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Social and ecological drivers of success in agri-environment schemes: the roles of farmers and environmental context

Morag E. McCracken[1], Ben A. Woodcock[1], Matt Lobley[2], Richard F. Pywell[1], Eirini Saratsi[2], Ruth D. Swetnam[1,3], Simon R. Mortimer[4], Stephanie J. Harris[4], Michael Winter[2], Shelley Hinsley[1], and

James M. Bullock[1]*.

[1]NERC Centre for Ecology and Hydrology, Benson Lane, Wallingford, UK, OX10 8BB

[2] Centre for Rural Policy Research, Department of Politics, University of Exeter, Rennes Drive, Exeter, UK, EX4 4RJ

[3]Department of Geography, Staffordshire University, Leek Rd, Stoke-on-Trent, UK, ST4 2DF

[4]School of Agriculture, Policy and Development, University of Reading, Earley Gate, Reading, UK, RG6 6AR

[*]**Corresponding author**: James Bullock; NERC Centre for Ecology and Hydrology, Benson Lane, Wallingford, UK, OX10 8BB; jmbul@ceh.ac.uk; +44 (0)7824 460866

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Summary

1. Agri-environment schemes remain a controversial approach to reversing biodiversity losses, partly because the drivers of variation in outcomes are poorly understood. In particular, there is a lack of studies that consider both social and ecological factors.

2. We analysed variation across 48 farms in the quality and biodiversity outcomes of agri-environmental habitats designed to provide pollen and nectar for bumblebees and butterflies or winter seed for birds. We used interviews and ecological surveys to gather data on farmer experience and understanding of agri-environment schemes, and local and landscape environmental factors.

3. Multimodel inference indicated social factors had a strong impact on outcomes and that farmer experiential learning was a key process. The quality of the created habitat was affected positively by the farmer's previous experience in environmental management. The farmer's confidence in their ability to carry out the required management was negatively related to the provision of floral resources. Farmers with more wildlife-friendly motivations tended to produce more floral resources, but fewer seed resources.

4. Bird, bumblebee and butterfly biodiversity responses were strongly affected by the quantity of seed or floral resources. Shelter enhanced biodiversity directly, increased floral resources and decreased seed yield. Seasonal weather patterns had large effects on both measures. Surprisingly, larger species pools and amounts of semi-natural habitat in the surrounding landscape had negative effects on biodiversity, which may indicate use by fauna of alternative foraging resources.

5. *Synthesis and application.* This is the first study to show a direct role of farmer social variables on the success of agri-environment schemes in supporting farmland biodiversity. It suggests that farmers are not simply implementing agri-environment options, but are

learning and improving outcomes by doing so. Better engagement with farmers and working with farmers who have a history of environmental management may therefore enhance success. The importance of a number of environmental factors may explain why agri-environment outcomes are variable, and suggests some – such as the weather – cannot be controlled. Others, such as shelter, could be incorporated into agri-environment prescriptions. The role of landscape factors remains complex and currently eludes simple conclusions about large-scale targeting of schemes.

Keywords: birds; bumblebees; butterflies; experiential learning; farmer; farmland; habitat quality; interdisciplinary; landscape; multimodel inference

Introduction

Agri-environment schemes offer farmers financial incentives to adopt wildlife-friendly management practices, and are implemented in several parts of the world with the goal of reversing biodiversity losses (Baylis *et al.* 2008; Lindenmayer *et al.* 2012). These schemes are costly – the European Union budgeted €22.2bn for the period 2007–2013 (EU 2011) – and controversial. Controversy arises because researchers have reported variable success of agri-environment schemes in enhancing biodiversity (Kleijn *et al.* 2006; Batary *et al.* 2010b). It is clear that well-designed and well-managed options can benefit target taxa. For example, Pywell *et al.* (2012) found that options designed for birds, bees or plants had increased richness and abundance of both rare and common species. Baker *et al.* (2012) showed positive effects of options providing winter seed resources on granivorous bird populations. The question therefore arises – what causes variation in the success of agri-environment schemes?

Some options seem to work less well than others. Pywell *et al.* (2012) demonstrated that general compared to more targeted management had little effect in enhancing birds, bees and plants, while Baker *et al.* (2012) found that habitats providing breeding season resources for birds were less effective than those supplying winter food. But even within options there is great variation in biodiversity responses (Batary *et al.* 2010a; Scheper *et al.* 2013). There are several studies of the drivers of agri-environmental success (with success defined variously), but individual projects have looked at only one or a few drivers. In this paper we take a holistic approach by assessing a number of putative social and environmental constraints on success; specifically farmer experience and understanding, landscape and local environment, and the weather. In doing so, we consider success in terms of both biodiversity outcomes and habitat quality.

Social scientists have long considered the role of the farmer in agri-environment schemes, but their questions have tended to focus on why farmers do or do not participate in the schemes (Wilson & Hart 2001; Wynne-Jones 2013) or how to change farmer behaviours in relation to environmental management (Burton & Schwarz 2013; de Snoo *et al.* 2013). There is a consensus that many farmers show limited engagement with the aims of agri-environment schemes (Wilson & Hart 2001; Burton, Kuczera & Schwarz 2008), leading to concern that this may jeopardize scheme success (de Snoo *et al.* 2013). There is, however, little direct evidence to link farmer understanding of, and engagement with, agri-environmental management with biodiversity outcomes on the farm (Lobley *et al.* 2013). Indeed, despite calls for more interdisciplinary social and ecological research into rural land use (Phillipson, Lowe & Bullock 2009) there is little such work in relation to agri-environment schemes.

Much ecological work has focused on the roles of landscape and local environments in determining biodiversity outcomes. Several studies have shown that the abundance and diversity of target species in agri-environment habitats is greater: a) in landscapes with higher target species richness or amount of (semi-)natural habitat; and/or b) where local habitat quality (e.g. food plant diversity) is greater (Carvell *et al.* 2011; Concepcion *et al.* 2012; Shackelford *et al.* 2013). While weather conditions are rarely considered, it is likely that weather during surveys will affect animal activity and the weather during the preceding seasons will affect local population sizes (Pollard & Moss 1995).

While most studies focus on success in terms of biodiversity outcomes, the farmer can only directly affect the quality of the created habitat. It is therefore useful to consider success in these terms as well. In this paper we derive measures of habitat quality related to the foraging resources made available to the target biota. As well as impacts of the farmer's activities, such quality measures may be affected by local abiotic factors such as soil type, shading and seasonal weather (Myers, Hoksch & Mason 2012).

Putting these social and ecological factors together, we hypothesize that the richness and abundance of target taxa using agri-environment habitats are increased where: the landscape contains more target species and semi-natural habitat, the quality of the created habitat is higher and when weather conditions during the season and the survey period are more optimal for these taxa. We expect local habitat quality to be important and hypothesize that this is in turn affected by the farmer's experience in, and understanding of, agri-environmental management, as well as local abiotic environmental factors. We consider these hypotheses for agri-environment options developed to provide resources for key declining taxa of the farmed environment: pollen and nectar for bees and butterflies; and winter food for granivorous farmland birds.

Materials and methods

STUDY SITES AND AGRI-ENVIRONMENT OPTIONS

We assessed the success of two options available to arable farmers under the English Entry Level agri-environment scheme (ELS), which involve sowing selected plant species in 6 m wide strips at field edges. The Nectar Flower Mixture option NFM ('EF4' under ELS; Natural England (2013)) uses a mixture of at least three nectar-rich plant species to support nectar-feeding insects, specifically bumblebees and butterflies. The Wild Bird Seed Mixture WBM ('EF2' under ELS) requires at least three small-seed bearing plant species to be sown, and is designed to provide food for farmland birds, especially during winter and early spring (see Appendix S1 in Supporting Information for more detail). We assessed NFM and WBM because they had specific success criteria, in terms of the taxa targeted (Pywell *et al.* 2012).

We selected 48 arable or mixed farms that had NFM or WBM strips sown between autumn 2005 and autumn 2006. To represent a range of English farming landscapes, 24 farms were in the east (Cambridgeshire and Lincolnshire), which is flat with large arable fields, and 24 in the south-west (Wiltshire, Dorset, Devon & Somerset), which is more hilly, with smaller fields and more mixed arable and grass farms. Half of the farms in each region had NFM options and half WBM. All farms had a minimum of two fields with the relevant ELS option. The farms were selected: a) first by Natural England – the statutory body that manages ELS – examining their GENESIS database for farms meeting the required geographic, date and ELS option criteria; and then b) by contacting farmers until sufficient had been found that were willing to take part.

FARMER INTERVIEWS

Semi-structured interviews were conducted in 2007 with all farmers. The interviews were designed to explore farmer attitudes towards, and history of, environmental management and their perceptions and understanding of the management requirements for NFM or WBM. Lobley *et al.* (2013) analysed these interviews, and we used them to calculate three measures of farmer attitudes to, and engagement with, agri-environment schemes. "Experience" describes, on a four point scale, the farmer's history of environmental management both formally as part of a scheme and informally: some had long-lasting and frequent engagement (4); others less frequent engagement (3); while some had limited experience, perhaps undertaking a single project (2); and some had no previous engagement (1).

"Concerns" represents farmer statements about their perceptions as to how easy it would be to meet the stipulations for creating and managing the habitat (e.g. establishing the plants, limiting herbicide use, cutting requirements). Responses to each requirement were scored 1 (very difficult) to 5 (easy), and a mean score across requirements was derived for each farmer. Finally, "Motivation" categorized the farmers in terms of their stated motivation for where they placed the strips on the farm, from more wildlife-focused to more utilitarian. The three categories were: 1) the best for wildlife, 2) to fit in with farming operations, or 3) simply to fulfill ELS requirements. Spearman rank correlations across the 48 farms indicated that these measures were independent of each other. We did not consider the influence of farmer demographic variables (e.g. age or education) as these have a complex relationship with environmental behaviours (Burton 2014).

ECOLOGICAL SURVEYS

Ecological surveys were carried out in 2007 and repeated in 2008. Three strips – or two if there were no more – were surveyed on each farm and parallel measures were made in a nearby 'control' cropped area at a field edge and of equivalent size, shape and aspect. A shelter score (0–8) was calculated, which represented the number of directions in which the strip was protected by hedges, etc (Dover 1996). We obtained data from national sources further describing the physical environment of each strip: the Agricultural Land Classification ALC, which grades land from 1–5 according to its agricultural quality; and the soil type, which we classified into light, medium or heavy soils (see Appendix S2).

For NFM strips we counted the number of flower units (i.e. a single flower, a multi-flowered stem or an umbel; Heard *et al.* (2007)) and identified these to species in five 1 m^2 quadrats at 10 m intervals along two parallel 50 m transects during July and again in August (for later emerging species). Bumblebees (as colour groups, e.g. Heard *et al.* (2007) – for brevity we refer to these as species) and butterflies (to species) were surveyed along these transects by recording those foraging within a 4 m band centred on the transect. Insect surveys were carried out between 10·30 h and 17·00 h during dry weather at temperatures >16 °C, and weather conditions – air temperature and wind speed (from 0=calm to 5=strong breeze) – were recorded.

For WBM strips, we estimated the seed resource by gathering all seeds from each sown species in three 1 m^2 quadrats at 10 m intervals along two parallel 50 m transects in September. Samples were stored at -20 ^{o}C in the dark until processing, at which time the seeds were separated from other plant material, dried at 80 °C for 24 hr and weighed. Bird use of the whole strip was monitored in November, January and February, during weather conducive to bird activity (e.g. avoiding rain or high winds). Timed bird counts were made from a distance and then all birds were flushed (Hinsley *et al.* 2010).

LANDSCAPE AND SEASONAL WEATHER VARIABLES

To describe the landscape context of each farm, land cover was mapped in a 4 x 4 km square centred on each farm using Google Earth and the CEH Land Cover Map 2007. We used this single square size and a single landscape measure – the percentage cover of semi-natural habitats (grassland, woods, heaths, etc) – to avoid type 1 errors and highly correlated variables. This scale encompasses foraging distances of the target taxa (e.g. Osborne *et al.* 2008), although the exact scale used was probably unimportant as differences among farms in % semi-natural cover were very similar for 2 x 2 km and 4 x 4 km squares (correlation coefficient = 0.81). Species pools were estimated from national datasets of species lists mapped on a 10 x 10 km grid (Appendix S2). The grid square overlapping the centre point of each farm was interrogated for species lists of: butterflies for the period 2005–2009; granivorous birds during the winter for 2007–2011; and bumblebees from 2000–2010.

Daily weather data through 2007 and 2008 were obtained from the British Atmospheric Data Centre for the weather station closest to each farm. Daily maxima or minima were averaged across specific seasons (winter = December–February, etc) according to hypotheses about how weather would affect certain response variables (e.g. winter bird numbers would be affected by winter minimum temperatures).

STATISTICAL ANALYSES

We analysed the success of NFM and WBM habitats in terms of: a) biodiversity responses and b) habitat quality in terms of resources for the target taxa. For a), we considered the number and species richness of butterflies, bumblebees and granivorous birds. Number was the sum across the multiple surveys in a year, and species the total seen across the surveys. For b), we considered the number and species richness of flowers (mean across the quadrats and surveys) and seed weight (mean across quadrats). Determinants of success were analysed using general linear mixed models in R (R_Core_Development_Team 2008) using the 'glme' function of the lme4 package (Bates 2010). The nine response variables were tested against subsets of continuous and categorical explanatory variables ('fixed effects': Tables 1, 2), which were selected to reflect our hypotheses about the roles of farmer and environmental factors. Note that because we included 'region' as a separate factor, any effects of other variables do not reflect differences between the south-western and eastern regions.

In addition to these fixed effects, year was treated as a repeated measure by nesting it as a random effect within a subject factor describing the smallest sampling unit, i.e. the individual strip. To account for additional random effects, replicate strips were nested within farm, allowing analysis of factors at both the farm and the strip scale (Table 1). All data were counts and were modelled using a Poisson error term with a log link function, with the exception of seed weight, which was ln(n+1) transformed and modelled with normal errors. When used as explanatory variables, seed weight and flower numbers were ln(n+1) transformed. For the analysis of seed weight responses, four outlier values (>1000 mg) were removed to improve model fit and ALC was excluded as performance of the mixed models showed it to be strongly collinear with other explanatory variables. Because birds were surveyed over the whole strip we considered strip area in preliminary analyses, but this was collinear with other factors and had low importance and so was excluded from the full analyses.

We used multimodel inference, which allowed us to consider competing models and moderately collinear variables (Burnham & Anderson 2002; Freckleton 2011). For each response variable, models representing all possible combinations of the fixed effects (excluding interactions), including a null model and a saturated global model, were created and the *AIC* difference (Δ_i) was calculated as:

$$\Delta_i = AIC_i - AIC_{\min},$$

where AIC_{min} is the lowest value of any model, and AIC_i is the model-specific value. Following Burnham and Anderson (2002), models with $\Delta_i < 4$ were considered to form a set that best explained variation. For this subset of *R* models, Akaike weights (w_i) were derived:

$$w_i = \frac{\exp\left[-\frac{1}{2}\Delta_i\right]}{\sum_{r=1}^{R}\exp\left[-\frac{1}{2}\Delta_r\right]},$$

where w_i represents the probability that model *i* would be the best fitting if the data were collected again under identical conditions. The relative importance of individual variables can be calculated as the w_i of all models within the $\Delta_i < 4$ subset sums to 1. The importance of individual fixed effects was assessed by summing the w_i values of all models containing that explanatory variable within the subset using the 'MuMIn' package (Bartoń 2013). As many variables were modelled, we focused subsequently on the most frequently-included variables with an importance ≥0.4 (all included variables are given in Tables 1, 2). Parameter estimates were weighted by w_i and averaged across all models. Following Symonds and

Moussalli (2011) we calculated the marginal R^2 value for the global model to indicate goodness of fit.

Results

The ELS strips were successful in that they had more target species and resources than the paired control (crop) strips. Generalized linear mixed models using Poison errors and pairing ELS and control strips showed the former had higher bumblebee numbers (mean *per* strip, *per* year 10.6 vs. 0.3; $F_{1,242} = 686$, $P<0.001$) and species (2.0 vs. 0.1; $F_{1,242} = 91$, $P<0.001$), butterfly numbers (6.1 vs. 0.6; $F_{1,242} = 346$, $P<0.001$) and species (2.2 vs. 0.5; $F_{1,242} = 75$, $P<0.001$), flower numbers (672 vs. 71; $F_{1,242} = 39676$, $P<0.001$), granivorous bird numbers (63 vs. 1.7; $F_{1,230} = 2946$, $P<0.001$) and species (4.4 vs. 1.1; $F_{1,230} = 150$, $P<0.001$), and seed weight (124 vs. 0 g; $F_{1,230} = 2629$, $P<0.001$).

BIODIVERSITY OUTCOMES

The agri-environment strips had a wide range of bumblebee numbers (*per* strip, *per* year; 0–97) and species (0–6), butterfly numbers (0–50) and species (0–8), and granivorous bird numbers (0–485) and species (0–13). The global models explained variation in each response quite well (R^2 = 0.28–0.68), and to a similar extent to other large-scale agro-ecology studies (Gabriel *et al.* 2010). The most important explanatory variables were those describing the local environment (Table 1). Bumblebees, butterflies and birds were more abundant and diverse in strips which had more abundant and diverse flowers or a greater seed mass (Fig. 1), and in strips which were more sheltered. Weather conditions during the survey had generally minor importance, which may be because the surveys were done during a narrow set of benign conditions. Unsurprisingly, farmer social variables had little direct importance for biodiversity measures although there were more bumblebee numbers and species on farms with more experienced farmers, and more butterfly species where farmers placed their strips in locations they considered best for wildlife.

Region had contrasting effects, with south-western farms having more bumblebee numbers and species, fewer butterfly numbers and species, and similar bird numbers and species to eastern farms. Landscape factors were often important, in that both the percentage of semi-natural habitat and the size of the species pool had (surprisingly) negative relationships with biodiversity. Bird numbers and species were enhanced under higher winter minimum temperatures, and a similar pattern was seen for insect numbers in relation to summer maximum temperatures.

HABITAT QUALITY OUTCOMES

There was large variation among strips in flower number (*per* strip, *per* year; 0–9329) and species (0–17), or seed weight (0–597 mg). No model explained variation in flower species richness in the NFM strips well ($R^2 \leq 0.06$), and no variable had high importance (Table 2). Models for flower number and seed weight performed better. According to these, more experienced farmers produced strips with more resources (Fig. 2). Higher flower numbers were also found on strips created by farmers who placed them on the basis of wildlife-focused than utilitarian motives, but the opposite pattern was shown for seed weight. Interestingly, farmers who had envisioned greater problems with establishing and maintaining these habitats produced strips with a greater seed yield. Of the environmental factors, region had little importance and the local conditions were important only in determining flower numbers, which were greater on sites of poorer agricultural quality and which were more sheltered. Flower numbers and seed weight were boosted by higher maximum temperatures in the season preceding maturation of flowers (spring) or seeds (summer). In addition, flower numbers were negatively affected by higher temperatures in the summer.

Discussion

As we hypothesized, the biodiversity outcomes of the agri-environment schemes were influenced by a range of factors, including landscape variables, the quality of the local habitat, seasonal weather and conditions during the surveys. Habitat quality itself – i.e. floral or seed resources – responded to the farmers' experience and understanding of agri-environmental management as well as local environment and seasonal weather. Below we consider the factors in detail, but this study has highlighted the importance of multiple drivers in explaining variation in the success of agri-environment schemes. This builds on previous work, which has shown that a suite of factors are required for agri-environment success, including relevant prescriptions, adequate management and proximity to source populations (Whittingham 2011; Pywell *et al.* 2012). We have for the first time demonstrated the direct roles of social alongside these ecological factors. This interdisciplinary insight suggests actions to improve the success of agri-environment schemes need to consider farmers' motivations, landscape factors and the local environment.

FARMER EXPERIENCE AND UNDERSTANDING

While social scientists have researched farmers' attitudes and motivations towards agri-environmental management (de Snoo *et al.* 2013), little is known about whether and how these social drivers affect biodiversity outcomes. The social and natural sciences have different research traditions, and while there are a number of studies which have used interdisciplinary approaches (Phillipson, Lowe & Bullock 2009; Austin, Raffaelli & White 2013) there is still little work linking social and ecological data in quantitative analyses. Interviews provide complex qualitative data, and those with our farmers revealed a range of previous engagement with agri-environmental management, a variety of opinions about the ease with which farmers felt they would be able to implement the required management, and different motivations for taking part (Lobley *et al.* 2013). The social scientists in the project team translated these qualitative responses into quantitative scores, which allowed us to combine social with ecological data in linear mixed models.

This approach proved to be powerful in linking biodiversity outcomes to farmer motivations. In the agri-environment options investigated, farmers are asked to establish specific seed mixes in field margins, which supply food resources to the target taxa. Farmers with greater agri-environmental experience produced strips with more of these resources. Experience was scored relative to the length of time and frequency with which farmers stated they had been involved in environmental management. Agri-environment schemes such as that in England, which simply pay farmers to follow specific prescriptions, have been criticized as not actively engaging farmers or allowing them to develop skills in environmental management (Burton, Kuczera & Schwarz 2008; de Snoo *et al.* 2013). In our case, it seems that farmers had developed such skills through their involvement in agri-environmental management.

The unexpected findings that more experienced farmers had more bumblebees and more wildlife-focused farmers had more butterfly species on their strips independent of their effects on habitat quality raises the tantalizing prospect that more continuous agri-environmental management had allowed populations to increase. While this interpretation is speculative, it reflects the scheme’s aim to facilitate population recovery of target species (Baker *et al.* 2012).

The fact that farmers with more concerns about the ease of management produced greater quantities of seed suggests that if farmers are learning experientially (Riley 2008) then this is more successful if they are aware of their own knowledge gaps. That is, those who thought it would be easy had a misplaced confidence. The conflicting effects of farmer motivation for strip placement on the quality of the two strip types may reflect the relative levels of knowledge about these habitats. NFM was quite novel for many farmers and so those more motivated by wildlife benefits may have managed these strips more carefully. Farmers are more familiar with the requirements for WBM as many sow game cover, which is similar. While the differences were small, utilitarian farmers achieved better WBM results.

The three social variables were not correlated and so these relationships reveal different aspects of the agri-environmental role of farmers. We did not link these social variables to specific actions carried out by the farmer. This was because: a) we did not want to burden farmers with recording their actions or to influence their behaviours by doing so; and b) we were more interested in the farmers’ experience and motivations than the well-studied issue of how management affects outcomes. However, it is clear that we are only beginning to understand the role of farmers in achieving agri-environmental success.

LOCAL AND LARGE-SCALE ENVIRONMENTAL FACTORS

The agri-environmental prescriptions were supported by the importance of the abundance and richness of flowers in attracting bumblebees and butterflies (Carvell *et al.* 2011) and of seed resources in attracting granivorous birds (Hinsley *et al.* 2010). Shelter benefits animals by providing warmth and protection (Pywell *et al.* 2004). Our findings of a positive effect of shelter on flower numbers, but a negative effect on seed weight are more novel, and may reflect a balance of competition (e.g. shading) and facilitation (e.g. warming). More flowers under conditions of low agricultural quality (i.e. low ALC) may reflect lower cover of competitive grasses, etc (Pywell *et al.* 2005).

Several studies have found that bee and bird abundance and richness are higher within agri-environmental options in landscapes with more semi-natural habitat (Concepcion *et al.* 2012; Shackelford *et al.* 2013). There is less information on the role of the species richness in the landscape, although Pywell *et al.* (2012) found this had a positive effect for bees but none for birds. By contrast, our study suggested negative effects of the proportion of semi-natural habitat and/or the size of the species pool on all but one of the biodiversity measures. Some studies have shown that agri-environmental options can have smaller effects on biodiversity in more diverse landscapes, presumably because these offer alternative foraging resources (Batary *et al.* 2010a; Carvell *et al.* 2011). In our case it may be that smaller species pools and areas of semi-natural habitat indicate fewer alternative resources and so the agri-environment strips act as 'honey pots' in attracting more birds or insects. Whatever the mechanism, landscape effects on agri-environmental outcomes are not straightforward.

Seasonal weather effects on abundance of the target biota and floral and seed resources are not surprising and reflect fundamental biological optima (Anguilletta 2009). However, it is important to note the importance of weather patterns for spatio-temporal variation in success, and that these may cause apparent failures which are beyond anyone's control.

IMPLICATIONS FOR IMPROVING AGRI-ENVIRONMENT SUCCESS

Agri-environmental research needs to move on from the question that has predominated for some time – 'do they work?' – to ask instead – 'what are the causes of variation in success?'. While some factors that affect outcomes have been studied – such as landscape context – this paper has shown that a holistic understanding of drivers is necessary. In particular, we have demonstrated the role of the farmer. In implementing agri-environment management, the farmer is not simply carrying out prescribed tasks, but is making decisions which impact on success. The importance of experience suggests that farmers gain experiential understanding of agri-environment management. This indicates scheme success might be improved by ensuring farmers stay engaged and build up experience. Indeed, Jarratt (2012) found that as farmers become more engaged in environmental-friendly farming there is a willingness to take on more complex conservation activities. This leads to the question whether actively training farmers in agri-environment management might expedite such learning (Lobley *et al.* 2013). Indeed a review of the English scheme (Defra 2008) recommended that farmers should get increased advice, although it remains to be seen whether this will be implemented.

The farmer has a role in choosing which agri-environment options to use, their placement on the farm and their establishment and management. Our study covered the latter two processes and these determined the quality of habitat produced and, ultimately, how many birds or insects used these strips. The fact that the amount of shelter affected both the quality and biodiversity outcomes suggests that farmers might be advised to consider this factor when deciding where to place strips. Similarly, pollen and nectar flower strips might be best placed on poorer quality land. Understanding of the role of the weather has a different implication, in that it can help farmers and others understand why agri-environment options may perform badly sometimes, much as crops do. Landscape factors have a complex role and the lack of general patterns (Batary *et al.* 2010a; Concepcion *et al.* 2012) suggests that any large-scale targeting of agri-environment schemes should be done with caution.

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Data accessibility

- Social and environmental data: NERC-Environmental Information Data Centre doi:10.5285/d774f98f-030d-45bb-8042-7729573a13b2 (McCracken *et al.* 2015)

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Supporting Information

Supporting information is supplied with the online version of this article.

Appendix S1. Description of Nectar Flower Mix and Wild Bird Mix options.

Appendix S2. Additional data sources.

Table 1. The importance of social and ecological drivers of biodiversity outcomes across 24 farms with agri-environment options targeted at pollen and nectar feeding insects and 24 farms with options targeted at seed-eating birds. Importance was derived using Akaike weights (w_i) following averaging of linear mixed models, and the parameter estimates (Param. est.) are weighted by w_i and averaged across models. Categorical variables are marked * and the parameter estimates are given. The most important variables – with importance ≥0.4 – are highlighted

Level	**Local (strip) environment**			**Landscape**		**Farmer social**			**Seasonal weather**	**Weather during survey**		**Region* E;SW**
Variable	**Flower #**	**Flower species**	**Shelter**	**% Semi-natural habitat**	**Species pool**	**Experience**	**Concerns**	**Motivation* 1;2;3**	**Summer max. temperature**	**Temperature**	**Wind**	
Response = Bumblebee numbers. Marginal R^2 = 0.68. Models where Δ_{AIC} < 4 = 31 of 4096												
Importance	**1**	**1**	**0.55**	**1**	**0.63**	**1**	0.18	0.13	0.32	**1**	**0.40**	**0.83**
Param. est.	**0.46**	**0.11**	**0.11**	**-0.06**	**-0.07**	**0.28**	0.13	0.06;0.32;0.46	0.21	**0.17**	**-0.07**	**0.06;0.49**
Response = Bumblebee species richness. Marginal R^2 = 0.48. Models where Δ_{AIC} < 4 = 144 of 4096												
Importance	**1**	**0.57**	**0.95**	0.31	**0.53**	**0.63**	0.12	0.05	0	0	0.15	**0.74**
Param. est.	**0.25**	**0.04**	**0.1**	-0.01	**-0.03**	**0.13**	-0.02	0.38;0.41;0.15	-	-	-0.04	**0.38;0.56**
Response = Butterfly numbers. Marginal R^2 = 0.28. Models where Δ_{AIC} < 4 = 99 of 4096												
Importance	**0.46**	**1**	**0.73**	0.17	**0.48**	0.12	0.12	0.12	**0.85**	0.09	0.1	**0.62**
Param. est.	**0.05**	**0.07**	**0.14**	-0.02	**-0.04**	-0.06	0.09	2.12;0.91;0.17	**0.43**	0.01	-0.02	**2.14;0.55**
Response = Butterfly species richness. Marginal R^2 = 0.29. Models where Δ_{AIC} < 4 = 72 of 4096												
Importance	**0.71**	0.15	**0.83**	0.27	0.18	0.38	0.08	**0.87**	0.12	0.08	0.08	**1**
Param. est.	**0.07**	-0.02	**0.09**	-0.01	-0.02	-0.12	-0.01	**1.44;0.53;0.69**	-0.09	0.01	0.1	**1.43;0.13**

Variable	**Seed weight**	**Shelter**	**% Semi-nat. habitat**	**Species pool**	**Experience**	**Concerns**	**Motivation* 1;2;3**	**Winter min. temperature**	**N/A**	**Region* E;SW**
Response = Granivorous bird numbers. Marginal R^2 = 0.36. Models where Δ_{AIC} < 4 = 19 of 512										
Importance	**1**	**1**	0.17	**0.45**	0.17	0.38	0.05	**1**		0.18
Param. est.	**0.16**	**0.27**	0.01	**-0.14**	-0.09	-0.23	8.8;12.5;14.5	**0.46**		8.8;7.5
Response = Granivorous bird species richness. Marginal R^2 = 0.36. Models where Δ_{AIC} < 4 = 41 of 512										
Importance	**1**	0.38	**0.69**	**0.57**	0.37	0.14	0.12	**1**		0.29
Param. est.	**0.1**	0.04	**-0.02**	**-0.06**	-0.08	-0.04	0.92;1.03;1.18	**0.21**		0.92;0.79

Table 2. The importance of social and ecological drivers of habitat quality across 24 farms with agri-environment options targeted at pollen and nectar feeding insects (quality = flower numbers and species richness) and 24 with options targeted at seed-eating birds (quality = weight of seed). Importance was derived using Akaike weights (w_i) following averaging of linear mixed models, and the parameter estimates (Param. est.) are weighted by w_i and averaged across models. Categorical variables are marked with * and the parameter estimates are given. The most important variables – with importance ≥0.4 – are highlighted. ALC = Agricultural Land Classification

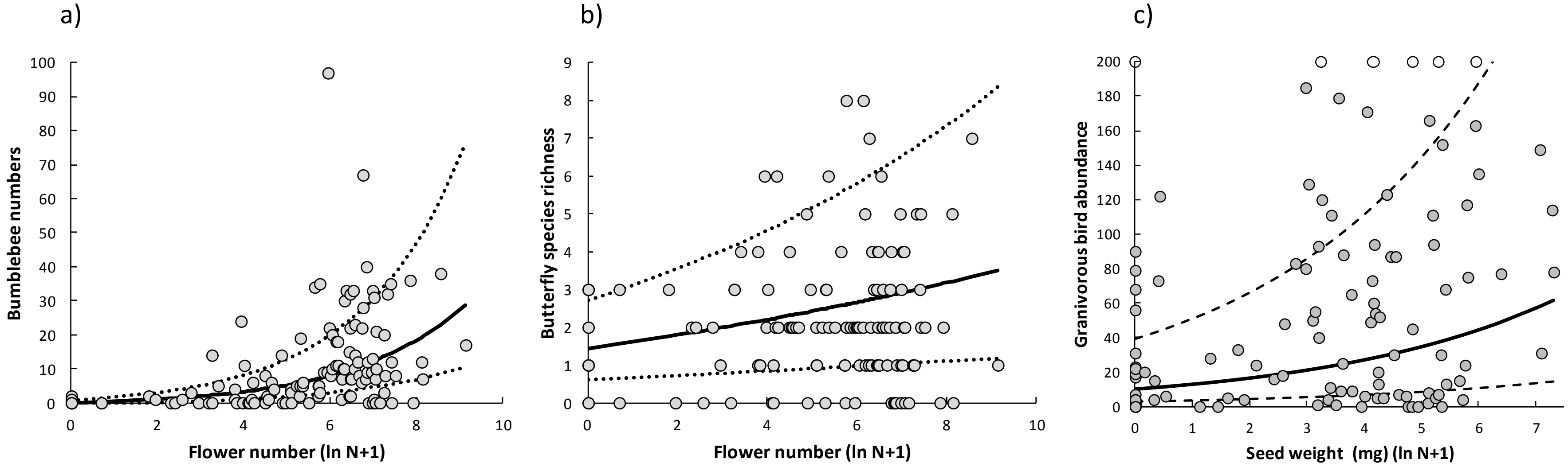
Level	**Local (strip) environment**			**Farmer social**			**Seasonal weather**			**Region* E;SW**
Variable	**ALC**	**Soil* Light;Med;Heavy**	**Shelter**	**Experience**	**Concerns**	**Motivation* 1;2;3**	**Spring max. temperature**	**Summer max. temperature**		
Response = Flower numbers. Marginal R^2 = 0.42. Models where $\Delta_{AIC} < 4$ = 14 of 512										
Importance	**1**	0.24	**1**	**0.97**	0.23	**0.43**	**1**	**1**		0.34
Param. est.	**-0.72**	963;720;1478	**1.45**	**0.46**	0.27	**1477;720;166**	**4.5**	**-0.31**		1477;741
Response = Flower species richness. Marginal R^2 = 0.06. Models where $\Delta_{AIC} < 4$ = 49 of 512										
Importance	0.35	0.04	0.22	0.36	0.21	0.01	0.21	0.21		0.17
Param. est.	0.07	4.96;4.07;4.64	-0.05	0.06	0.05	4.64;5.12;4.53	0.07	0.06		4.64;4.81
Variable	**ALC**	**Soil* Light;Med;Heavy**	**Shelter**	**Experience**	**Concerns**	**Motivation* 1;2;3**	**Spring max. temperature**	**Summer max. temperature**	**Autumn max. temperature**	**Region* E;SW**
Response = Seed weight. Marginal R^2 = 0.21. Models where $\Delta_{AIC} < 4$ = 55 of 512										
Importance	-	0.01	**0.43**	**0.7**	**0.74**	**0.64**	0.15	**0.71**	0.31	0.19
Param. est.	-	167;166;191	**-11.5**	**36.4**	**-35.1**	**191;200;299**	-6.45	**46**	-35	191;184

Figure legends

Fig. 1. Examples of relationships between the major habitat quality drivers and biodiversity outcomes (see all drivers in Table 1). Circles show raw data, solid lines the fitted relationship (from linear mixed models, so accounting for other drivers) and dotted lines ±1 standard error. a) Numbers of bumblebees, and b) Butterfly species richness as affected by the number of flowers. c) Numbers of seed-eating birds as affected by the weight of seeds. The unfilled circles in c) show large abundance values, which are, in order from left to right: 422, 485, 362, 223, 314 and 224.

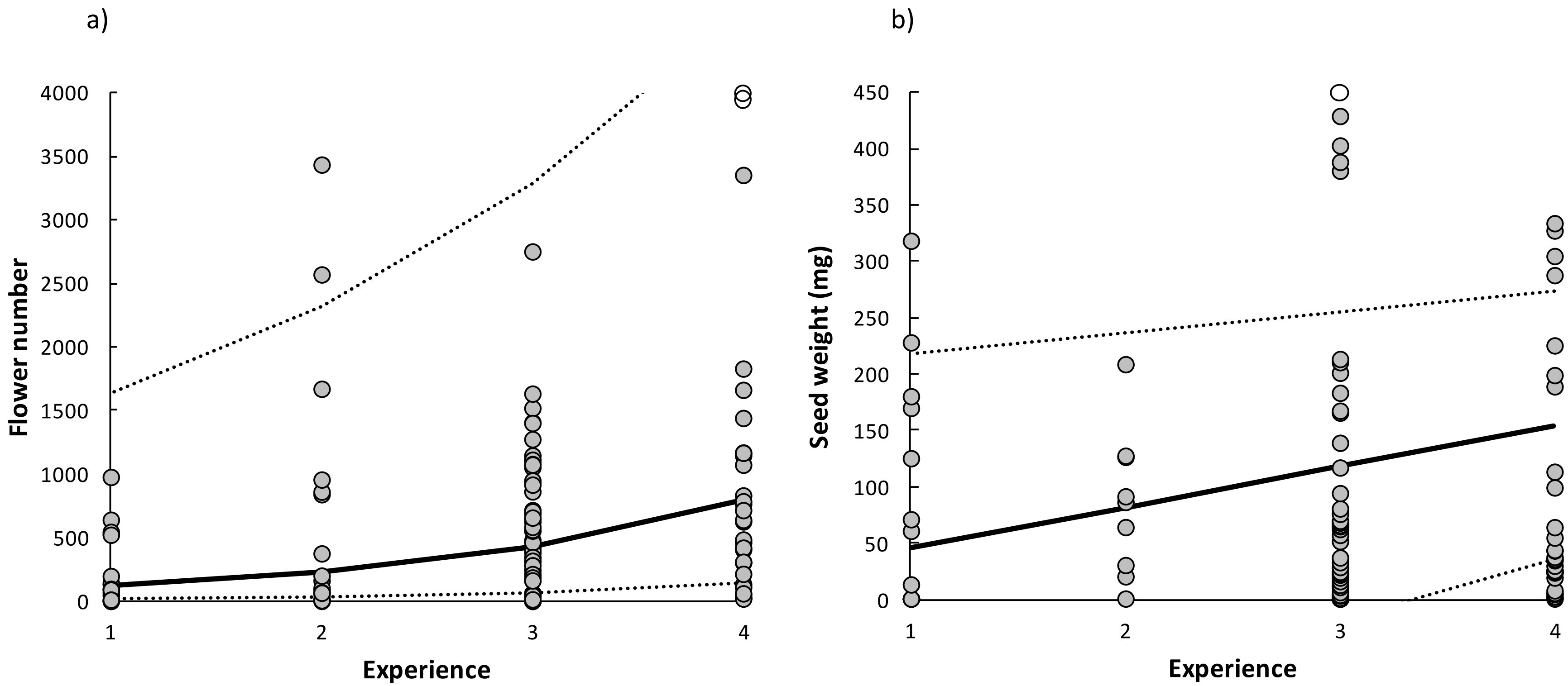
Fig. 2. Examples of relationships between the length and intensity of the farmer's previous experience of environmental management (from 1 none to 4 high) and habitat quality measures in agri-environment strips (see all drivers in Table 2). Circles show raw data, solid lines the fitted relationship (from linear mixed models, so accounting for other drivers) and dotted lines ±1 standard error of this fit. a) Number of flowers in a nectar flower strip. b) Weight of seeds in a wild bird seed strip. The unfilled circles show large values, which are: in a) 9329 and 5218; and in b) 597 mg.

Fig. 1



a)
Bumblebee numbers
Flower number (ln N+1)
b)
Butterfly species richness
Flower number (ln N+1)
c)
Granivorous bird abundance
Seed weight (mg) (ln N+1)

Fig. 2


a)
4000
3500
3000
2500
2000
1500
1000
500
0
Flower number
1
2
3
4
Experience
b)
450
400
350
300
250
200
150
100
50
0
Seed weight (mg)
1
2
3
4
Experience