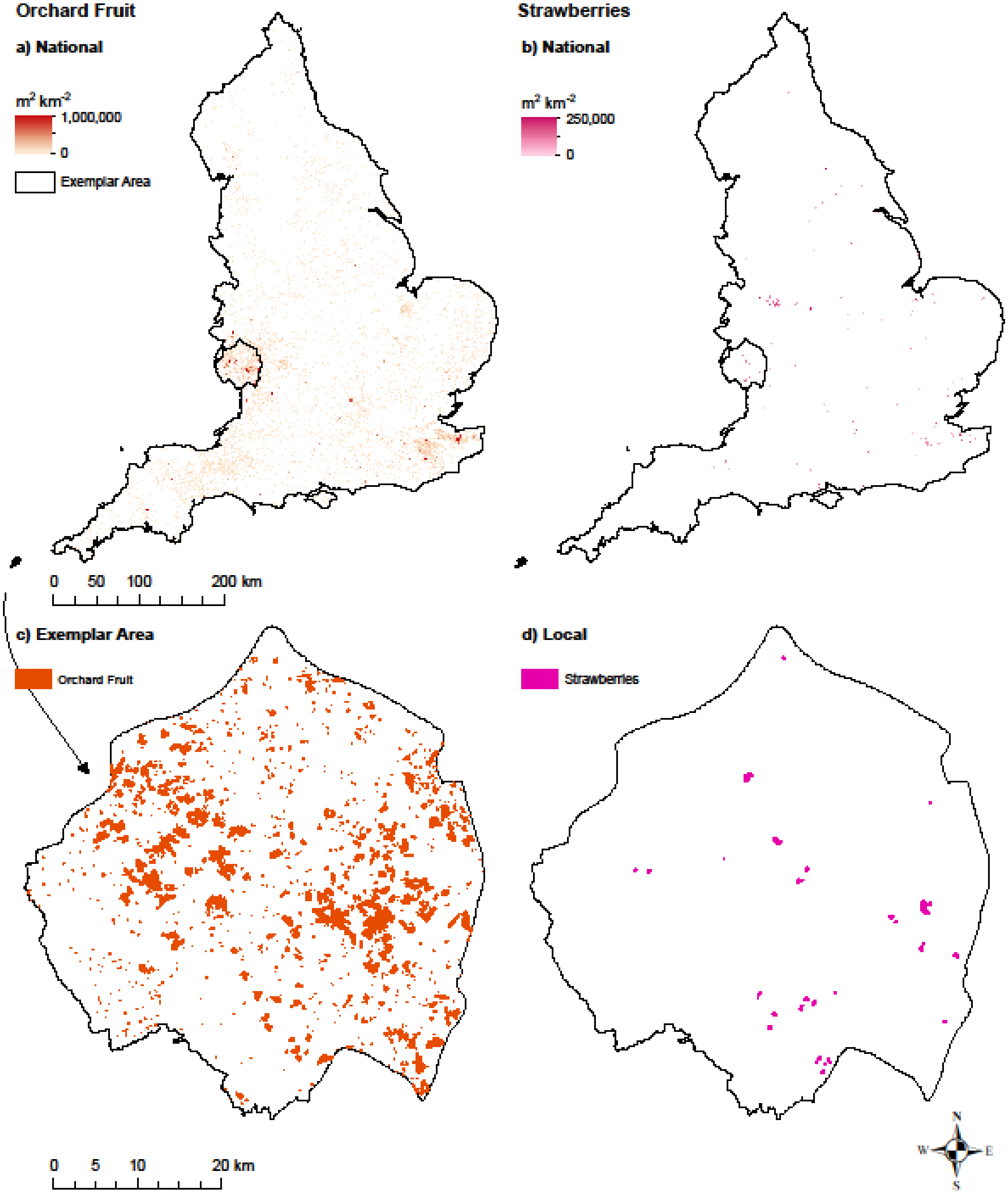

*Figure S14: **Geographical distribution of orchard fruit and strawberries** across England (a, b) and an exemplar area (c, d) in 2016. The national maps show crop density (m^2) within a $1km^2$ grid. The exemplar area maps show actual features. Strawberries refers to both strawberries and raspberries not in polytunnels.*

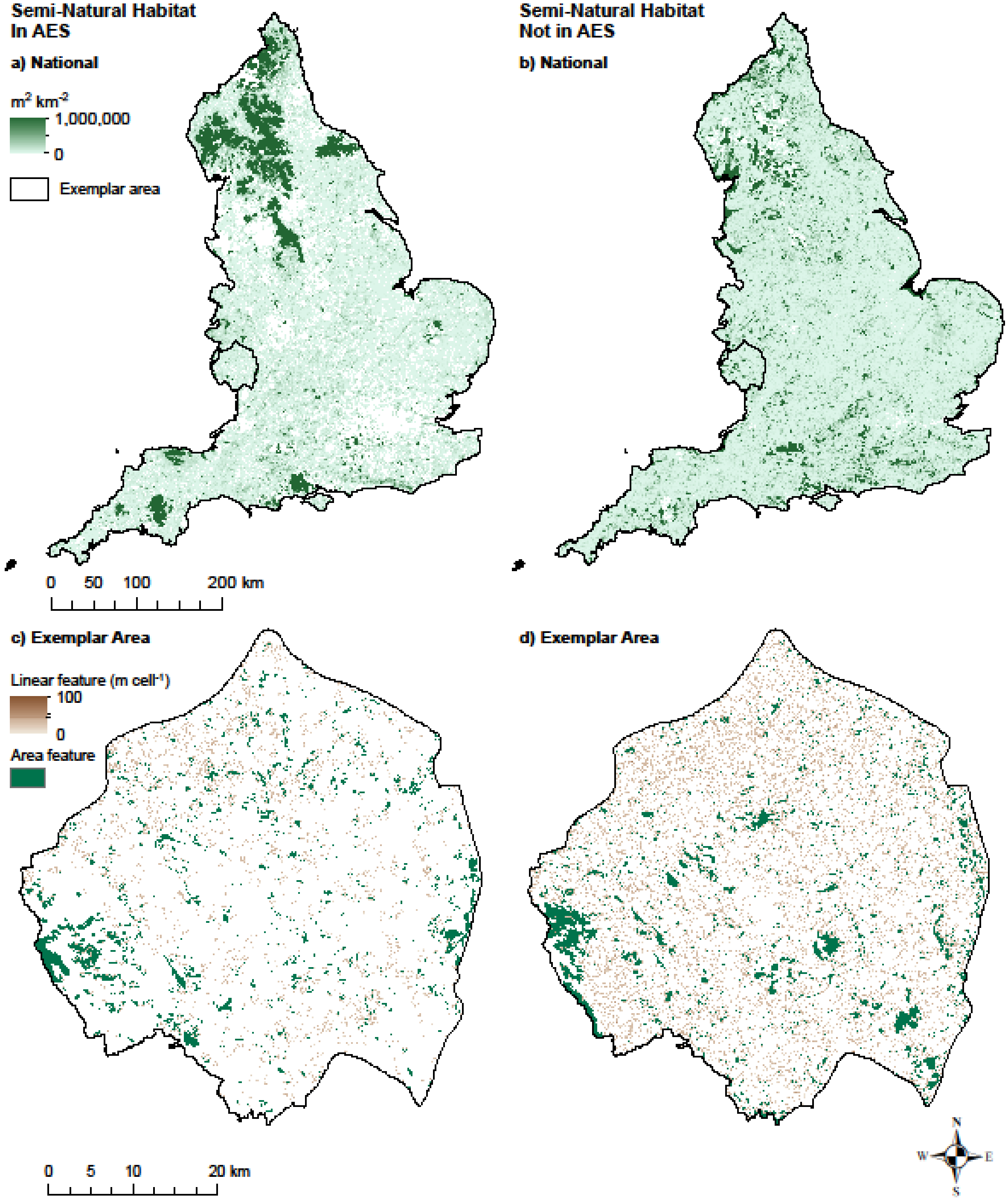

*Figure S15: **Geographical distribution of semi-natural habitat** across England (a, b) and an exemplar area (c, d). Maps a) and c) show features under Agri-environment scheme (AES) management. Maps b) and d) show features outside AES management. National maps show total area (m^2) of all features within a $1km^2$ grid. Local maps show linear feature as length (m) per cell ($25m^2$) and area feature as whole cell ($25m^2$). Semi-natural habitat includes grasslands, heathlands, wetlands, moorlands, woodland features, fallow, ley, grass margin, buffer strips, hedgerows, ditches, woodland edge.*

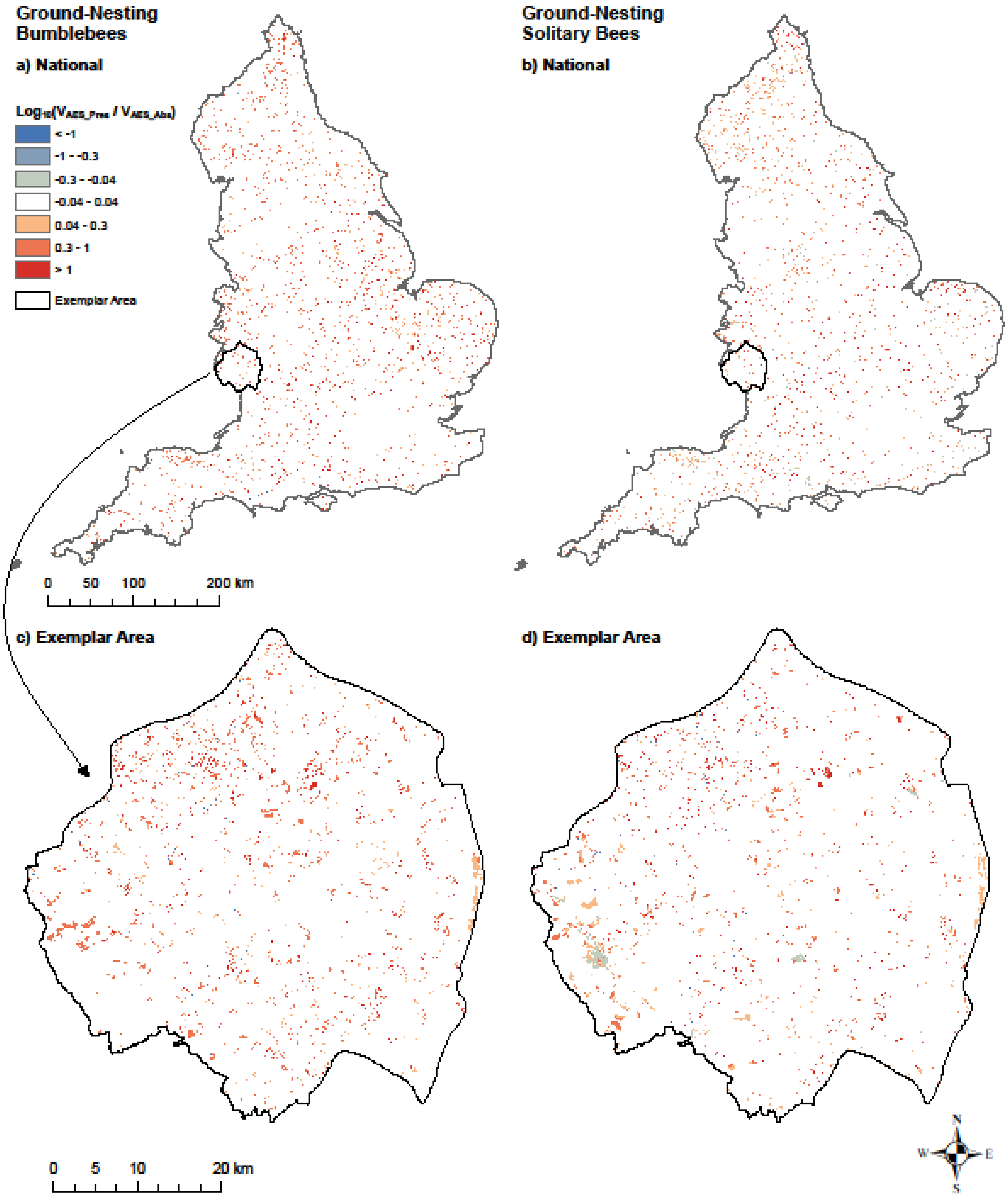

Figure S16: ***Impact of Agri-environment schemes on floral visitation rate*** *(V) for ground-nesting guilds in England for* ***summer*** *2016 at national scale (a, b) and for an exemplar area (c, d) in western England. The impact is shown as the log of the ratio of V (visitation/25m2) between scenarios with AES present and absent. Only cells with significant change are shown - where the log ratio is at least 2 standard deviations from zero. Summer: early/mid-June– early/mid-September*

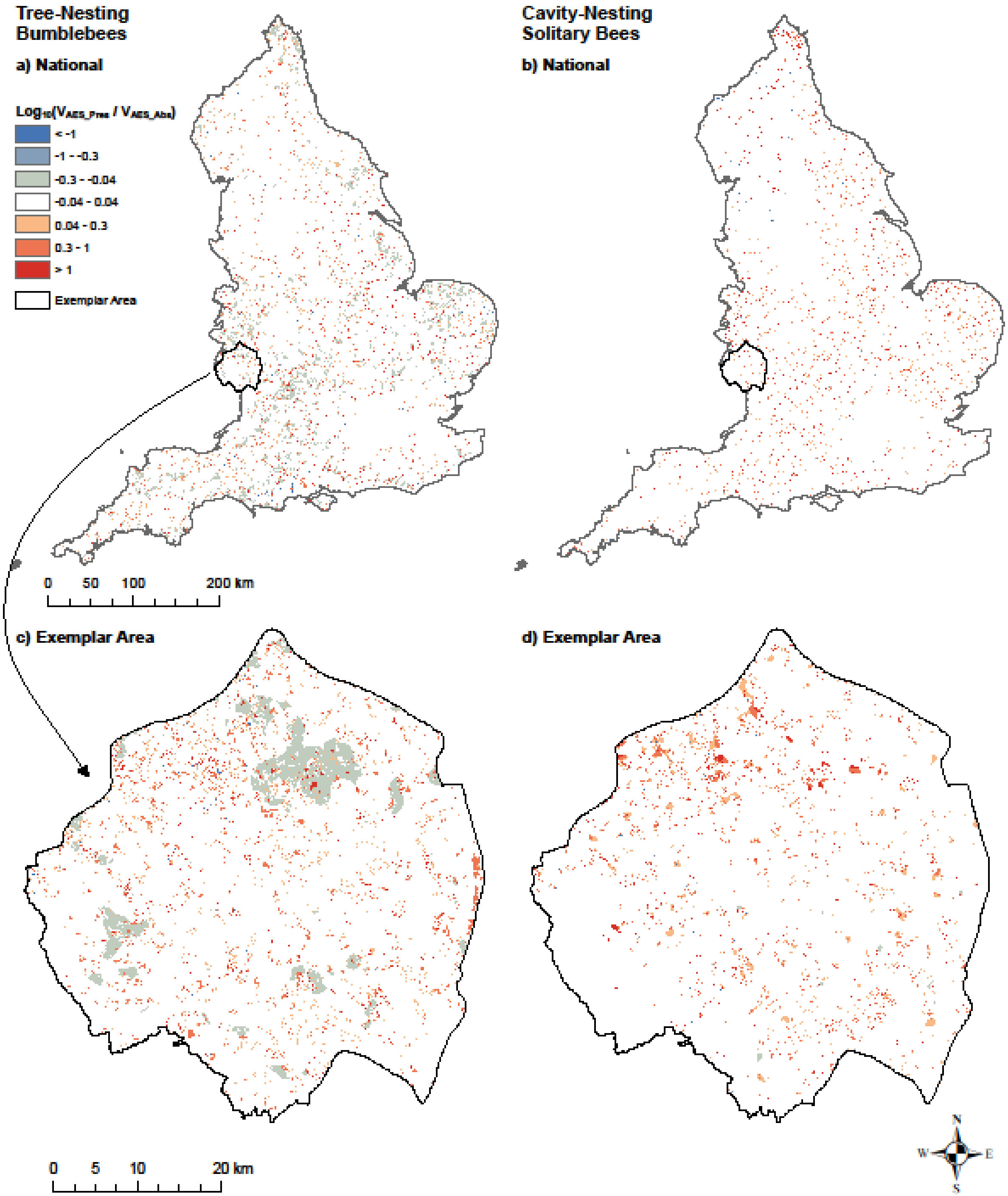

*Figure S17: **Impact of Agri-environment schemes on floral visitation rate** (V) for tree and cavity-nesting guilds in England for **early spring** 2016 at national scale (a, b) and for an exemplar area (c, d) in western England. The impact is shown as the log of the ratio of V (visitation/25m2) between scenarios with AES present and absent. Only cells with significant change are shown - where the log ratio is at least 2 standard deviations from zero. Early spring: early/mid-March – late April/early May.*

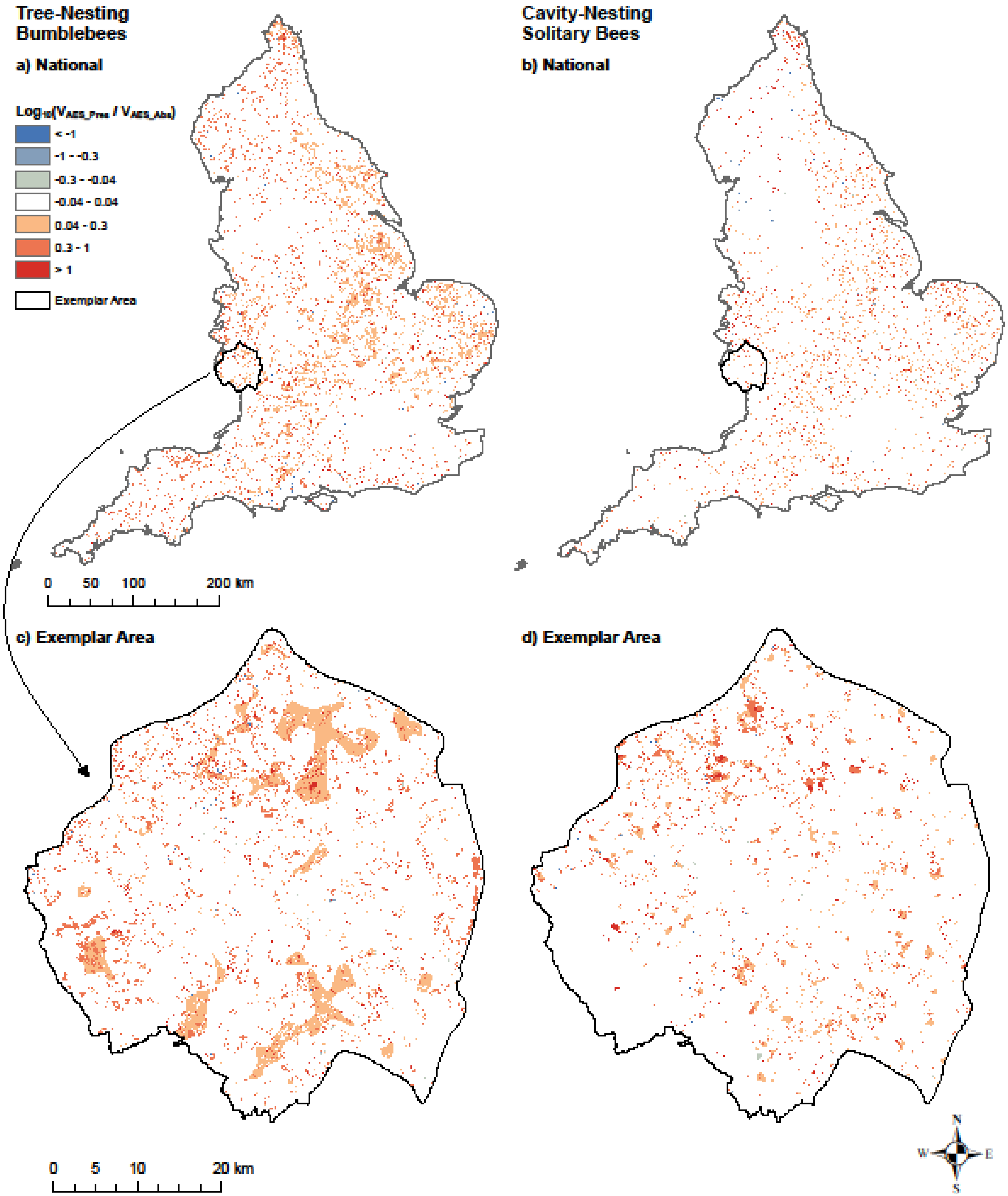

*Figure S18: **Impact of Agri-environment schemes on floral visitation rate** (V) for tree and cavity-nesting guilds in England for **late spring** 2016 at national scale (a, b) and for an exemplar area (c, d) in western England. The impact is shown as the log of the ratio of V (visitation/25m2) between scenarios with AES present and absent. Only cells with significant change are shown - where the log ratio is at least 2 standard deviations from zero. Late spring: late April/early May - early/mid-June.*

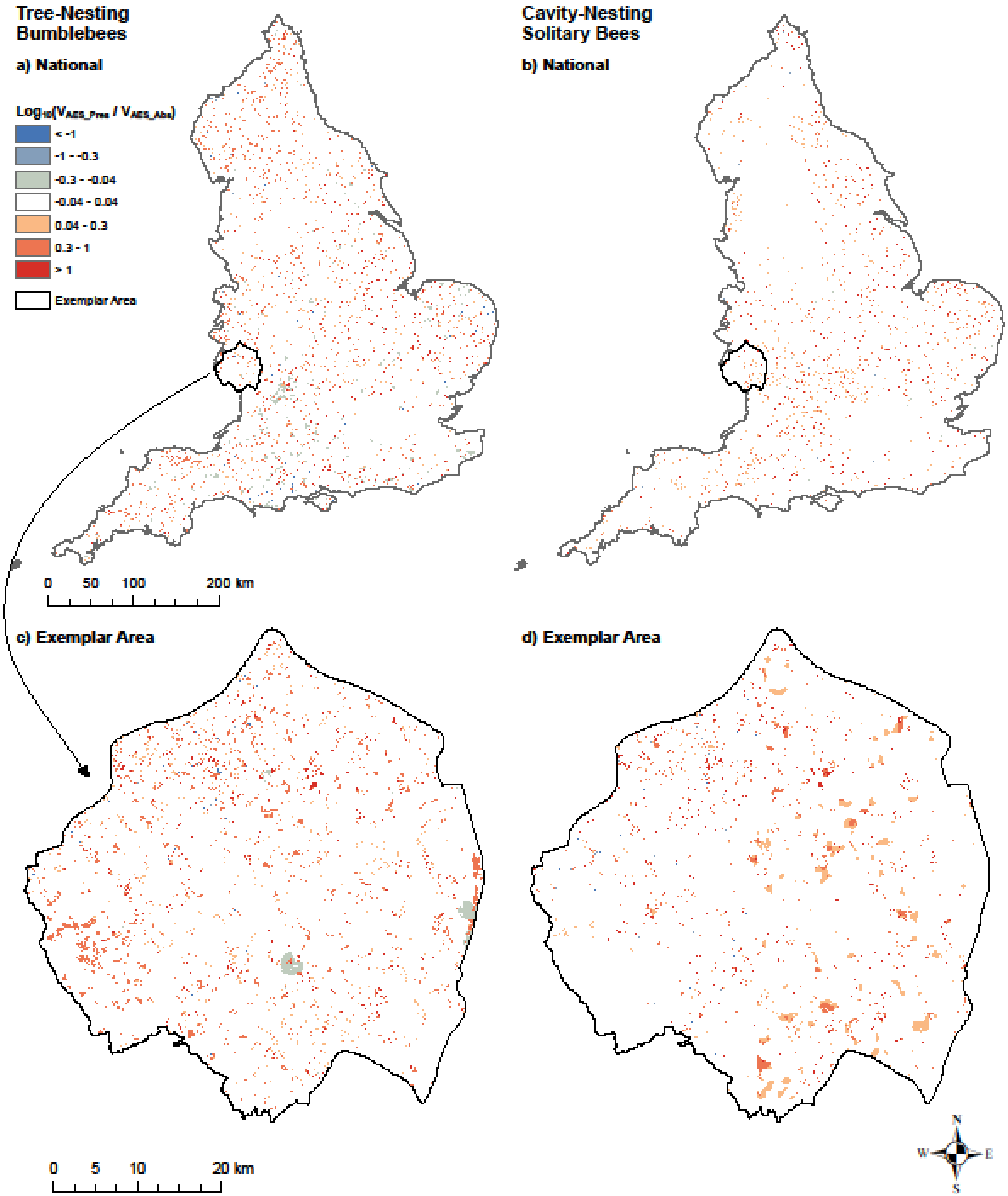

*Figure S19: **Impact of Agri-environment schemes on floral visitation rate** (V) for tree and cavity-nesting guilds in England for **summer** 2016 at national scale (a, b) and for an exemplar area (c, d) in western England. The impact is shown as the log of the ratio of V (visitation/25m2) between scenarios with AES present and absent. Only cells with significant change are shown - where the log ratio is at least 2 standard deviations from zero. Summer: early/mid-June– early/mid-September*

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