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Optimizing the biodiversity gain from agri-environment schemes

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ABSTRACT

How best to optimize the biodiversity gain from agri-environment schemes (AES) has recently been identified as a key policy-relevant question. Here, the effects of two features of lowland agricultural landscapes on the abundance and diversity of larger moths are contrasted. Although both features bring about positive effects, hedgerow trees have a larger impact than 6 m wide grassy field margins. Whilst AES payments are given to create and maintain grass margins, no financial reward is currently offered for the retention of hedgerow trees. Furthermore, it was only in areas where the amount of land under AES was experimentally increased, by targeting farmers, that the presence of hedgerow trees resulted in a substantially higher abundance (+60%) and diversity (+38%) of moths. Thus, by using larger moths as bio-indicators of landscape-scale quality, it is demonstrated that improvements to the cost-effectiveness of AES could be achieved, firstly, by providing more appropriate financial rewards to farmers for different landscape features, and secondly, through landscape-scale targeting of farmers to encourage participation in AES.

1. Introduction

Agri-environment schemes (AES) provide financial support to farmers for adopting environmentally friendly ways of managing land. Their implementation is currently considered the most important and only realistic policy instrument through which to reverse widespread biodiversity declines across European and North American agricultural landscapes (Donald and Evans, 2006; Tscharntke et al., 2007; Warren et al., 2008). However, there is ample room for increasing their cost-effectiveness, both in terms of biodiversity gain (Kleijn and Sutherland, 2003; Kleijn et al., 2006), and socio-economics (Wätzold and Schwerdtner, 2005).

Here, this optimization issue is addressed in two ways: (i) by contrasting the cost-effectiveness in terms of biodiversity gain of two features that are common within agricultural landscapes, and (ii) by investigating the impacts on biodiversity of an experimentally increased AES uptake at the landscape scale. These higher levels of scheme uptake, and hence higher levels of land managed in a more environmentally friendly way, were achieved by targeting farmers in specific areas within the Upper Thames catchment, UK, encouraging them to take part in the AES and actively supporting them. Farmers received free advice and guidance concerning habitat management and enhancement on their land, including a 'whole farm conservation plan', and they were offered assistance with grant application forms (both for the Entry and Higher Level Stewardship Schemes; DEFRA, 2005). Such landscape-scale targeting contrasts with the usual method of AES uptake, which depends on farmers making a voluntary effort to apply for AES. Landscape-scale targeting of whole areas in terms of actively encouraging farmers to take up general AES, as opposed to specific AES measures within certain areas that target specific species or species groups (e.g. Peach et al., 2001), is currently seen as a key issue in enhancing the wider ecological benefits of AES (Whittingham, 2007; DEFRA, 2008), but so far very little empirical evidence exists that it works (Dutton et al., 2008).

Larger moths are an ecologically diverse and species-rich group, occurring abundantly in farmland landscapes, and constituting an important food resource for bats, birds, small mammals and invertebrates (e.g. Vaughan, 1997; Wilson et al., 1999). They are considered a sensitive indicator group for measuring biodiversity in terrestrial ecosystems (Luff and Woiwod, 1995; New, 2004; Thomas, 2005), although they have hitherto been little studied in relation to the impacts of farmland management (but see Merckx et al., 2009). However, rapid and significant declines have been recorded for many common and widespread moth species that inhabit farmland in the UK, and possibly in the majority of temperate zones (Conrad et al., 2006).

The effects of two key landscape features within arable land, namely grassy field margins and hedgerow trees, on the abundance and species diversity of larger moths, were assessed in a multi-site

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experiment using light traps. Both features provide habitat for moths. Wide field margins provide a relatively undisturbed breeding habitat and can act as buffer zones against the impact of agricultural chemicals on moth larvae and their host plants (Longley and Sotherton, 1997; Pywell et al., 2004). Hedgerow trees provide some species with larval (and/or adult) food resources and, more generally, provide a further level of structural diversity (Maudsley, 2000), and a more sheltered microclimate. Within agricultural landscapes, hedgerow complexes contain a greater diversity of organisms than do other habitats, as they often provide the only surrogate habitat in the wider countryside for species with dwindling areas of optimum habitat (Burel, 1996). Hence, our findings are likely to be representative of many terrestrial insect groups that occur in this ubiquitous type of habitat. This must also have implications across trophic levels and for the provision of ecosystem services (e.g. pollination; Kremen and Chaplin-Kramer, 2007).

Wide (6 m) field margins are an important conservation tool (Feber et al., 1996; Macdonald et al., 2000). Unlike hedgerow trees, their restoration and management is a financially rewarded option under current AES, widely taken up by farmers (grass/buffer strips on arable land covered over 47,000 ha in English AES by autumn 2006; DEFRA, 2005; Butler et al., 2007). Here, it is tested (i) whether the presence of these wide margins has a positive impact on moth abundance and diversity and (ii) whether this impact of wide margins is larger than the impact on abundance and diversity of the presence of hedgerow trees. Furthermore, the effects of these two features are compared at the landscape scale (i.e. 10 km × 20 km), rather than at farm- or field level. In doing so, it is tested whether a concerted effort across a targeted area to help farmers improve farmland habitat, and to assist them in securing financial support through the uptake of AES, adds to the biodiversity benefits that such schemes bring.

2. Materials and methods

2.1. Study sites and design

Standardised year-round daily sampling with Rothamsted light traps has shown little variation in moth species diversity between sites on lowland agricultural land over a wide area of southern England (i.e. Devon to Norfolk), UK [yearly log-series α diversity indices averaged over a recent period of 5 years: 31.0 ± 1.98 (mean ± S.E.; $N = 10$) (I. Woiwod, pers. comm.)]. Here, an experiment was conducted in four adjacent areas that together comprise only a small fraction of this lowland agricultural landscape (i.e. central Oxfordshire), and hence broadly share the same species pool. Two targeted areas, in which farmers were systematically encouraged over a period of 2 years (2004–2006) to take up AES (i.e. Entry and Higher Level Environmental Stewardship of English AES; DEFRA, 2005), were contrasted with two control areas where active targeting was not carried out. Control areas were representative of the ubiquitous and standard method of AES uptake, which relies upon farmers making a voluntary effort to apply for AES, and hence results in a 'scattergun' uptake. Targeted and control areas did not differ with regard to the proportion of land under scheme at the start of targeting in 2004 (0.31 ± 0.04 (mean ± S.E.) *vs.* 0.29 ± 0.05, respectively; $t = 0.31$, d.f. = 1, $p = 0.81$). The four areas were selected on the basis of having similar proportions of arable land, pasture and woodland within the same buffered targeted and control areas, respectively: arable land: 0.43 ± 0.05 *vs.* 0.49 ± 0.04; $t = 0.69$, d.f. = 1, $p = 0.62$; pasture: 0.27 ± 0.02 *vs.* 0.23 ± 0.01; $t = 2.20$, d.f. = 1, $p = 0.27$; woodland: 0.03 ± 0.01 *vs.* 0.09 ± 0.02; $t = 1.92$, d.f. = 1, $p = 0.31$. Solitary hedgerow trees were counted in an area of 1.77 km^2 [Google Earth (2008); eye altitude: 1.5 km] centred on the three trap sites for each of the 16 farms (see below). Their density did not differ between targeted and non-targeted areas (mean count ± S.E.: 155 ± 35.3 *vs.* 167 ± 12.9, respectively; $t_{8.84} = 0.32$, $p = 0.76$). After only 2 years of landowner targeting, one outcome was an increase in the areas of land with the enhanced hedgerow management option (DEFRA, 2005) under AES relative to control areas (Natural England Environmental Stewardship data: 5197 ± 1113 ha *vs.* 1972 ± 326 ha; $t = 11.68$, d.f. = 1, $p = 0.05$). Within the targeted areas, this resulted in approximately 219 km of hedgerow under enhanced management *vs.* 83 km in control areas. This specific AES option requires that no more than one third of the hedges be cut per farm in each year, that hedges are maintained to a height of no less than 2 m and that each hedge is cut no more than once every 3 years.

Wide (6 m) perennial grass margins (current agri-environment option; DEFRA, 2005) were compared with standard (ca. 1 m; cross-compliance) margins in the fields sampled, and presence/absence of an open-grown hedgerow tree (minimum height: 15 m; predominantly *Quercus robur* L., pedunculate oak). Within each study area, 12 sites were sampled spread over 4 predominantly arable farms, 3 per farm, to give 48 sites in total. Each farm was from a different experimental group as follows: (i) hedgerow tree + wide margin; (ii) hedgerow tree + standard margin; (iii) no hedgerow tree + wide margin; (iv) no hedgerow tree + standard margin.

2.2. Sampling

Larger moths (all families as covered by Skinner, 1998 and Waring and Townsend, 2003) were sampled using 6 W Heath pattern actinic light traps (Heath, 1965). These operate on the 'lobster-pot principle', whereby moths are drawn to an actinic tube held vertically between baffles, fall unharmed down a funnel, and rest on the inside of the trap or on pieces of egg-tray provided. Traps were operated from dusk until dawn, when the live sample was enumerated, identified to species and released *in situ*. For a small suite of species groups, identification was to generic or species-pair level, since species-level identification would have meant the collection and microscopic examination of a large number of specimens. Occasionally, specimens were collected for confirmation of their identity.

Each farm was sampled 11 times from mid-May to mid-October 2006, in discrete fortnightly periods, once in each period, in random order within the period. A maximum of three farms (i.e. nine sites) were sampled on any one night, and traps were collected in and moved to a different site after each sample. Sampling sites were carefully selected so that the variation in hedgerow tree and margin characteristics other than the subject variables was minimal throughout. All sites were ≥100 m apart in order to minimize a possible confounding effect of action radius interference between light traps, and fixed for the duration of the experiment. All sites were more than 50 m from hedgerow intersections in order to minimize a possible confounding effect of local aggregation of individuals that use hedgerows as flight corridors (Maudsley, 2000). Sampling sites were always located 1 m from average-sized hedgerows (2–3 m high; 1.5–2.5 m wide), bordering arable land on both sides with no banks or ditches. Sampling points were positioned nearby the trunk of a hedgerow tree, but never directly under the canopy, at least for the experimental groups with hedgerow trees present. The aspect of the sampling site with respect to the hedge was not taken into account, as this had no effect on species diversity in an earlier experiment with the same equipment in the same study areas ($F_{3,170} = 1.75$, $p = 0.16$) (T. Merckx, unpubl.). This preceding experiment also showed that a sampling intensity of three sites per experimental group was sufficient, since data gathered on any one occasion from three sampling sites explained $90.0 \pm 0.021\%$ (mean ± S.E.; $N = 18$) of the species diversity value obtained when data from 10 sites were combined.

Sampling followed a strict protocol to control for confounding factors between sites and between sampling events. Traps were placed upon a 2 m^2 white cotton sheet held in position on the ground with metal tent pegs. This enhanced and equalized the visibility of the trap to moths by covering the vegetation, and increased sample size by enabling to record individuals resting on the ground close to the trap (recorded separately along with moths resting on the outside of the trap itself) without creating bias towards more brightly marked, conspicuous species. For the same reason, moths resting on the surrounding vegetation were disregarded. Sampling occurred under pre-defined weather forecast criteria of minimum night temperature (10 °C) and maximum wind speed (20 km/h). All traps were equipped with temperature loggers (iButton DS1921G-5; Maxim/Dallas; Sunnyvale, USA) programmed to read ambient temperature 60 cm above ground level at 1 h intervals. The afternoon before each trapping night the following variables were recorded as predicted for the Oxford area between sunset and sunrise on http://uk.weather.com: minimum temperature; maximum wind speed; maximum humidity; average wind direction (eight classes); cloudiness (cloudy; partly cloudy; clear); moon phase, i.e. darkness (three classes).

2.3. Analyses

Total number of moth individuals (abundance, N) and species diversity (log-series diversity index, α) was calculated for each farm by combining the data from the three sampling sites. Diversity indices excel over the use of the straight number of species (species richness) as the latter is highly vulnerable to sample size bias.

In a first set of analyses (see Table 1) abundance ($\log N+1$) and species diversity of moths from farms where we sampled sites with standard field margins and no hedgerow trees were simply contrasted with farms where we sampled sites with the three other combinations of presence/absence of wide field margins and hedgerow trees. These analyses were performed by student t-tests (Proc Ttest, SAS 8.2).

A second set of analyses were mixed regression models (Proc Mixed, SAS 8.2) with which the same effects of hedgerow trees and wide field margins on moth abundance and species diversity were analysed, but they also took the landscape-scale effects of targeting into account. These regression models were run on fortnightly data, as this resulted in models with a higher significance than general linear models where data were combined over the entire period, though the latter gave similar results. The dependent variables were log-transformed. Data points where $N < 40$ were omitted since such low N-values are more likely to cause stochastic variation, and hence result in less reliable α-values (Taylor et al., 1976). Data were analysed in relation to the fixed effects of 'targeting' (targeted *vs.* control areas), 'tree' (hedgerow tree present *vs.* absent), 'margin' (wide *vs.* standard field margin) and all possible interactions. Date and fortnight were included as random variables, as well as a set of covariates to correct for their assumed impact on the variability of the data: maximum humidity; maximum wind speed; average wind direction; cloudiness; moon phase; and minimum temperature (from three temperature loggers per farm). Final models were obtained by starting with a full model and applying backward deletion of non-significant factors, although factors with p-values < 0.25 (retention criterion), all main effects, and all random factors were invariably left inside the models. Models had a better fit when they included moths found resting on the sheet and on the outside of the traps (5.47% of the total). Model residuals were normally distributed (Shapiro-Wilk). Degrees of freedom were calculated using the Satterthwaite option (Littell et al., 1996).

Table 1
Effects of presence/absence of hedgerow trees and wide field margins.

Variable	Combination	Mean ± S.E.	t	p
(a) Abundance	Tree + wide margin	3.30 ± 0.052	$t_6 = -2.87$	0.028
	Tree + standard margin	3.20 ± 0.11	$t_6 = -0.90$	0.40
	No tree + wide margin	3.11 ± 0.024	$t_6 = -0.34$	0.75
	No tree + standard margin	3.09 ± 0.049		
(b) Diversity	Tree + wide margin	31.1 ± 1.00	$t_6 = -5.94$	0.0010
	Tree + standard margin	27.2 ± 1.90	$t_6 = -2.54$	0.044
	No tree + wide margin	26.7 ± 2.00	$t_6 = -2.21$	0.069
	No tree + standard margin	21.4 ± 1.29		

Overview of effects on overall (a) abundance ($\log N+1$) and (b) species diversity (log-series α) of larger moths. Experimental combinations are contrasted against the 'no tree + standard margin' combination via t-tests.

3. Results

On total 27,071 macro-moths from 270 species were recorded. Abundance varied greatly, six species having >1000 (maximum 3119), 104 species <5 individuals.

3.1. Contrasting wide field margins and hedgerow trees

Overall, the presence of wide field margins had a positive impact on moth abundance and moth species diversity. However, this impact was smaller than the impact of hedgerow trees. The presence of hedgerow trees resulted in a higher diversity index α than the presence of wide field margins (Table 1a and b). For instance, while there was only a trend for higher moth species diversity due to the presence of a wide field margin at farms where sample sites lacked hedgerow trees, moth species diversity was significantly higher when hedgerow trees were present at sites with standard field margins (Table 1b).

3.2. Effects of targeting at the landscape level

Although landscape-scale targeting showed no significant effect overall, it was only in targeted areas that the presence of hedgerow trees significantly increased moth abundance; hedgerow trees had no effect on abundance in the control areas (Table 2a; Fig. 1). Also, the positive effect of hedgerow trees on species diversity was significantly stronger in the targeted areas than in the control areas (Table 2b; Fig. 2). This differential effect of hedgerow trees with the 'targeting' variable was more pronounced at farms with standard rather than wide field margins (Table 2b; Fig. 2). As differences in hedgerow tree characteristics and density were controlled for by careful site selection, this effect of 'targeting' was not merely due to differences in hedgerow trees or in

Table 2
Landscape-scale effects of hedgerow trees and wide field margins.

Variable	Effect	F	p
(a) Abundance	Targeting × tree	$F_{1,118} = 4.58$	0.034
	Targeting	$F_{1,108} = 1.09$	0.30
	Tree	$F_{1,111} = 2.64$	0.11
	Margin	$F_{1,117} = 3.33$	0.071
(b) Diversity	Targeting × tree × margin	$F_{1,101} = 5.26$	0.024
	Targeting × tree	$F_{1,113} = 8.83$	0.0036
	Targeting × margin	$F_{1,105} = 3.14$	0.079
	Tree × margin	$F_{1,106} = 3.48$	0.065
	Targeting	$F_{1,98.9} = 1.38$	0.24
	Tree	$F_{1,104} = 15.98$	0.0001
	Margin	$F_{1,112} = 14.01$	0.0003

Results of mixed regression models for (a) abundance ($\log N+1$) and (b) species diversity (log-series α) of fortnightly sampled larger moths in relation to the landscape 'targeting' variable and the presence of hedgerow trees and wide field margins. Mixed procedure was applied (SAS) using type III sums of squares.

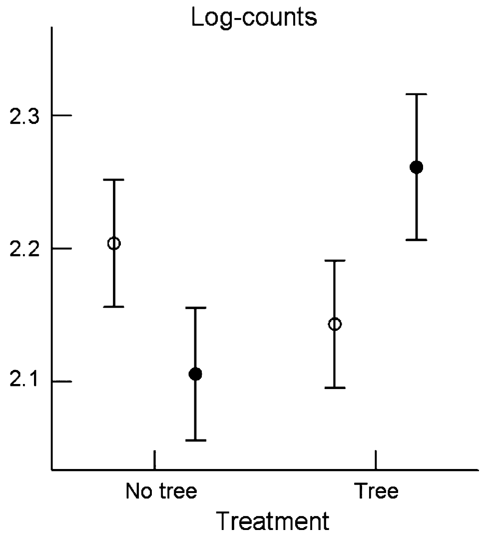

Fig. 1. Fortnightly individual moth counts (log $N + 1$) contrasting the effects of presence/absence of hedgerow trees on abundance within areas where farmers had (●) and had not been (○) targeted (with SE).

hedgerow tree density between targeted and control areas. Although the effect of 'margin' on moth abundance was not significant, wide field margins significantly increased moth diversity, both in targeted and control areas (Table 2a and b; Fig. 2). However, the (main) effect of 'tree' on diversity was slightly larger (Table 2b).

4. Discussion

Wide field margins, financially rewarded under AES in England and other European countries (Kleijn and Sutherland, 2003; DEFRA, 2005), resulted in significantly higher levels of moth species diversity and a trend towards higher abundances compared to standard field margins. However, the benefits were smaller than those obtained from the presence of hedgerow trees, especially in targeted areas. Since the presence of hedgerow trees is currently not financially supported under English AES, one way of enhancing the cost-effectiveness of the current schemes would be to apply a targeted landscape approach, and include financial incentives for management of hedgerow trees to increase their density and improve age structure. Our results provide strong support for the recent recommendations regarding hedgerow tree establishment and protection included in the English Environmental Stewardship Review of Progress report (DEFRA, 2008).

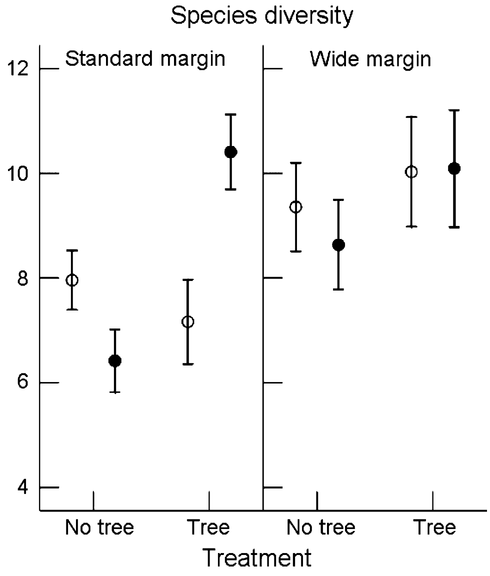

Fig. 2. Fortnightly log-series α indexes of moth communities contrasting the effects of presence/absence of hedgerow trees and wide field margins on species diversity in areas where farmers had (●) and had not (○) been targeted (with SE).

A mechanistic interpretation of the results suggests that the shelter provided by hedgerow trees is probably the key reason for their beneficial effects on moth abundance and diversity. *A posteriori* tests showed that the presence of hedgerow trees increased the abundance of moth species irrespective of whether they use *Q. robur* as host plant or other plant species found in the margins and hedgerows, albeit the effect was, as expected, significantly larger for the *Q. robur* dependent species (+300%; $N = 39$) than for the other species (+43%; $N = 204$). This finding demonstrates that the observed beneficial effect of hedgerow trees is partly an effect of increased abundance of the host plant, but not simply so. We suggest that the shelter created by hedgerow trees enhances a hedgerow's potential ability to function as a corridor for many species (reviewed in Davies and Pullin, 2007). Hence, better management of hedgerow trees could play a vital role in lessening the effects of habitat fragmentation, which is especially prevalent within agricultural landscapes. This also implies that the retention and replacement of hedgerow trees within landscapes should be part of a set of AES measures that provide and link habitats, such as wide field margins, enhanced hedgerows and native woods. It has been shown that diversified landscapes with a high prevalence of such landscape features hold most potential, both for biodiversity conservation (Weibull et al., 2000; Rundlöf and Smith, 2006; Rundlöf et al., 2008b) and sustaining pest control (Bianchi et al., 2006).

The landscape-scale approach allowed to show that both moth abundance and moth species diversity are positively affected when hedgerow trees are present, but only so in landscapes with a higher proportion of land under AES. This result demonstrates that the effect of this prominent landscape feature depends on the landscape context, which suggests that beneficial effects of other landscape features and scheme options might become apparent only when landscape connectivity has been substantially increased. We believe that measures under the current English AES translate into more favourably managed land for moths, and thus result in larger areas of spatially more connected habitat and in a lower resistance of the agricultural matrix (Critchley et al., 2006). Our rationale behind landscape-scale targeting hence differs from, but is also complimentary to other support for targeting based upon the occurrence of target organisms, extant biodiversity, or regional variation in responses to management (Peach et al., 2001; Whittingham et al., 2007) (see also Dutton et al., 2008). We believe the key element here is that the area-specific targeting of farmers increases landscape connectivity to a much greater extent than a normal, untargeted and diffuse uptake of AES measures – a factor likely to be very important, *inter alia*, in the context of adaptation to climate change. The area-specific targeting hence allows both generalist and specialist moth species to move more easily through the landscape matrix. As landscape connectivity is a species (population)-specific parameter, we believe that the general aim of a concerted targeting effort should be to alter the extent and configuration of specific landscape elements such that the resistance of the landscape matrix decreases for the large majority of species (populations) present in the regional pool. This would then allow significant levels of dispersal through the landscape, resulting in more sustainable metapopulations and the colonisation of new sites.

Although our study is focused on larger moths only, they are considered to be a sensitive indicator group for terrestrial biodiversity (Luff and Woiwod, 1995; New, 2004; Thomas, 2005). We believe this group is indeed indicative of many other insect groups, which form a large part of, and play a key role within, terrestrial ecosystems in general, and agricultural ecosystems in particular. Both microclimate and landscape connectivity are key issues for the majority of these insects, which are ectothermic and hence need some degree of shelter within the typically exposed, open agricultural landscapes. Sheltered spots may provide other (larval and adult) resources, such as food and mates, and may in turn help to reduce the resistance of the agricultural matrix in terms of dispersal. At the community level, such a raised biomass and more diverse composition of the insect community would allow other species (taxa) to make better use of this resource, resulting in an increase in biodiversity at different trophic levels.

Our results add to those of recent studies that show the significant impacts of landscape context on biodiversity (e.g. Hendrickx et al., 2007; Holzschuh et al., 2007; Kivinen et al., 2007). For example, Rundlöf et al. (2008a) showed that, in an agricultural region in southern Sweden, "local butterfly species richness was [also] positively affected by a large proportion of organic farming in the surrounding landscape, independent of the local farming practice". To our knowledge, the evidence presented here provides the first strong support that an approach which targets whole landscapes for AES uptake, rather than the classic scattered approach focused on single sites, will have positive biodiversity gains. Both studies demonstrate the importance of the spatial distribution of AES, be it organic or conventional agriculture, on species richness and species diversity.

We assert that the way to increase biodiversity at regional scales is to move forward from conservation largely within protected areas towards landscape-scale conservation. A recent change in this direction, based upon insights from metapopulation and landscape ecology, is apparent in the growing move towards landscape-scale projects within nature conservation bodies, and in some policy statements. For example, the English government's statutory nature conservation body 'Natural England' announced that a new approach to targeting agri-environment funding is required to maximize environmental benefits, moving away from an entry-for-all approach towards a targeted, invitation-only system (NE, 2007).

AES are costly (Europe, 2008). Therefore, it is important that governments regularly review AES in the light of new research results (see also Whittingham, 2007), and that they follow an evidence-based approach to increase the cost-efficiency of their investments in AES. In doing so, these AES would increase farmland ecosystem resilience and mitigate the detrimental synergy between habitat fragmentation and climate change on biodiversity in agricultural landscapes.

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