Final report for the project:

‘Synthesizing evidence in the economics of farm environmental biodiversity‘

Funded by the Natural Environment Research Council

Grant ref: NE/W007495/1

15th October 2022

Riccardo Scarpa, Ashar Aftab, Daniel Leppert and Sim Reany

Durham University Business School, Durham University, Durham, U.K.

Introduction

Effective agri-environmental policies are needed to ensure the sometimes opposing but crucially important goals of sustaining productive agriculture while maintaining landscape biodiversity and ecosystem services are met. The planned reform of UK agricultural policies following Brexit should support these goals while wrestling with the consequences for the sector from leaving the single market and the growing threat of climate change.

This research project focuses on factoring biodiversity values and designing cost-effective spatially targeted agri-environmental schemes. This is achieved by focusing on farmers’ commitment to supporting ecosystem services where such services have the most significant impact. Data-driven tools are used to estimate the multifunctional value of natural landscapes and design contracts that support both biodiversity and flood management. The underlying concept is that of providing schemes that encourage and reward farmers for collaborating with their neighbours to maximise habitat gains from relatively small individual commitments. In this project some ways are proposed to limit the costs to the sector and ensure the greatest return on future public spending. This cutting-edge interdisciplinary research will interest a broad spectrum of academics researching agri-environmental- and ecological economics, ecology, environmental management, and land use policy. These include research staff at SEPA, Natural England and DEFRA, who have shown considerable interest in follow-up projects based on this line of research.

Academics will also benefit from the estimation of land-use policy transaction costs. It is acknowledged that excluding transaction costs from analysis distorts considerably policy outcome forecasts. By quantifying the transaction costs of collaborative agri-environmental schemes via a discrete choice experiment and making them available to academics, our research will significantly improve the reliability of academic research into multifunctional land-use policy in the broadest possible sense.

We have met most aims outlined in our initial proposal and are on track to meet the rest:

a) Our systematic review of the literature, focusing on biodiversity values is included in this report, with a special focus on land management schemes and fragmentation of pollinator habitats. ;

b) We present practical methodology for cost-benefit analysis of agri-environmental schemes for biodiversity conservation, and we have successfully run discrete choice experiments with 309 farmers. ;

c) Our DCEs and SDM reveal predictors of successful habitat connectivity improvement via ELM schemes.

Despite delays due to the pandemic and difficulties reaching farmers to participate in the survey, we are on track to publish the results and associated spatial targeting maps in peer-reviewed outlets in the coming year.

2. Literature synthesis on biodiversity values

Economists have long discussed the value of biodiversity (Brock and Xepapadeas 2003). Heal (2000) recognised that although biodiversity and associated “ecosystem services” may seem intuitively valuable and important, their market value is more ambiguous. Some studies (e.g. Costanza et al. 1997; Holling 2001) have focused on how natural resources may be extracted for short term economic gain at the expense of the long term health of ecosystems upon which those resources depend. These relate to the indirect use value of an ecosystem (Nijkamp et al. 2008), where it supports marketed natural resources. Due to the complexity of ecological systems, such values may not be obvious (Hanley and Perrings 2019). Attempts have also been made to estimate the recreational use value of biodiversity (Lundhede et al. 2014; Giguere et al. 2020), such as the value people put on the ability to witness animals and plants in their natural habitat (Yao et al, 2014, 2019) and nature reserve status of woodlands (Scarpa et al. 2000). Neither of these values is obvious to estimate. Revealed preference techniques, such as the travel cost method, are expensive and often impose limitations on the types of ecosystems that can be valued, such as those national parks that are subject of many recreational visits. Hedonic models have also been criticised because hedonic attributes are necessarily defined by the researcher and may not reflect what people consider salient (Vatn and Bromley 1994).

Similarly, hypothetical contingent valuation methods may suffer from drawbacks such as hypothetical bias where willingness to pay for biodiversity is overstated. A second stated preference method, choice experiments, attempts to reduce hypothetical bias by presenting respondents with pre-defined options instead of open-ended elicitations of value. Research on these issues is ongoing, see, e.g. Carson (2012), Hausman (2012), Haab et al. (2013) and Johnston et al. (2017), and in this section we present values estimated with different methods.

To define the universe for this literature synthesis, we initially searched for peer-reviewed research without geographical constraints, ecosystem service or valuation method. The search string “subject CONTAINS ‘biodiversity’ AND ‘economic’ AND ‘value’” were entered into the Durham University library database and returned 1,632 article results. Figure 2.1 summarises the 300 most relevant results in terms of year of publication and journal.

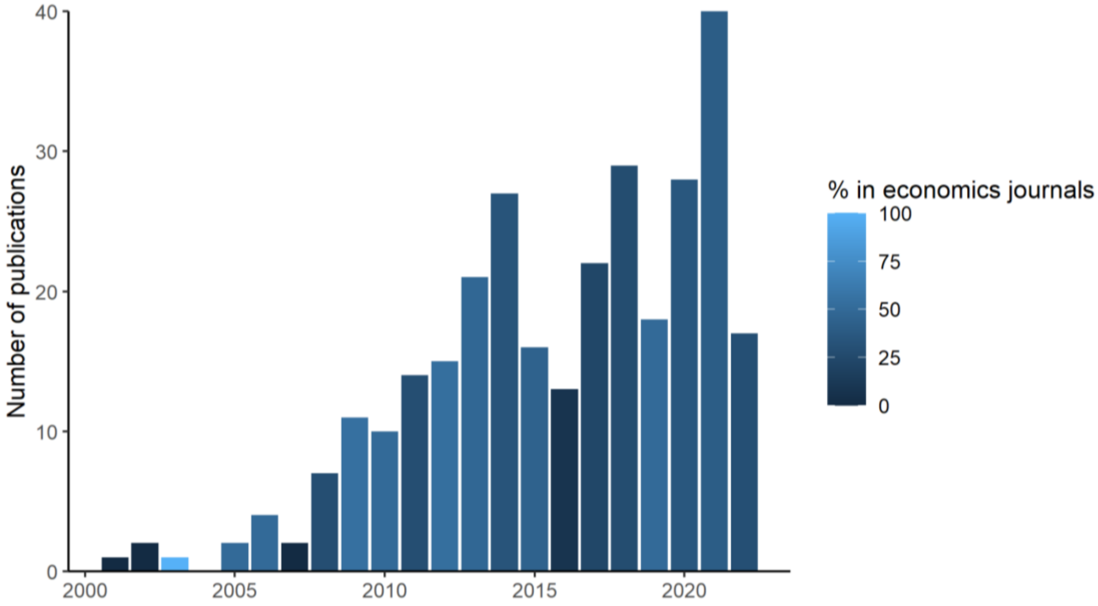

Figure 2.1: Evolution of publications on the valuation of biodiversity

As figure 2.1 shows, since the early 2000s the peer-reviewed literature on biodiversity values has grown rapidly, from a rather negligible output. A Web of Science review by Porto et al. (2020) with a sample of 100 identifies publication peaks in 2013, 2014, and 2016. The proportion of research published in economics journals has remained relatively stable at around 35%. *Ecological Economics* (Elsevier) accounts for the large majority of economics publications on the topic, followed by *Environmental & Resource Economics* (Springer) and the *American Journal of Agricultural Economics*. The remaining research is published in a variety of ecology and conservation journals. Figure 2.2 shows the evolution of empirical methods over time within our sample. Among empirical valuation research, analysis attributing biodiversity to crop yields and contingent valuation methods are most common. Discrete choice experiments and revealed preference methods are rare, accounting for only circa 2% of sampled articles. Articles that did not include in either their title or abstract a reference to an established valuation method, but were theoretical or exploratory in nature, were excluded in the next step.

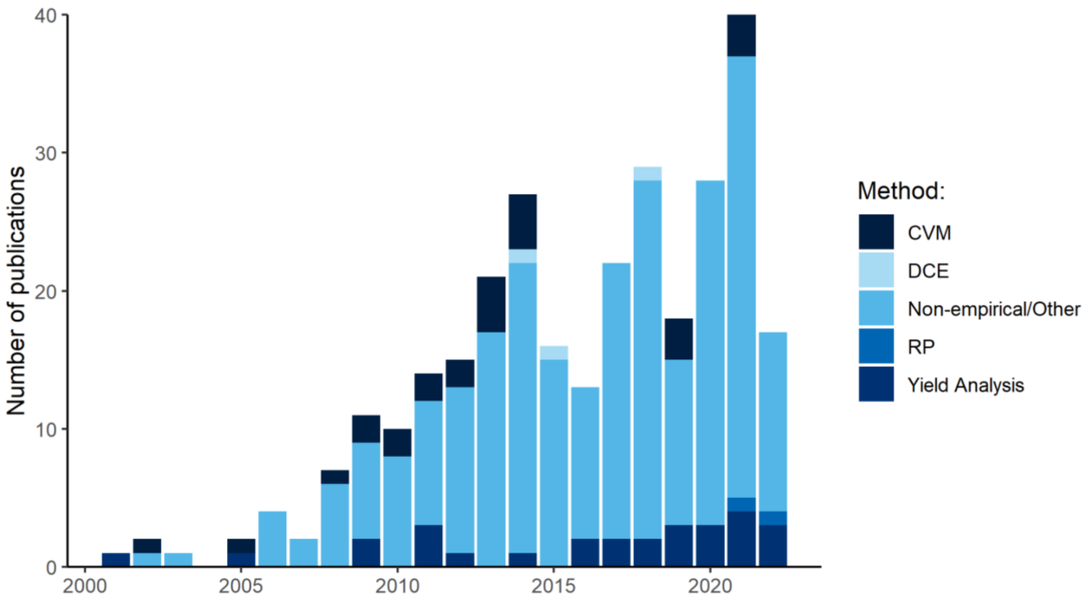

Figure 2.2: Evolution of valuation methods over time

For the literature synthesis, we moved on with the following procedure: We limited the scope to insect pollinators and the economic value of pollination. We motivate this restriction on the following grounds:

- Hanley and Perrings (2019) identify pollination as a key ecosystem service contingent on biodiversity and a determinant of ecosystem function;
- A previous UK study links changes in land use to a decline in pollinator populations (Donkersley et al. 2014);
- We model the impact of our proposed agri-environmental scheme on honeybees in the UK using species distribution modelling

From the initial sample of 1,632 articles, we further restrict the sample with the query “subject CONTAINS ‘pollinator’ OR ‘pollination’ AND any field CONTAINS ‘biodiversity’”, returning 53 results, of which 16 focused on the honeybee (genus: *Apis*). The most represented journals were *Ecological Economics* and *Economic Entomology*. The sample includes both stated preference- (Breeze et al. 2015) and yield analysis studies (Breeze et al. 2021, Garratt et al. 2014). Yield analysis can be done by estimating the market value of the pollinated crop share, described in Breeze et al. (2021) as the [pollination] dependency ratio.

In a literature review, Klein et al. (2007) show that pollinators impact food supply globally, as pollinator-dependent crops contribute to ~35% of overall crop production by volume. It is estimated that 87 of the 115 major crops grown worldwide depend on biotic pollination to set fruits and seeds to at least some degree. Globally, the economic value of pollination is estimated at US$225 billion (Giannini et al., 2015). Pollination is essential for farming apples, cacao and vanilla and of great importance for buckwheat, pears, and berries. (Klein et al. 2007) The use of animal pollinated biofuel crops is growing, with the cultivation area of oilseed rape, sunflowers and soybeans increasing by 4.2 million hectares (32%) across Europe between 2005 and 2010 (Breeze et al. 2014). The pollination dependence rankings across crops shown in Klein et al. (2007) also need to be evaluated in the context of their total economic value. For example, Breeze et al. (2021) show that 50% of the UK pollination benefit come from oilseed rape and strawberries. While pollinator dependence for the former is moderate, it is widely grown.

Powney et al. (2019) and Potts et al. (2016) present data showing a reduction of wild pollinator populations at the regional level, especially within Europe and North America. Most studies focus on bees, particularly honeybee and bumblebee species, with a smaller number involving hoverflies and lepidopterans. The causes of pollinator decline include the indiscriminate use of pesticides, biological invasions, genetically modified (GM) crops, intensification and expansion of agricultural practices and parasites (Dicks et al. 2016; IPBES 2016; Potts et al. 2016), as well as habitat loss and fragmentation associated with farming and urbanisation (Potts et al. 2010; Donkersley et al. 2014; Xiao et al. 2016). Properly targeted agri-environmental schemes provide measurable improvement in fragmented landscapes (Donald and Evans 2006). Understanding how land management affects pollinator abundance and diversity in combination with other drivers is necessary to design more targeted, adaptive management strategies at national scales (Garibaldi et al., 2020).

Analysis of cropland in the UK since 1984 indicates that insect-pollinated crop area has risen by 57.5%, covering 848,946 hectares of UK cropland in 2007, growing at an average rate of 21,250 ha per year. This represents 20.4% of the 2007 UK cropland. Recent research suggests that the occupancy of bee and hoverfly species has declined by an average of 25% across Britain since 1980, particularly among specialist species (Powney et al., 2019). A comparative study of European honeybee colonies showed that while there were honeybee deficits (insufficient stocks to supply 90% of national demands) in 23 countries in 2005 and 22 in 2010, only the UK and Moldova had a pollinator stock capacity below 25%. (Breeze et al., 2014)

If pollination services decline, then prices for insect-pollinated crops will rise due to their lower yields. This will result in a loss of economic welfare as people are forced to pay more to obtain the same quantity of these crops, limiting their capacity to spend their money on other goods and services.

From our sample of 53, we exclude non-empirical research and restrict our sample further to studies carried out in the UK. The values are summarised in table 2.1. The total contribution of pollinators to UK agricultural value is estimated between £188.7M and £379M per year. This represents between 1.7% and 3.5% of total crop values in 2021 (UK Government 2022). In a 2020 synthesis of the international pollination values, Porto et al. (2020) find that across a sample of 100 articles, the economic benefits of pollination services have not yet translated into targeted policymaking.

Table 2.1: Summary table of UK pollinator values

Article	Crop	Method	Published value
Breeze et al., 2021	Total	Yield Analysis	£188.7M/year
Breeze et al., 2015	Total	SP	£379M/year
Garratt et al., 2014	Apples	Yield Analysis	£36.7M/year
Garratt et al., 2016	Apples	Field survey	£91.2M/year

Note: The articles in Table 2.1 were selected from the 16 that empirically presented values of honeybee pollination by restricting the sample further to studies from the UK.

3. Methodology

As set out in our initial grant proposal and in the following project execution, we followed two separate but complementary methodological approaches within the scope of the awarded grant. First, we carried out two discrete choice experiments (DCE) with a sample of 309 farmers in northern England, mostly from Cumbria and Northumberland. The DCEs aimed to estimate farmers’ willingness to participate in an environmental land management scheme to create habitat patches in agricultural landscapes.

DCEs were first used to value environmental resources by Adamowicz et al. (1994) and have since been a popular method due to limited market data for environmental services (Hoyos 2010). Our proposed scheme is designed to be conceptually similar to the proposed Landscape Recovery scheme piloted by Defra in 2022 and planned to launch in 2024 (Defra 2022). The Landscape Recovery scheme will provide funding for long-term, large-scale projects that “restore priority habitats, improve habitat quality, and increase species abundance” in England by, e.g. building or linking nature reserves, creating woodlands, or improving habitat connectivity (Defra 2022). Additionally, on top of an annual grant payment, our scheme features a bonus for coordinating with one or more neighbouring farmers to connect habitats with strips of set-aside land that improve connectivity (Correa Ayram et al. 2016).

Second, we estimate the effect of land use choices on honeybee abundance through species distribution modelling. We will combine the two methods in a future project in which we produce a cost-benefit analysis of the spatially targeted land management scheme. The scheme's cost is obtained from the DCE, in which we estimate the payment farmers require to participate. The benefit is taken from the literature review of pollination values and the outcome from the species distribution model. We will next present our hypotheses. The following sections will describe these methods in turn.

3.1 Hypotheses

Scheme 1 involves an annual payment to create NFM features on retired land, either by planting trees or by natural regeneration, as detailed in the proposed hypothetical contract between agency and farmer. No coordination is involved. Scheme 2 includes a coordination bonus to connect NFM features via ecological corridors between farms.

Since retiring farmland to create natural features carries an opportunity cost from the lost agricultural output, we expect farmers to require compensation to participate in the schemes. We refer to the required compensation as the reservation price or “willingness to accept”. It follows that a higher opportunity cost should result in a higher reservation price, e.g. to create features on high-yield farmland over rough, steep grazing or in the middle of a field instead of along farm boundaries or river edges. Conversely, small farms where agriculture is not the primary source of household income, face lower opportunity costs and are expected to enrol at lower level of compensation.

Crucially, we seek to study the willingness to collaborate with neighbouring farmers to improve habitat connectivity. We expect that more established social ties with neighbours lowers the cost of communicating, negotiating, and coordinating the creation and maintenance of ecological corridors. We differentiate between general social ties evaluated via self-rated engagement in the community and farming/specific collaboration. Farmers with strong social networks are likely more willing to participate in schemes involving coordination.

3.2 Discrete choice experiment

A discrete choice experiment is a survey in which respondents are asked to choose their preferred option from a set of discrete alternatives. Each option is associated with a set of characteristics, or attributes, that differentiate it from the other options. The theoretical foundation for DCEs is hedonic consumer theory (Lancaster 1966), in which goods or services can be broken down into attributes that each contribute differently to an individual’s utility from consuming that good or service. The respondent’s choices are assumed to be determined by their tradeoffs between the attributes, and the respondent is expected to choose the alternative that maximises their net utility. Respondent i’s utility for each alternative j is assumed to be continuous and a function of the attributes k and their associated so-called attribute coefficients.

$$u_{ij} = \sum_{k=1}^{K} \mathbf{x}_{kj}{}' \boldsymbol{\beta}_{ki} + \varepsilon_{ij}$$

From the perspective of the researcher utility is stochastic, as the unobserved utility terms ε_{ij} are independently Gumbel-distributed across alternatives and respondents. The attribute coefficients or “attendance” $\boldsymbol{\beta}$ describe the importance a respondent assigns to each attribute. A positive coefficient implies that an increase in a (continuous) attribute improves utility and raises the probability of the alternative being chosen. Categorical attributes measure the shift in probability of choice from some baseline value. (McFadden 1974) Attributes of another alternative or even the existence of another alternative should not enter the utility of alternative j. This ensures consistency with utility maximisation, where improvements in one attribute can compensate for a worse performance for another attribute. Of course, the probability of choosing an option still depends on the existence and attributes of other alternatives. The coefficients were estimated using conditional logit model (Train 2009).

The specification of alternatives and attributes into “choice tasks” is the DCE design. The design aims to maximise efficiency, or the information obtained about the respondent’s preferences. We obtain a D-efficient design by assigning uniformly distributed priors for the coefficients and choosing the design which minimises the determinant of the variance-covariance matrix, the D-error (Sandor and Wedel 2001, Scarpa and Rose 2008, Rose and Bliemer 2009). It is the most widely used measure of efficiency because of its insensitivity to the magnitude of the scale of the parameters (Street 2005). By anchoring the alternatives in our choice experiments with real-life ELM schemes and by reference to economic theory (Parkhurst and Shogren 2007, Polasky et al. 2008) and recent UK studies (Hurley et al. 2022, Coyne et al. 2021), we improve the accuracy of our priors. When priors are well informed, efficient designs are also likely to produce the smallest errors (Ferrini and Scarpa 2007).

Respondents were asked to choose their preferred option from two schemes and a status-quo alternative reflecting nonparticipation. Each choice experiment consisted of a block of eight choice tasks, assigned in a random order. Deciding on the number of choice tasks is a tradeoff between insufficient statistical power (increasing the likelihood of type II errors) and cumulative respondent fatigue, which may increase error variance. To navigate this tradeoff, we follow the procedure in de Bekker-Grob et al. (2015) and set the target sample size at 300 as per our project proposal. With eight choice tasks, achieving a likelihood of type II errors below 5% requires a minimum sample of 278 for DCE 1 and 291 for DCE 2. The order between DCE 1 and 2 was also randomised among respondents to minimise any bias resulting from respondent fatigue (Johnston et al., 2017). Example choice cards are shown in the appendix.

We recruited participants from the north of England to participate in the survey, including mostly from the following counties: Cumbria, Northumberland and County Durham. Farmers were identified from the county electoral rolls and contacted via mail. Invitations to participate were mailed out in two rounds approximately three weeks apart to 2,401 addresses. In addition, reminders were sent out once via email and phone call to individuals who had indicated interest by responding to the advert but had not completed the survey. The survey was administered on a screen via surveying software Qualtrics. It contained an initial set of questions focusing on respondents’ demographic, economic, and social attributes, followed by three choice experiments involving variants of the ELM scheme. While most were completed remotely online, we also administered 36 surveys in person to include farmers who were unfamiliar with web-based survey participation. These were either conducted in focus groups or individually at the respondent’s home. In-person surveys were more costly but allowed us to reach a wider set of respondents and clarify any ambiguities in the survey presentation.

3.2.1 Scheme 1: Habitat creation only

Scheme 1 involves an annual payment to create habitat features on retired land, either by planting trees or by natural regeneration, as per the contract. Table 3.1 shows the first choice experiment's attributes, attribute levels, priors and variable descriptions. Respondents weighed the perceived tradeoff between the annual payment amount, the size of the land parcel to be set aside, and the type of habitat to create. Priors about coefficients for type, location, land quality and area were based on the expected cost of creating the feature(s) and the opportunity cost of retired land in terms of lost agricultural output. The prior for payment is trivially positive.

Table 3.1

Attribute	Description	Levels	Prior
Type	[Dummy] The type of habitat to participants of the scheme must create	[0] Planted trees [1] Natural regeneration	U(0.01, 0.5)
Location	[Categorical] The type of land on the respondent’s farm to be used in the scheme	[0] In-field [1] River edge [2] Field boundary	[1] U(0.01, 0.5) [2] U(0.51, 1)
Land quality	[Dummy] The agricultural quality of land to be used in the scheme	[0] Prime grazing land or high-yield crops [1] Rough grazing, wet, steep, rocky or in a dip, etc.	U(0.01,0.5)
Area	[Continuous] The area to be set aside in square metres	[500, 1,000]	U(-0.5, -0.01)
Payment	[Continuous] Annual payment received to participate in the scheme (£)	[200, 300, 400, 500]	U(0.01, 0.5)

3.2.2 Scheme 2: Habitat connectivity

Scheme 2 adds a so-called agglomeration bonus provision (Banerjee 2018) to scheme 1. The agglomeration bonus is an additional one-off payment to farmers who coordinate with one or more neighbours to connect habitats on their respective lands with ecological corridors, strips of retired land that improve the habitat connectivity of the landscape. Burkle et al. (2013) found that only 24% of original pollinator-plant interactions remained after loss of connectivity. Such losses are particularly destructive to specialist species (Xiao et al. 2016). The total bonus payment for coordination increases with the number of participants to compensate for rising coordination costs. Figure 3.1 illustrates how these feature-connecting corridors would work between two farms. Our priors for the effects of corridor width and number of collaborators are negative, as such corridors are expected to be more costly to construct and coordinate, respectively.

On the other hand, farmers well integrated in the local farming community and who already collaborate with neighbours in farm activities are expected to be more willing to participate in the scheme. Overall, we expect younger and more educated farmers to be more aligned with environmental concerns and, therefore, more willing to participate. However, older respondents may have more established social networks. Therefore, our survey includes questions to gauge respondents' social ties with local farmers to disentangle these effects.

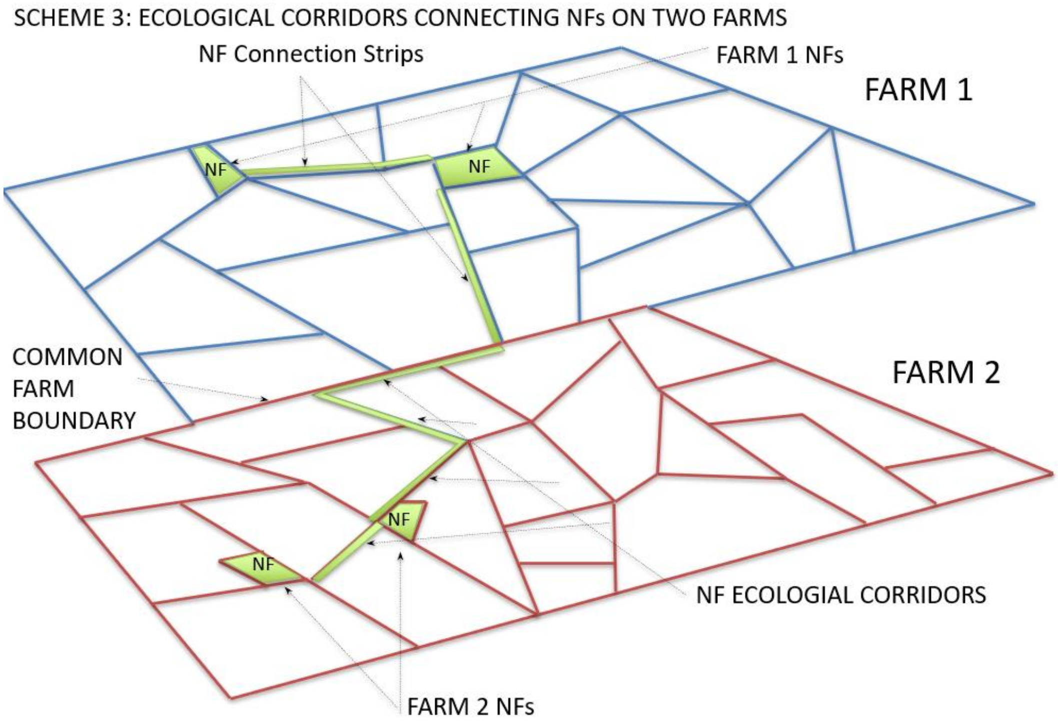

Figure 3.1 Corridors connecting natural features across two farms

Table 3.2

Attribute	Description	Levels	Prior
Type	[Dummy] The type of habitat participants of the scheme must create	[0] Planted trees [1] Natural regeneration	U(0.01, 0.5)
Coordination	[Categorical] The number of neighbours to coordinate with	[0] No coordination [1] One neighbour [2] Two neighbours	[1] U(-0.01, -0.5) [2] U(-0.51, -1)
Corridor width	[Dummy] The width of the ecological corridor	[0] 10 meters [1] 20 meters	U(-0.5, -0.01)
Bonus	[Continuous] One-off bonus received per coordinating farmer	[200, 300, 400, 500]	U(0.01, 0.5)
Payment	[Continuous] Annual payment received to participate in the scheme (£)	[200, 300, 400, 500]	U(0.01, 0.5)

3.3 Species distribution modelling

While DCEs can inform the costing part of a cost-benefit analysis of agri-environmental schemes, the ecological benefits must also be quantified. To this end, we estimate the effect of the potential of our proposed schemes to increase the range of pollinators using species distribution modelling (SDM). This is a technique commonly used in ecology and environmental science to estimate the habitat range of a species and to do an impact assessment of environmental change (human-caused or otherwise) on natural habitats. The methodology and framework were summarised in reviews (Franklin 1995; Guisan and Zimmermann 2000, Zimmermann et al. 2010), still widely used as references in the modelling literature.

SDM requires minimum spatial (geocoded) data of species observations and environmental variables such as temperatures, precipitation, elevation, and land cover. Additional variables of human influence may be added. These predictor variables come in raster format, where the resolution determines the number of cells, and hence the area of each cell. Since it is considerably more expensive to prove the absence of a species at a location, much of the species distribution literature relies on presence-only data, e.g. from citizen science surveys.

We collect occurrence data on the Western honeybee (Apis mellifera) from the UK National Biodiversity Network (NBN) records. These are the most comprehensive, open-access source of biodiversity data for the UK and have been used in earlier SDM studies (Rodriguez-Rey et al., 2021, Petrovan et al., 2020). Data for 2019 was downloaded (to avoid surveying disruptions due to covid-19) and restricted observations to the catchment area for DCE respondents. While concerns have been raised about the risk of geographic sampling bias in citizen science records (Kramer-Schadt 2013), recent findings by Petrovan et al. (2020) suggest that SDM based on NBN records did not significantly skew habitat predictions in favour of urbanised areas.

We use maximum entropy (MaxEnt) modelling (Phillips et al., 2006) to predict the habitats of the western honeybee. MaxEnt has become a rather popular tool to model the potential distribution of rare or threatened species of conservation concern, separate ecological niches, and forecast future distributions under environmental change (Polce et al. 2013, Agguire-Gutierrez et a. 2017). MaxEnt uses the principle of maximum entropy to relate presence-only data to environmental variables to estimate a species' niche and potential geographical distribution (Phillips et al., 2006). Two types of probability distributions are sampled: First, the distribution of presences over the background variables and second, the distributions of background variables over the study area. The principle of maximum entropy is invoked to find the most uniform distribution given the means of background variables across pixels where the species is present (Elith et al., 2011). MaxEnt is popular because it is easy to use and it produces robust results with sparse, irregularly sampled data and minor location errors (Kramer-Schadt et al. 2013).

Predictor variables are the monthly minimum and maximum temperatures, precipitation (Polce et al. 2014), land use, distance to freshwater, air pollution (PM2.5), and population density. In addition, climate variables were obtained from the HadUK-Grid (Met Office 2018) and land use rasters from Land Cover Map (2019). Figure 3.2 shows the distribution of land use in our study area, along with a sample of surveyed farms.

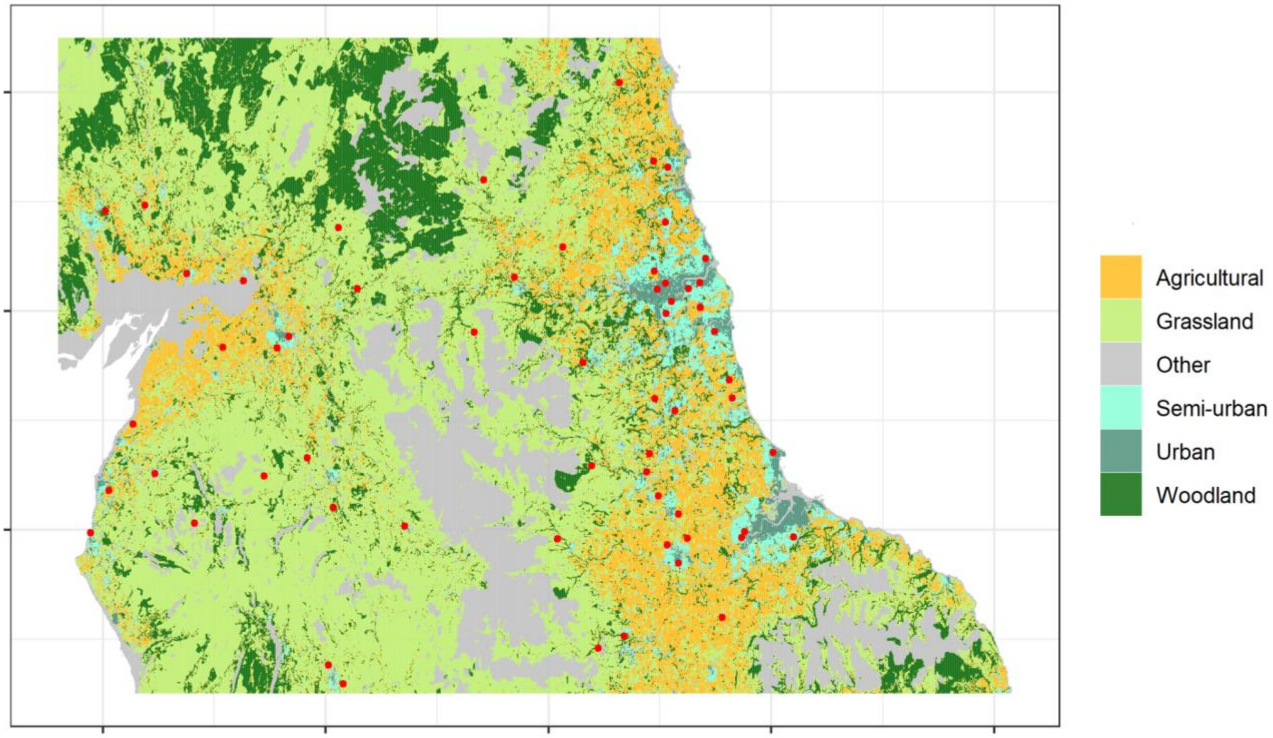

Figure 3.2 Land use and a sample of areas surveyed (250m resolution)

4. Results

309 farmers completed the survey and the 2 choice experiments. A sample of farm locations is shown in figure 3.2. Approximately two-thirds of respondents were male, and the average age was 53. The average farm size was 231,7 hectares, which is larger than the regional averages, which range from 93 to 144 hectares (Defra 2021). A majority (72%) also reported that farming was their primary source of income. 54% of respondents are currently enrolled in some type of agri-environmental scheme. 50% of respondents who submitted an address were in Cumbria, 31% in North Yorkshire, 11% in Lancashire, and 9% reside in other English counties. Just over 15% of respondents had only GCSE-level education, while 18% had completed secondary school. 32% had completed a university degree, compared with 40.6% among the general working-age population (ONS 2021). The natural features also contribute to natural flood management by increasing surface roughness and preventing runoff, and willingness to participate may stem from perceived flood risk. When asked to rate their own concern about flooding in the catchment, 28% of respondents were not concerned at all, while 6% were very concerned.

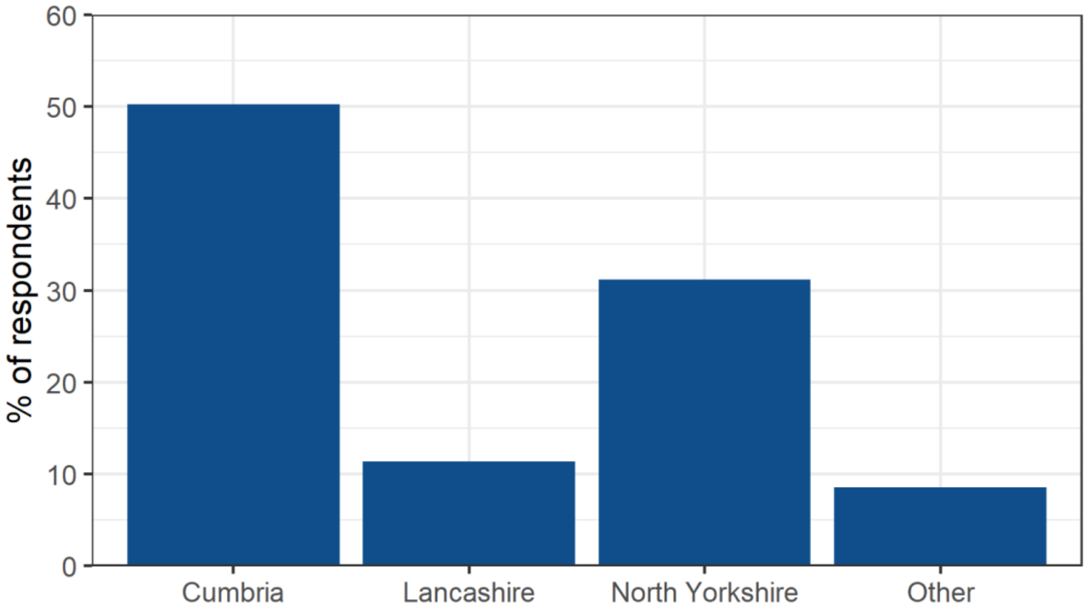

Figure 4.1 Geographic distribution of survey respondents. Note: Figure 4.1 represents an incomplete sample as not all respondents were possible to match with valid Ordnance Survey postcodes

4.1 Discrete choice experiments

Table 4.1 shows the results obtained from the first of the 2 choice experiments (DCE 1). Effects are interpreted as the average change in compensation required (or willingness-to-accept) to pick a particular alternative as the attribute changes, either continuously or (in the case of categorical attributes) compared to a baseline level. WTA for socioeconomic and demographic variables represent the change in compensation required to participate in the scheme.

DCE 1 shows that the location of the natural features, in general, was considered more important than the quality of land retired. Respondents require, on average, £232 less compensation per year when offered a scheme with features along field boundaries compared to when the proposed feature is located within the middle of fields; and £271 less when the proposed features are located along river edges. Comparatively, high-quality land (high-yield crop growing, prime grazing) is only valued at £36 per year 3.60 over low-quality land. Controlling for location, land quality and feature type, the average marginal reservation price for land is £1.80 per square metre.

In line with our priors, farmers who already participate in real agri-environment schemes are associated with lower costs and a higher likelihood of opting into our proposed schemes than a status quo alternative. Similarly, having a higher level of educational attainment lowers the barrier to uptake by £21221.15 for GCSEs to £35935.39 for A-levels, depending on education level attained. Farm size was negatively correlated with willingness to participate. Since farm size was also positively correlated with stating farming as the primary source of household income, we hypothesise that larger farms are more reliant on income from agriculture and therefore demand more compensation (£14.60 - £57.80) to retire productive land. However, the effect of primary income has a low significance effect (p-value = 0.055), as has the correlation between farm size and primary farm income.

Table 4.1 DCE 1 MNL results

Variable	**Effect on WTA (£/year)**	**Standard errors**	**Categorical Baselines**
Planted trees	**85**	22.7 (***)	Natural regeneration
River edge	**-271**	38 (***)	In-field
Field boundary	**-232**	38 (***)	In-field
High-quality land	**36**	21.6 (**)	Poor quality land
Feature size (square meters)	**1.80**	0.4 (***)	
Socioeconomic and demographic variables			
AES participation	**-247**	51.3 (***)	
Age (years)	**7.40**	2.1 (***)	
Farm tenure (years)	-3.18	1.8 (*)	
GCSEs or equivalent	**-243**	68.7 (***)	No formal qualification
A levels or equivalent	**-361**	76 (***)	No formal qualification
Undergraduate degree	**-282**	66 (***)	No formal qualification
Postgraduate degree	**-351**	92 (***)	No formal qualification
Farm size (hectares)	**0.1**	0.04 (***)	
Primary income	87	54.6 (*)	
Self-rated community participation	**-69**	24.1 (***)	

Note: p-value < 0.01 (***), 0.05 (**), 0.1 (*)

Results for the second choice experiment featuring a scheme with coordination are shown in table 4.2. Coordinating with two neighbours was perceived as more costly than no coordination. However, the estimated shift in WTA was smaller than expected, with no significant preference for no coordination requirements over coordination with one neighbour. The average respondent required higher annual compensation (£157) to consider a scheme requiring wider corridors (20m over 10m), as well as features of planted trees over natural regeneration (£118).

As with the first scheme, current AES participation and academic attainment correlated with a greater likelihood of participation and lower WTA estimates. Self-rated community participation (assessed with a Likert scale from 1 to 5, rating respondents' degree of social engagement in the local community) was not significantly associated with a shift in the WTA. Instead, sharing farm equipment with neighbouring farmers made respondents more willing to opt into the scheme. These results indicate that unlike the scheme without collaboration, willingness to coordinate to improve habitat connectivity is not driven by general ties to the community but by lower coordination costs from having collaborated with individual farmer neighbours in the past.

Table 4.2 DCE 3 MNL results

Variable	**Effect on WTA (£/year)**	**Standard errors**	**Categorical Baselines**
Planted trees	**118**	21.2 (***)	Natural regeneration
Coordination (1 neighbour)	-26.30	23	No coordination
Coordination (2 neighbours)	**54**	28 (**)	No coordination
20 m corridor width	**157**	22.5 (***)	10 m corridor width
Coordination bonus	**-0.23**	0.08 (***)	
Socioeconomic and demographic variables			
AES participation	**-226**	42.7 (***)	
Age (years)	**10.60**	2.1 (***)	
Farm tenure (years)	**-4.5**	1.6 (***)	

GCSEs or equivalent	**-229**	56.7 (***)	No formal qualification
A levels or equivalent	**-144**	52.1 (***)	No formal qualification
Undergraduate degree	**-406**	63 (***)	No formal qualification
Postgraduate degree	**-329**	76 (***)	No formal qualification
Farm size (hectares)	0.02	0.04	
Self-rated community participation	4.8	18.9	
Shared boundaries	**21**	5.1 (***)	
Sharing equipment	**-146**	40.1 (***)	

Note: p-value < 0.01 (***), 0.05 (**), 0.1 (*)

4.2 Species distribution model

A maximum entropy (Maxent) model was run on the NBN presence data for the Western honeybee, based on the following predictors: Monthly maximum and minimum temperatures, precipitation (Polce et al. 2014), land use categories, distance to rivers and streams, population density, and air pollution. Raster resolution was 25m, and data for 2019 were used. Figure 4.2 shows the cross-validation metric used to evaluate the model's predictive accuracy. The true positive rate (TPR), also known as sensitivity, is defined as the ability of the model to correctly predict a presence; hence: TPR = true presences / (true presences + false absences). Similarly, the false positive rate (FPR) is defined as FPR = false presences / (false presences + true absences). Maximising TPR - FPR improves predictive accuracy (Hijmans 2012) and is represented in Figure 4.2 as an AUC score closer to 1. The AUC = 0.5 line represents a fully random prediction.

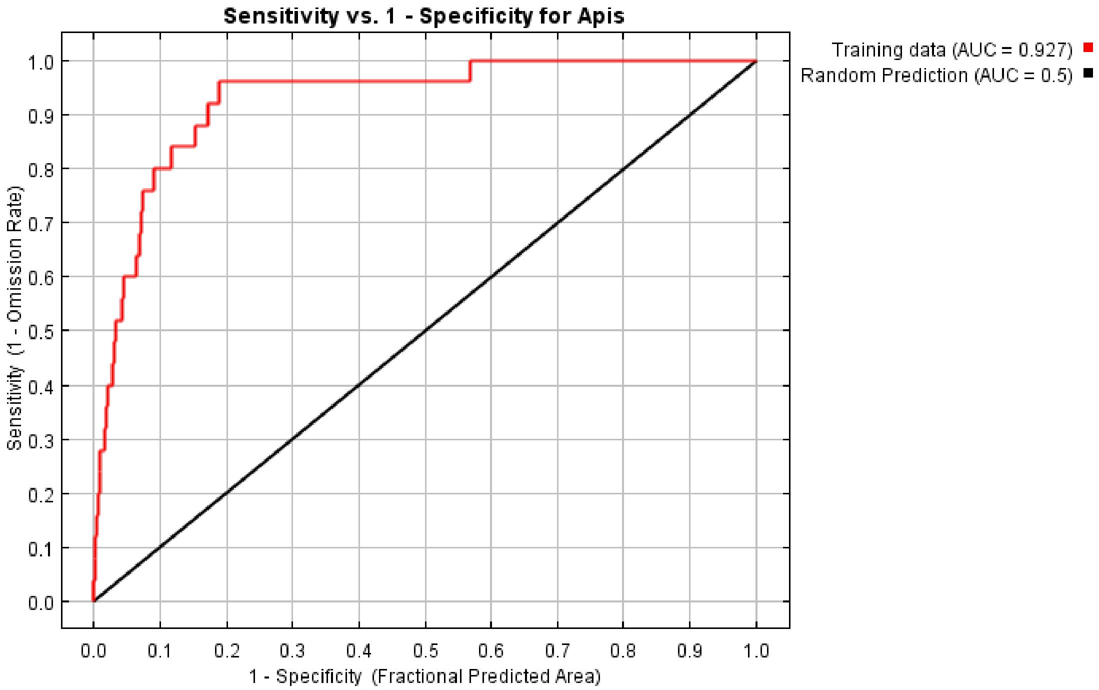

Figure 4.2 Predictive accuracy for Apis mellifera Maxent model

Figure 4.3 shows each environmental variable's contribution to the final prediction accuracy. Land use produces the best prediction on its own and reduces accuracy the most when left out of the model. Distance to freshwater and population density also significantly reduce accuracy when left out. Winter minimum temperatures (November - February) are also important predictors, as an entire hive can collapse if the queen does not survive the cold season. Cold summers with high precipitation are also negatively associated with presence, as is the distance to a river or lake.

As shown in Figure 4.3, arable farmland (category 3) is considerably less suitable to the species than broadleaved woodland (category 1) and acid grassland (category 7)[1]. Urban- and semi-urban (20 and 21) are also identified as suitable but lose some significance when controlling for population density, which can be attributed to higher sampling intensity in populated urbanised areas. These results indicate that converting arable farmland to broadleaved (planted) woodland or grassland.

---

[1] See Morton, D.; Marston, C. G,; O'Neil, A. W.; Rowland, C. S. (2020). Land Cover Map 2019 (25m rasterised land parcels, GB). NERC Environmental Information Data Centre. https://doi.org/10.5285/f15289da-6424-4a5e-bd92-48c4d9c830cc for a dictionary on land use classes.

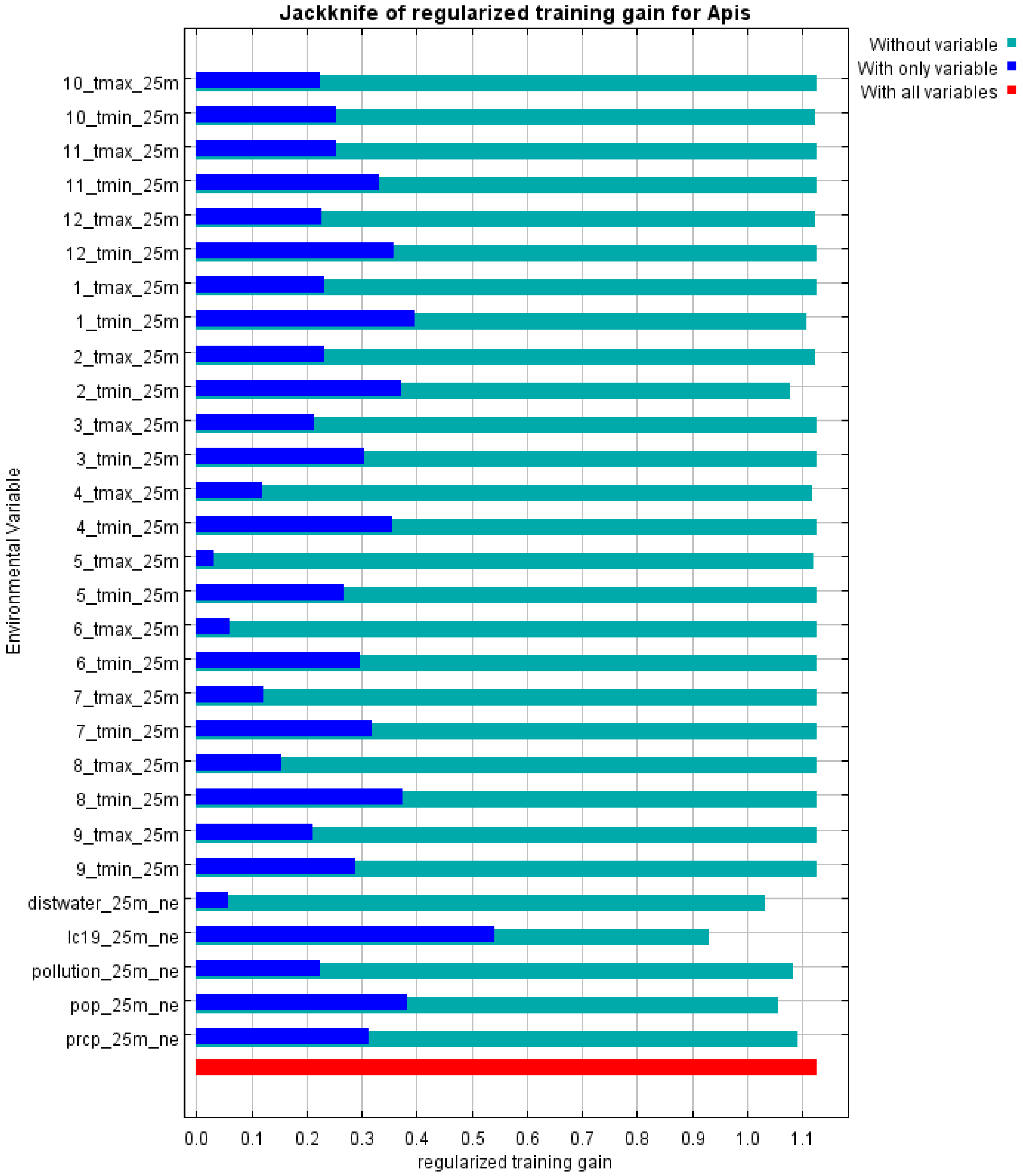

Figure 4.2 Variable contribution to predictive accuracy

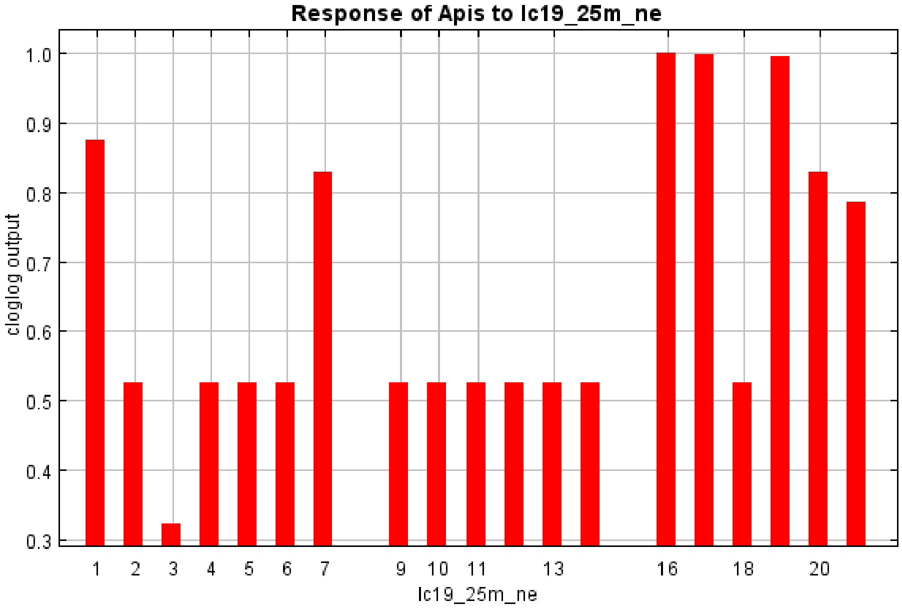

Figure 4.3 Response of bee presence to land use category

5. Conclusion

Initial results from our project have found that an annual payment of between £200 and £500 could incentivise farmers in the north of England to create natural features of 500-1000 square metres in their land and that a one-off coordination bonus can facilitate coordination between neighbours that results in improved habitat connectivity. To encourage uptake and flexibility for farmers, such corridors should be as narrow as possible while maintaining connectivity benefits. On average, younger, more educated farmers with previous exposure to government ELM schemes were more likely to participate in our proposed schemes. Farmers who share farm equipment with their neighbours were also comparatively more likely to agree to connect features with a neighbour and required lower compensation. On the cost side, schemes involving natural regeneration along field edges will likely require the smallest government transfers.

On the benefits side, the literature review indicates that protecting pollinator communities could save the UK between £189 - £378 million in averted yield losses from pollinated crops. Species distribution modelling with the MaxEnt approach shows that arable farmland is the least suitable for honeybee communities among the 19 distinct land use categories available. While sampling bias and sources and extent of taste heterogeneity must be better addressed in our upcoming work, the preliminary results suggest that ELM schemes of the type proposed here could be effective in providing well-targeted improvements in habitats. In the upcoming work in progress, we will extend these results by improving the model and estimating the marginal effect on habitats from growing patches of woodland and grassland by converting arable land. As we can simulate such conversion for any 25m pixel in our land use data, we will be able to show where positive effects are most pronounced. This, combined with estimates of likely costs from our choice experiments, can provide policymakers with a tool to evaluate spatially targeted schemes.

References

Adamowicz, W., Louviere, J. and Williams, M., 1994. Combining revealed and stated preference methods for valuing environmental amenities. Journal of environmental economics and management, 26(3), pp.271-292.

Aguirre-Gutiérrez, J., Kissling, W.D., Biesmeijer, J.C., WallisDeVries, M.F., Reemer, M. and Carvalheiro, L.G., 2017. Historical changes in the importance of climate and land use as determinants of Dutch pollinator distributions. Journal of Biogeography, 44(3), pp.696-707.

Banerjee, S., 2018. Improving Spatial Coordination Rates under the Agglomeration Bonus Scheme: A Laboratory Experiment with a Pecuniary and a Non-Pecuniary Mechanism (NUDGE). American Journal of Agricultural Economics, 100(1), pp.172-197.

Breeze, T.D., Bailey, A.P., Balcombe, K.G., Brereton, T., Comont, R., Edwards, M., Garratt, M.P., Harvey, M., Hawes, C., Isaac, N. and Jitlal, M., 2021. Pollinator monitoring more than pays for itself. Journal of Applied Ecology, 58(1), pp.44-57.

Breeze, T.D., Bailey, A.P., Potts, S.G. and Balcombe, KG, 2015. A stated preference valuation of the UK's non-market benefits of pollination services. Ecological Economics, 111, pp.76-85.

Brock, W.A. and Xepapadeas, A., 2003. Valuing biodiversity from an economic perspective: a unified economic, ecological, and genetic approach. American Economic Review, 93(5), pp.1597-1614.

Burkle, L.A., Marlin, J.C. and Knight, T.M., 2013. Plant-pollinator interactions over 120 years: loss of species, co-occurrence, and function. Science, 339(6127), pp.1611-1615.

Carson, R.T., 2012. Contingent valuation: A practical alternative when prices aren’t available. Journal of economic perspectives, 26(4), pp.27-42.

Correa Ayram, C.A., Mendoza, M.E., Etter, A. and Salicrup, D.R.P., 2016. Habitat connectivity in biodiversity conservation: A review of recent studies and applications. Progress in Physical Geography, 40(1), pp.7-37.

Costanza, R., d’Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O’neill, R.V., Paruelo, J. and Raskin, R.G., 1997. The value of the world’s ecosystem services and natural capital. Nature, 387(6630), pp.253-260.

Coyne, L., Kendall, H., Hansda, R., Reed, M.S. and Williams, D.J.L., 2021. Identifying economic and societal drivers of engagement in agri-environmental schemes for English dairy producers. Land Use Policy, 101, p.105174.

de Bekker-Grob, E.W., Donkers, B., Jonker, M.F. and Stolk, E.A., 2015. Sample size requirements for discrete-choice experiments in healthcare: a practical guide. The Patient-Patient-Centered Outcomes Research, 8(5), pp.373-384.

Defra, 2021. Defra Statistics: Agricultural Facts England Regional Profiles.

Defra, 2022. Environmental Land Management schemes: overview, available online at https://www.gov.uk/government/publications/environmental-land-management-schemes-overview/environmental-land-management-scheme-overview

Dicks, L.V., Viana, B., Bommarco, R., Brosi, B., Arizmendi, M.D.C., Cunningham, S.A., Galetto, L., Hill, R., Lopes, A.V., Pires, C. and Taki, H., 2016. Ten policies for pollinators. Science, 354(6315), pp.975-976.

Donald, P.F. and Evans, A.D., 2006. Habitat connectivity and matrix restoration: the wider implications of agri-environment schemes. Journal of applied ecology, 43(2), pp.209-218.

Donkersley, P., Rhodes, G., Pickup, R.W., Jones, K.C. and Wilson, K., 2014. Honeybee nutrition is linked to landscape composition. Ecology and evolution, 4(21), pp.4195-4206.

Elith, J., Phillips, S.J., Hastie, T., Dudík, M., Chee, Y.E. and Yates, C.J., 2011. A statistical explanation of MaxEnt for ecologists. Diversity and distributions, 17(1), pp.43-57.

Ferrini, S. and Scarpa, R., 2007. Designs with a priori information for nonmarket valuation with choice experiments: A Monte Carlo study. Journal of environmental economics and management, 53(3), pp.342-363.

Franklin, J., 1995. Predictive vegetation mapping: geographic modelling of biospatial patterns in relation to environmental gradients. Progress in physical geography, 19(4), pp.474-499.

Garibaldi, L.A., Sáez, A., Aizen, M.A., Fijen, T. and Bartomeus, I., 2020. Crop pollination management needs flower-visitor monitoring and target values. Journal of Applied Ecology, 57(4), pp.664-670.

Garratt, M.P., Breeze, T.D., Jenner, N., Polce, C., Biesmeijer, J.C. and Potts, S.G., 2014. Avoiding a bad apple: Insect pollination enhances fruit quality and economic value. Agriculture, ecosystems & environment, 184, pp.34-40.

Giannini, T.C., Cordeiro, G.D., Freitas, B.M., Saraiva, A.M. and Imperatriz-Fonseca, V.L., 2015. The dependence of crops for pollinators and the economic value of pollination in Brazil. Journal of economic entomology, 108(3), pp.849-857.

Giguere, C., Moore, C. and Whitehead, J.C., 2020. Valuing hemlock woolly adelgid control in public forests: scope effects with attribute nonattendance. Land Economics, 96(1), pp.25-42.

Haab, T.C., Interis, M.G., Petrolia, DR and Whitehead, J.C., 2013. From hopeless to curious? Thoughts on Hausman’s “dubious to hopeless” critique of contingent valuation. Applied Economic Perspectives and Policy, 35(4), pp.593-612.

Hanley, N. and Perrings, C., 2019. The economic value of biodiversity. Annual Review of Resource Economics, 11(1), pp.355-375.

Hausman, J., 2012. Contingent valuation: from dubious to hopeless. Journal of economic perspectives, 26(4), pp.43-56.

Heal, G., 2000. Valuing ecosystem services. Ecosystems, pp.24-30.

Hijmans, R.J., 2012. Cross-validation of species distribution models: removing spatial sorting bias and calibration with a null model. Ecology, 93(3), pp.679-688.

Holling, C.S., 2001. Understanding the complexity of economic, ecological, and social systems. Ecosystems, 4(5), pp.390-405.

Hoyos, D., 2010. The state of the art of environmental valuation with discrete choice experiments. Ecological economics, 69(8), pp.1595-1603.

Hurley, P., Lyon, J., Hall, J., Little, R., Tsouvalis, J., White, V. and Rose, D.C., 2022. Co-designing the environmental land management scheme in England: the why, who and how of engaging 'harder to reach' stakeholders. People and Nature.

Johnston, R.J., Boyle, K.J., Adamowicz, W., Bennett, J., Brouwer, R., Cameron, T.A., Hanemann, W.M., Hanley, N., Ryan, M., Scarpa, R. and Tourangeau, R., 2017. Contemporary guidance for stated preference studies. Journal of the Association of Environmental and Resource Economists, 4(2), pp.319-405.

Klein, A.M., Vaissière, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C. and Tscharntke, T., 2007. Importance of pollinators in changing landscapes for world crops. Proceedings of the royal society B: biological sciences, 274(1608), pp.303-313.

Kramer-Schadt, S., Niedballa, J., Pilgrim, J.D., Schröder, B., Lindenborn, J., Reinfelder, V., Stillfried, M., Heckmann, I., Scharf, A.K., Augeri, D.M. and Cheyne, S.M., 2013. The importance of correcting for sampling bias in MaxEnt species distribution models. Diversity and distributions, 19(11), pp.1366-1379.

Lancaster, K.J., 1966. A new approach to consumer theory. Journal of political economy, 74(2), pp.132-157.

Lundhede, T.H., Jacobsen, J.B., Hanley, N., Fjeldså, J., Rahbek, C., Strange, N. and Thorsen, B.J., 2014. Public support for conserving bird species runs counter to climate change impacts on their distributions. PloS one, 9(7).

McFadden, D., 1974. The measurement of urban travel demand. Journal of public economics, 3(4), pp.303-328.

Met Office, Hollis, D., McCarthy, M., Kendon, M., Legg, T., Simpson, I. (2018): HadUK-Grid gridded and regional average climate observations for the UK. Centre for Environmental Data Analysis, 25 September 2022. http://catalogue.ceda.ac.uk/uuid/4dc8450d889a491ebb20e724debe2dfb

Morton, D.; Marston, C. G,; O'Neil, A. W.; Rowland, C. S. (2020). Land Cover Map 2019 (25m rasterised land parcels, GB). NERC Environmental Information Data Centre. https://doi.org/10.5285/f15289da-6424-4a5e-bd92-48c4d9c830cc

Nijkamp, P., Vindigni, G. and Nunes, P.A., 2008. Economic valuation of biodiversity: A comparative study. Ecological economics, 67(2), pp.217-231.

ONS, 2017. Graduates in the UK labour market, available online at https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/employmentandemployeetypes/articles/graduatesintheuklabourmarket/2017

Parkhurst, G.M. and Shogren, J.F., 2007. Spatial incentives to coordinate contiguous habitat. Ecological economics, 64(2), pp.344-355.

Petrovan, S.O., Vale, C.G. and Sillero, N., 2020. Using citizen science in road surveys for large-scale amphibian monitoring: are biased data representative for species distribution?. Biodiversity and Conservation, 29(6), pp.1767-1781.

Phillips, S.J., Anderson, R.P. and Schapire, RE, 2006. Maximum entropy modeling of species geographic distributions. Ecological modelling, 190(3-4), pp.231-259.

Polasky, S., Nelson, E., Camm, J., Csuti, B., Fackler, P., Lonsdorf, E., Montgomery, C., White, D., Arthur, J., Garber-Yonts, B. and Haight, R., 2008. Where to put things? Spatial land management to sustain biodiversity and economic returns. Biological conservation, 141(6), pp.1505-1524.

Polce, C., Termansen, M., Aguirre-Gutiérrez, J., Boatman, N.D., Budge, G.E., Crowe, A., Garratt, M.P., Pietravalle, S., Potts, S.G., Ramirez, J.A. and Somerwill, K.E., 2013. Species distribution models for crop pollination: a modelling framework applied to Great Britain. PloS one, 8(10).

Porto, R.G., de Almeida, R.F., Cruz-Neto, O., Tabarelli, M., Viana, B.F., Peres, C.A. and Lopes, A.V., 2020. Pollination ecosystem services: A comprehensive review of economic values, research funding and policy actions. Food Security, 12(6), pp.1425-1442.

Potts, S.G., Imperatriz-Fonseca, V., Ngo, H.T., Aizen, M.A., Biesmeijer, J.C., Breeze, T.D., Dicks, L.V., Garibaldi, L.A., Hill, R., Settele, J. and Vanbergen, A.J., 2016. Safeguarding pollinators and their values to human well-being. Nature, 540(7632), pp.220-229.

Potts, S.G., Ngo, H.T., Biesmeijer, J.C., Breeze, T.D., Dicks, L.V., Garibaldi, L.A., Hill, R., Settele, J. and Vanbergen, A., 2016. The assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production.

Rodríguez-Rey, M., Consuegra, S., Börger, L. and Garcia de Leaniz, C., 2021. Boat ramps facilitate the dispersal of the highly invasive zebra mussel (Dreissena polymorpha). Biological Invasions, 23(5), pp.1487-1496.

Rose, J.M. and Bliemer, M.C., 2009. Constructing efficient stated choice experimental designs. Transport Reviews, 29(5), pp.587-617.

Sàndor, Z. and Wedel, M. 2001. Designing conjoint choice experiments using managers' prior beliefs, Journal of Marketing Research, 38, pp 430–444.

Scarpa, R. and Rose, J. M. 2008. Designs efficiency for nonmarket valuation with choice modelling: how to measure it, what to report and why. Australian Journal of Agricultural and Resource Economics 52(3), pp. 253–282.

Scarpa, R., Chilton, S.M. Hutchinson, W.G. and Buongiorno, J. 2000. "Valuing the recreational benefits from creation of nature reserves in Irish forests". Ecological Economics 33, pp. 237–250.

Train, KE, 2009. Discrete choice methods with simulation. Cambridge university press.

Vatn, A. and Bromley, D.W., 1994. Choices without prices without apologies. Journal of environmental economics and management, 26(2), pp.129-148.

Woodcock, B.A., Garratt, M.P.D., Powney, G.D., Shaw, R.F., Osborne, J.L., Soroka, J., Lindström, S.A.M., Stanley, D., Ouvrard, P., Edwards, M.E. and Jauker, F., 2019. Meta-analysis reveals that pollinator functional diversity and abundance enhance crop pollination and yield. Nature Communications, 10(1), pp.1-10.

Xiao, Y., Li, X., Cao, Y. and Dong, M., 2016. The diverse effects of habitat fragmentation on plant–pollinator interactions. Plant Ecology, 217(7), pp.857-868.

Yao, R., Scarpa, R., Harrison, D. and Burns, R. 2019. “Does the economic benefit of biodiversity enhancement exceed the cost of conservation in planted forests?” Ecosystem Services 38, p. 100954.

Yao, R., Scarpa, R., Turner, J.A., Barnard, T.D., Rose, J.M., Palma, J.H.N., and Harrison, D.R. 2014. “Valuing biodiversity enhancement in New Zealand’s planted forests: Socioeconomic and spatial determinants of willingness-to-pay”. Ecological Economics 98, pp. 90 –101.

Zimmermann, N.E., Edwards Jr, T.C., Graham, C.H., Pearman, P.B. and Svenning, JC, 2010. New trends in species distribution modelling. Ecography, 33(6), pp.985-989.

Appendix

Which of the available options do you prefer?

	Option A	**Option B**
Type of NFM feature	Set-aside with Natural Regeneration	Planted Woodland
Location of NFM feature on your land	River Edge	In-field
Quality of land where NFM is created	Rough grazing, wet, steep, rocky or in dip etc.	Rough grazing, wet, steep, rocky or in dip etc.
Size of NFM feature	1/10 of a hectare	1/20 of a hectare
Annual payment	**£500** (£5,000/ha)	**£200** (£4,000/ha)

	Option A	Option B	I want neither A nor B
Your choice:	○	○	○

Figure A.1 Example choice card (Scheme 1: No coordination)

Which of the available options do you prefer?

	Option A	Option B
Type of NFM feature	Natural Regeneration	Planted woodland
Number of neighbours you connect NFs with	Two neighbours	None
Width of connecting corridors	20 meters	10 meters
One-off bonus to each coordinating farmer	£400	£0
Annual payment (£/100 meters)	£300	£400

	Option A	Option B	I want neither A nor B
Your choice:	○	○	○

Figure A.2 Example choice card (Scheme 2: Coordination bonus)