Natural England Commissioned Report NECR157

Assessing the importance of spatial location of agri environment options within the landscape to butterflies

Correlative analysis of datasets to assess the degree of success in the delivery of Environmental Stewardship objectives

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Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. This project is supported by the Rural Development Programme for England, for which Defra is the Managing Authority, part financed by the European Agricultural Fund for Rural Development: Europe investing in rural areas.

Background

This study is one of three to correlatively analyse datasets to assess the degree of success in the delivery of Environmental Stewardship (ES) objectives. The studies are particularly relevant to ES, but do not discount the effects of earlier agri-environment schemes such as Environmentally Sensitive Areas and the Countryside Stewardship Scheme. The objectives for the project are to:

- Provide clear evidence of the extent to which existing ES scheme options have delivered against specific stated objectives or environmental outcomes by using appropriate extensive datasets, suitable for analysis both in spatial and temporal terms.
- Provide recommendations for future monitoring of ES option outcomes and requirements for data gathering or data coordination within and between existing monitoring schemes, including the potential for additional data gathering or modifications to monitoring protocols where this could be undertaken at little additional cost.

The aim is to evaluate how well Government funded agri-environment interventions are providing improved trajectories towards the planned objectives of the schemes.

This study used data from the UK and Wider Countryside Butterfly Monitoring Schemes (UKBMS and WCBMS respectively) to look at the impact of agri-environmental schemes on the populations of butterfly species.

Butterfly population densities were related to a number of land use variables for 1 km and 3 km buffers around the BMS transects. These variables included:

- areas under agri-environment scheme options;
- area of SSSI;
- area of land under arable and horticultural land cover; and
- level of pesticide usage.

The results of this report, NECR156 - *Assessment of the effect of Environmental Stewardship on improving the ecological status of grassland, moorland and heath* and NECR158 - *Assessment of the effects of Environmental Stewardship on landscape character* will contribute to a wider analysis of similar linkages between management options and ES objectives, which will be used to help formulate and implement the next Rural Development Programme for England.

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Keywords - butterflies, Environmental Stewardship (ES), monitoring

Further information
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Executive Summary

1. This study used data from the UK and Wider Countryside Butterfly Monitoring Schemes (UKBMS and WCBMS respectively) to look at the impact of agri-environmental schemes on the populations of butterfly species. Butterfly population densities were related to a number of land use variables for 1km and 3km buffers around the BMS transects. These variables included areas under agri-environment scheme options, area of SSSI, area of land under arable and horticultural land cover, and level of pesticide usage.

2. Both spatial and temporal effects of agri-environment implementation were tested for, with the temporal effect being examined using a break-point analysis of the UKBMS data based on the date of first Agri-Environment (AE) scheme option implementation.

3. From the spatial analysis across all species, area of AE scheme had a number of positive relationships with species population densities. However, these were related to the area under management in the classic schemes (Environmentally Sensitive Areas and Countryside Stewardship) rather than the current Environmental Stewardship scheme.

4. Model fit was better when a selected set of options, targeted to support butterflies, bees and vulnerable grasslands, were used instead of the full list of options. It was also found that the count of options applied within the buffer areas was a better predictor than total area of options. This may indicate the importance of protecting a range of key resources in order to support butterfly populations.

5. There was little evidence from the temporal analysis that the introduction of AE scheme options had a significant impact on butterfly population trajectories. This may be due to being only able to use data from the UKBMS which, in the spatial analysis, showed weaker relationships between species density and AE scheme area than the WCBMS. The temporal analysis is also further confounded by inter-annual variation in climatic conditions which may reduce the statistical power of the analysis to detect a breakpoint related to the introduction of AE scheme options.

6. There was no evidence that levels of pesticide use had affected population densities. In some cases there was a positive relationship between the level of pesticide use and the population density of species which would be expected to be at greatest risk (ie those that use *Brassica*s as food plants). Area of arable and horticulture was also generally positively related with species densities, which may be due to habitats associated with linear features (such as field margins and hedgerows) being capable of supporting higher densities of butterflies, and an introduced bias from surveyors using these features to undertake their transect walks.

7. Overall there was evidence that components of AE schemes are supporting butterfly populations within agricultural landscapes. However, for many specialist species protected (SSSI) semi-natural areas are more important than area under AE schemes, and so this study indicates that both protected sites and AE schemes would be needed to maintain butterfly diversity and populations across England.

Contents

1. Introduction

This report is part of a series of studies commissioned to determine the extent to which environmental changes can be attributed to the impacts of agri-environment schemes, and within those schemes, individual agreements. The studies are particularly relevant to Environmental Stewardship, but do not discount the effects of earlier agri-environment schemes such as Environmentally Sensitive Areas (ESAs), and the Countryside Stewardship Scheme (CSS).

The aim of this study was to investigate whether habitat enhancement options implemented as part of agri-environment schemes benefit butterfly species associated with those habitats. We use butterflies as a model species group for pollinators in the wider countryside as these are the only invertebrates with sufficient spatial and temporal population monitoring to conduct such an analysis. This group is sensitive to land use and climate change and butterfly trends are thought to be reasonable indicators of patterns in wider invertebrate biodiversity, including bees (Thomas 2005). We use two analytical approaches: one is a *spatial perspective*- investigating whether butterfly densities are higher in areas where AE schemes have been implemented. This approach has limitations in attribution of the effects of AE schemes, because spatial patterns in butterfly densities associated with AE schemes might simply reflect patterns from the targeting of schemes. Therefore, we also take a *temporal perspective*- investigating whether the start date of AE schemes in an area are associated with significant increases in butterfly population trajectories.

2. Hypotheses

Our specific hypotheses were as follows:

2.1 Spatial Perspective Hypotheses

1. Independent of regional climate and the area of semi-natural habitats outside AE schemes, the total area of AE schemes in landscapes will be positively correlated with butterfly densities.
2. Arable land without AE schemes will show lower butterfly densities than where AE schemes are present.
3. Area of SSSI land around monitoring sites will have a positive effect on butterfly densities.
4. Crop and pesticide loadings in local landscapes will have a negative effect on butterfly densities after accounting for the factors above.
5. Butterfly responses to AE schemes will vary between species. Only a small subset of species show strong positive associations with AE schemes. In contrast, a large area of SSSIs in the surrounding landscape will benefit a broader range of species.
6. ES schemes will have strongest impacts on butterfly densities at local scales (1km radius), but after accounting for this local effect the amount of land under AE schemes at larger spatial scales (3km radius) will also affect butterfly densities, in particular for more mobile species.

2.2 Temporal Perspective Hypotheses

1. Butterfly population trends over time will differ depending on the area and uptake date of AE schemes in the surrounding landscape. Specifically, for species known to benefit from AE schemes (identified in the spatial perspective analysis), population trends will differ significantly before and after the uptake of AE schemes in the surrounding landscape. Population trends will be more positive following the adoption of schemes.
2. For these species, there will be a lag effect of one to three years before the effect of AE schemes becomes realised, because plants providing shelter, nectar and host plants for butterflies may need time to become properly established.

3. Methods

3.1 Data collation

Two types of butterfly data were used, both collected by trained volunteers, thereby allowing high levels of spatial and temporal replication across the country. One is the Wider Countryside Butterfly Monitoring scheme (WCBMS; http://www.ukbms.org/wcbs.htm). This scheme involves two parallel transect walks within 1km squares, which are a random sample across the countryside. A minimum of two surveys are carried out in July and August, with at least 10 days between the two visits. The other scheme is the UK Butterfly Monitoring scheme (UKBMS; http://www.ukbms.org/). This scheme involves transects of varying lengths which are walked throughout the entire butterfly flight season (i.e. up to 26 weeks). The scheme has been running for much longer than the WCBMS and so has the benefit of allowing analysis of temporal trends in butterfly populations. However, the limitation of this scheme is that monitoring transects tend to be located in a non-random subset of higher quality sites (e.g. with less coverage of farmland). So these data may have lower statistical power to detect the effects of AE scheme implementations. In addition, the impact of AE schemes might be less if sites are located in higher quality landscapes (i.e. greater extents of semi-natural habitat; Tscharntke *et al.* 2005). Nevertheless, broader patterns in land use around UKBMS sites have been shown to have detectable effects on populations. These effects may extend up to 5km and potentially beyond for more mobile species (e.g. Oliver *et al.* 2010). A map of WCBMS and UKBMS site locations is shown in Figure 1.

Data on AE schemes around WCBMS and UKBMS monitoring sites were extracted from the national database supplied by Natural England. These comprised the total area of Environmental Stewardship (ES), Environmentally Sensitive Areas (ESA), Countryside Stewardship (CSS) schemes along with specific starting dates for different options in each area. ESA and CSS schemes ran prior to the ES scheme, with the ESA scheme commencing in 1987, followed by the CSS scheme in 1991 to cover the most important areas outside ESAs. Finally, after a major review in 2005, a new ES scheme was launched and the ESA and CSS schemes (now collectively referred to as classic schemes) were closed to new applicants. The ES scheme is currently still running with two tiers, Entry Level and Higher Level, with specific strands for organic farms and holdings in upland areas (Natural England 2009).

In addition to AE schemes, the total area of arable and horticulture land cover was also assessed using remote sensing data (CEH Landcover Map 2007; Centre for Ecology and Hydrology 2011). Finally, data from the June Agricultural Census performed in 2010 and the 2010 Pesticide Usage Survey were collated, which partition crops and the associated pesticide use to 2km grid cells using areal interpolation based on the intersection between the 2km grid cells and a database of land parcels for holdings derived from the Rural Land Register. These figures represent the number of hectares of crop that have been treated with a pesticide at a level greater than the threshold which would trigger additional risk assessments according to European ecotoxicology guidelines based on honeybee LD50s. All the above data were assessed in circular buffers of 1km and 3km radius around the centroid of the monitored sites.

We also made use of an existing dataset detailing the cover of protected areas around BMS monitoring sites. This data were derived from Natural England GIS layers on all SSSIs and were calculated as the total area of SSSI in the 1km square that a WCBMS transect route passed, or for the 1km square in which the centroid of a UKBMS site was located.

Correlations between these all these different explanatory variables can be found in the Appendix of supporting materials, Tables A1-A4[1].

Figure 1 Locations of a) the 451 UKBMS monitoring sites and b) the 399 WCBMS monitoring sites used in the analysis.

3.2 Spatial Perspective - multispecies analysis

This analysis was carried out using butterfly data from both butterfly monitoring schemes. For the WCBMS scheme, we took the sum count of all butterflies in each visit in a year and then took the mean of this sum count across all visits. To ensure a fair comparison between sites, we only included counts taken between July and August, and only included sites with at least two visits during this primary monitoring period. This leads to under recording of some spring flying species (e.g. orange tip, grizzled and dingy skippers), but ensures that counts can be compared across sites (i.e. each site contributes data from the same period). The mean total number of

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[1] Tables and Figures found in the Appendix are prefixed with the letter A.

butterflies per visit was then related to characteristics of the surrounding landscape, in terms of AE scheme, arable/horticulture and protected area cover and area of pesticide treatment in 2010. We assessed three different AE schemes (Environmentally Sensitive Areas scheme 'ESA'; Countryside Stewardship Scheme 'CSS'; Environmental Stewardship scheme 'ES'), each in terms of total area (based on boundaries of holdings with agreements) and number of individual options (e.g. number of margins plus number of managed hedgerows). The number of individual options is often correlated with total area (Tables A1-A4), and so these were fitted in separate statistical models. We included number of individual options because in addition to the total 'amount' of AE scheme it may capture other aspects such as the diversity of options both in terms of type but also different start dates of the same options. For statistical modelling, we used a linear mixed effects model, using the lme4 package in the program R (Bates *et al.* 2008; R Development Core Team 2009) following equation [1] or [2]:

$$\check{N}_{2010} \sim AH + ES_{area} + ESA_{area} + CS_{area} + PA + Pesticide_{2010} + \mathit{100km\_grid} \qquad [1]$$

$$\check{N}_{2010} \sim AH + ES_{option.count} + ESA_{option.count} + CS_{option.count} + PA + Pesticide_{2010} + \mathit{100km\_grid} \qquad [2]$$

Where $\check{N}$ is the mean total number of butterflies per visit in 2010 at each WCBMS site transformed by log (n + 1) to improve normality; AH is the total area of arable and horticulture and $Pesticide_{2010}$ is the total area of crop treated with a pesticide at a level greater than the threshold which would trigger additional risk assessments according to European ecotoxicology guidelines; ES_{area}, ESA_{area}, CS_{area} are the total areas of the respective agri-environment schemes in a 1km radius around the centre of each WCBMS square; $ES_{option.count}$, $ESA_{option.count}$, $CS_{option.count}$ are the total number of different agri-environmental management options historically adopted in each location; PA is percentage of protected (SSSI) land in a 1km radius. All the above explanatory variables are fixed effects. 100km_grid (100km x 100km) is a random effect included in the model to account for broader spatial pattern in butterfly density (e.g. with latitude). To assess significance of fixed effects we used MCMC sampling (1000 iterations; Baayen 2007) as other statistical tests on mixed models can sometimes yield p-values smaller than they should be (Pinheiro and Bates, 2000). We then repeated the above analysis using WCBMS data from 2011.

We also fitted a model to butterfly data from UKBMS sites. In this case, we used data from all years between 2006-2011. The response variable was the density of butterflies (of all species) per year. This was calculated by summing the annual index of abundance across all butterfly species per year (Rothery & Roy 2001), and dividing by the length of the transect. We fitted a model of similar structure to the above but with *Site* as an additional random effect to account for the repeated measures across years at each site, i.e. equations [3] and [4]:

$$\check{N} \sim \mathrm{AH} + \mathrm{ES}_{\mathrm{area}} + \mathrm{ESA}_{\mathrm{area}} + \mathrm{CS}_{\mathrm{area}} + \mathrm{PA} + \mathrm{Pesticide}_{2010+}\, \mathit{100km\_grid} + \mathit{Site} \qquad [3]$$

$$\check{N} \sim \mathrm{AH} + \mathrm{ES}_{\mathrm{option.count}} + \mathrm{ESA}_{\mathrm{option.count}} + \mathrm{CS}_{\mathrm{option.count}} + \mathrm{PA} + \mathrm{Pesticide}_{2010+}\, \mathit{100km\_grid} + \mathit{Site} \qquad [4]$$

These analyses were initially conducted on the total area or number of options of all possible AE options. However, it is clear that not all options would be expected to benefit butterflies. Therefore, we repeated the above statistical analyses using three alternative AE scheme categorisations which focussed on nested subsets of options that might benefit butterflies. The first set of options were those recommended by Natural England as benefitting butterflies, bees and vulnerable grassland in their 'Farming for Wildlife' leaflet (http://publications.naturalengland.org.uk/publication/35037?category=45001). These options pertain to the more recent ES scheme, but we also picked equivalent options from ESA and CSS (set A in Tables A5-A7). The next set included these options, but also any wild bird seed mixtures, which might provide additional floral resources (set A and B, Tables A5-A7). The final set included both the above sets along with tussocky grass margins and higher input land set aside, which might provide host plants for grass-feeding species (set A, B and C, Tables A5-A7).

Some of these options are recorded in NE databases as lengths in metres, rather than area in hectares. Therefore, we converted all values into hectares to make them comparable. For some linear options the width is specified explicitly (e.g. 3m field margins). However, for others we had to make assumptions. We assumed that hedgerows were 3 m in width (i.e. including the hedge and any taller vegetation border beside it), that 'field margins greater than 6m' were 7m wide and that CSS 'buffer strips' and wildlife strips of unspecified width were 3m wide.

3.3 Spatial Perspective – single species analysis

Assessing all species together can mask variation between individual species, especially if trends (e.g. of the impacts of AE scheme) average out across species. Therefore, using WCBMS data we fitted individual models for each species. Because this type of model fitting is quite data intensive we only analysed species previously classified as 'wider countryside' species, that are present at reasonably high frequencies across the UK landscape (Fox *et al.* 2006). From these species we additionally excluded the Orange tip *Anthocharis cardamines,* which is a spring species poorly recorded by the WCBMS summer surveying, and the two Hair streak *Neozephyrus quercus* and *Satryium w-album* which tend to be relatively rare. We repeated this analysis for all AE scheme types and option groupings.

3.4 Temporal Perspective

For this analysis we used data from the UKBMS and fitted regressions of population trend over time for each species at each site. We first filtered sites based on how well they were recorded, as long and reasonably complete time series were necessary for this analysis. We selected sites that had at least 13 years of records between 1995 and 2011 (i.e. each site needed to have a species index produced in at least 75% of years). We used the same set of species as in the spatial analysis above. Two types of regression were fitted. First a simple linear regression to population count data from years 1995-2011. Second, a piece-wise linear regression with a single breakpoint (i.e. effectively two non-overlapping linear regressions). This second model would be expected to be a better fit to the data if there had been some marked change in the population trajectory between 1995 and 2011 (e.g. an increase in density caused by the implementation of local AE schemes). We fitted several piece-wise linear regressions, one with a break point on the year of first adoption of an AE scheme in the local landscape (1km radius), and two others with breakpoints one or three years after this event (i.e. to account for lag effects in the impacts of AE schemes on butterfly populations). We then compared the fit of these four models (one linear, three piece-wise regressions) using AIC criteria (Akaike Information Criterion; Burnham & Anderson 2003). We then tallied the number of times that the different models gave the best fit (i.e. lowest AIC at a given site) across all sites for each species. We repeated this analysis for all AE scheme types and option groupings.

4. Results

4.1 Spatial Perspective - multispecies analysis

*4.1.1 Total area of **all** AE options in the local landscape*

From the multispecies models there was some evidence that butterflies occurred at higher densities on sites with greater implementation of AE schemes. Statistical models focussing on AE scheme area rather than number of individual AE options had a better goodness of fit (based on Akaike Information Criterion, AIC), and therefore we present only the former here. For the WCBMS in 2010, assessing land cover in 1km radius around sites, significant predictors of butterfly density were the extent of arable/ horticultural land cover, the total area of ESA schemes and the cover of protected areas (Table 1; Figure 2). In the model assessing land cover in 3km radius around sites, significant predictors of butterfly density were the extent of arable/ horticultural land cover and the total area of CSS (Table 2; Figure 3). We additionally tested for an interaction effect between extent of arable and horticultural land cover and total area of ESA or CSS but these were not significant (results not shown). Comparisons of the goodness of fit of models using land cover assessed at 1km versus 3km radius are only valid if sample sizes are the same. We therefore, repeated the 3km analysis limited to the same subset of sites as the 1km analysis (n = 387; there were slightly more sites at 3km as the pesticide data only included sites where arable land occurred in the buffers).

Table 1 Relationships between mean butterfly density (all species) in 2010 on 387 WCBMS sites and characteristics of the surrounding landscape, in terms of arable/horticulture, pesticide treatment, AE schemes (assessed at 1km radius) and protected area cover. Significant coefficients (p<0.05) have t-values highlighted in bold font.

Variable	**Coefficient**	**SE**	**t**
Arable and horticulture area	0.23230	0.06725	**3.45**
Pesticide treated area in 2010	0.00004	0.00073	0.05
ES scheme area	-0.02795	0.05139	-0.54
ESA scheme area	0.25650	0.11590	**2.21**
CS scheme area	0.06288	0.08507	0.74
Proportion of protected areas	0.00560	0.00232	**2.41**

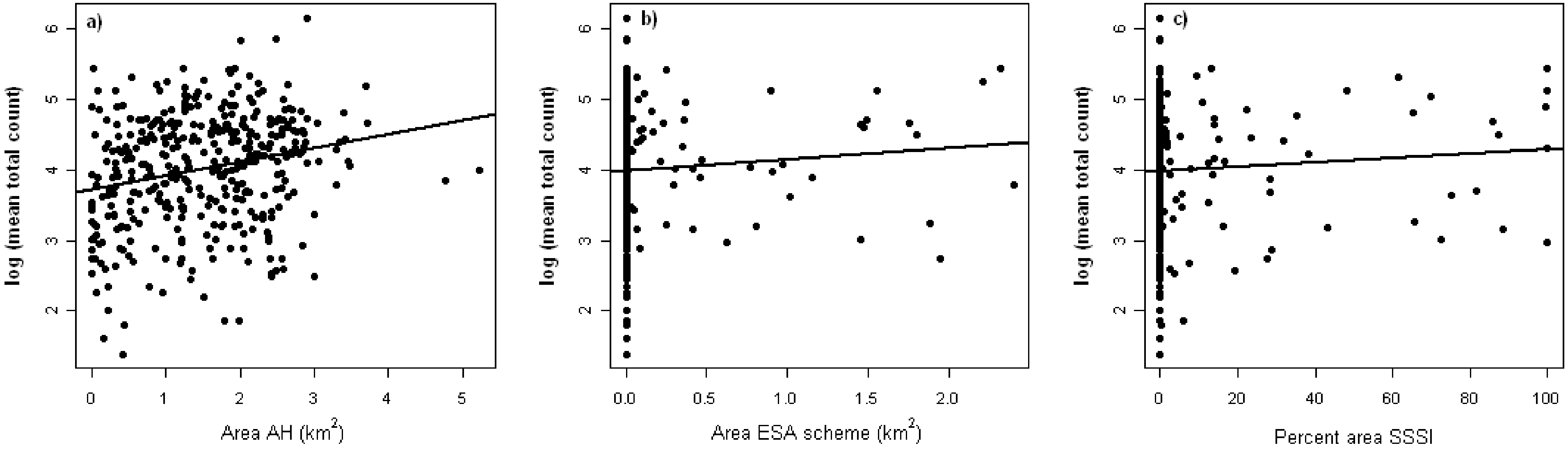


Figure 2 Relationship between mean butterfly density (all species) from WCBMS sites in 2010 and a) the area of arable and horticultural landcover, b) the total area of ESA scheme options, and c) percentage cover of SSSI, all assessed at 1km radius around sites.

The model fitted to landcover data at 3km had a better goodness of fit than the model fitted to 1km land cover based on comparison of model AIC scores (1km model: AIC = 961.6, n = 387; 3km model: AIC = 950.5, n = 387). For the UKBMS between 2006-2011 there were no associations between any of the land cover variables and butterfly densities (Tables 3 & 4).

Table 2 Relationships between mean butterfly density (all species) in 2010 on 399 WCBMS sites and characteristics of the surrounding landscape, in terms of arable/horticulture, pesticide treatment, AE scheme areas (assessed at 3km radius) and protected area cover. Significant coefficients ($p<0.05$) have t-values highlighted in bold font.

Variable	**Coefficient**	**SE**	**t**
Arable and horticulture area	0.02712	0.00815	**3.33**
Pesticide treated area in 2010	0.00001	0.00010	0.11
ES scheme area	0.00838	0.00908	0.92
ESA scheme area	-0.00089	0.01409	-0.06
CS scheme area	0.03797	0.01845	**2.06**
Proportion of protected areas	0.00296	0.00236	1.25

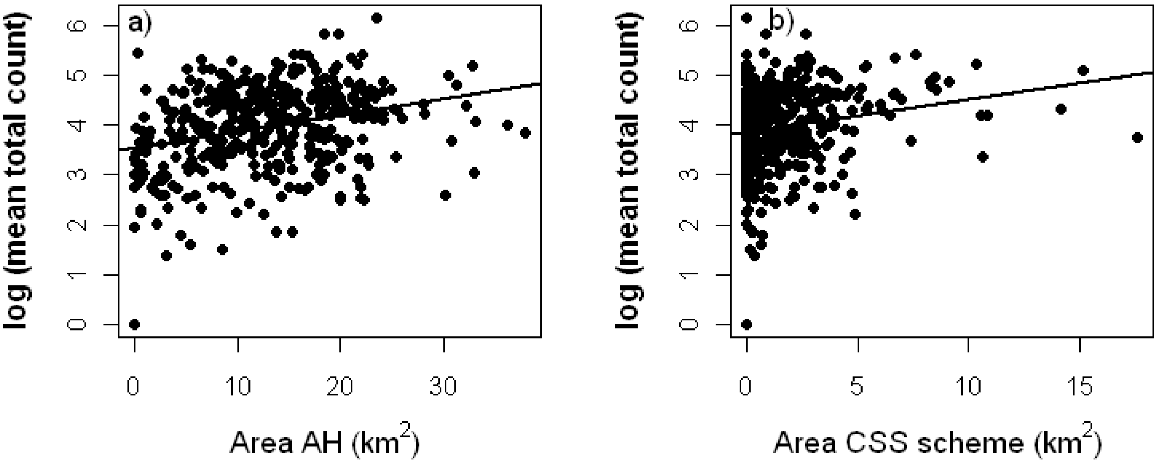


Figure 3 Relationship between mean butterfly density (all species) from WCBMS sites in 2010 and a) the area of arable and horticultural landcover and b) the area of CS schemes, both at 3km radius around monitoring sites.

Table 3 Relationships between mean butterfly density (all species) between 2006-2011 on 443 UKBMS sites and characteristics of the surrounding landscape, in terms of arable/horticulture, pesticide treatment, AE schemes (assessed at 1km radius) and protected area cover.

Variable	**Coefficient**	**SE**	**T**
Arable and horticulture area	0.1854279	0.1325806	1.4
Pesticide treated area 2010	0.0015076	0.0015987	0.94
ES scheme area	-0.0709821	0.0874835	-0.81
ESA scheme area	0.2191391	0.1816551	1.21
CS scheme area	-0.055234	0.1713007	-0.32
Proportion of protected areas	-0.0005137	0.0022559	-0.23

Table 4 Relationships between mean butterfly density (all species) between 2006-2011 on 451 UKBMS sites and characteristics of the surrounding landscape, in terms of arable/horticulture, pesticide treatment, AE schemes (assessed at 3km radius) and protected area cover.

Variable	**Coefficient**	**SE**	**T**
Arable and horticulture area	0.013698	0.0178601	0.767
Pesticide treated area 2010	0.000276	0.0002245	1.227
ES scheme area	-0.01338	0.0137831	-0.971
ESA scheme area	0.014542	0.0250748	0.58
CS scheme area	0.029051	0.0329812	0.881
Proportion of protected areas	-0.001	0.002169	-0.459

*4.1.2 Total count of **selected** AE options in the local landscape*

We also assessed the effects of area and individual option count for subsets of selected AE scheme options that were hypothesised to be beneficial to butterflies. For the both butterfly monitoring schemes, and at both 1km and 3km radius, we found that the smaller set of targeted options were the best predictor of butterfly densities (i.e. set A, Tables A5-A7; based on model AIC values). Therefore, we only present results for this grouping here. In addition, based on model AICs we found that the total count of individual options was a better predictor of butterfly densities than total area of the options. For example, for the WCBMS and assessing AE schemes at 1km radius around sites, the model considering total count of different options had an AIC of 7137, whilst the model considering total area of different options had an AIC of 7152 (with lower AIC indicating better goodness of fit). Therefore, only models for total option count of AE schemes are presented here.

We compared the AIC of these models based on a subset of selected AE options which might benefit butterflies with the models considering total area of all AE options (see previous section), and found that models based on a subset of selected AE options had better goodness of fit. For example, the model considering the smallest subset of AE options (Set A, Tables A5-A7) at 3km radius around sites had an AIC of 944.8, compared with an AIC of 950.5 for the model considering total area of all AE options at 3km radius.

Table 5 Relationships between mean butterfly density (all species) in 2010 on 387 WCBMS sites and characteristics of the surrounding landscape, in terms of arable/horticulture, pesticide treatment, selected AE schemes (which might benefit butterflies, assessed at 1km radius) and protected area cover. Significant coefficients ($p<0.05$) have t-values highlighted in bold font.

Variable	Coefficient	SE	T
Arable and horticulture area	0.2015	0.0651	**3.1**
Pesticide treated area 2010	0.0000	0.0007	-0.04
Total count subset ES scheme options	0.0080	0.0128	0.62
Total count subset ESA scheme options	0.0213	0.0331	0.64
Total count subset CS scheme options	0.0885	0.0586	1.51
Proportion of protected areas	0.0057	0.0023	**2.42**

Considering these models of selected AE options, for the WCBMS there was no evidence that total option count of AE schemes assessed at 1km radius was associated with higher butterfly densities (Table 5). However, at 3km radius, the total count of CSS options and of ES scheme options were associated with higher butterfly densities (Table 6; Figure 4a). For the UKBMS, no landscape variables were significant in the model assessed at 1km radius (Table 7), but for the model at 3km radius, the total count of CSS options was positively associated with butterfly density (Table 8; Figure 4b).

Table 6 Relationships between mean butterfly density (all species) in 2010 on 399 WCBMS sites and characteristics of the surrounding landscape, in terms of arable/horticulture, pesticide treatment, selected AE schemes (which might benefit butterflies, assessed at 3km radius) and protected area cover (see methods for variable abbreviations). Significant coefficients ($p<0.05$) have t-values highlighted in bold font.

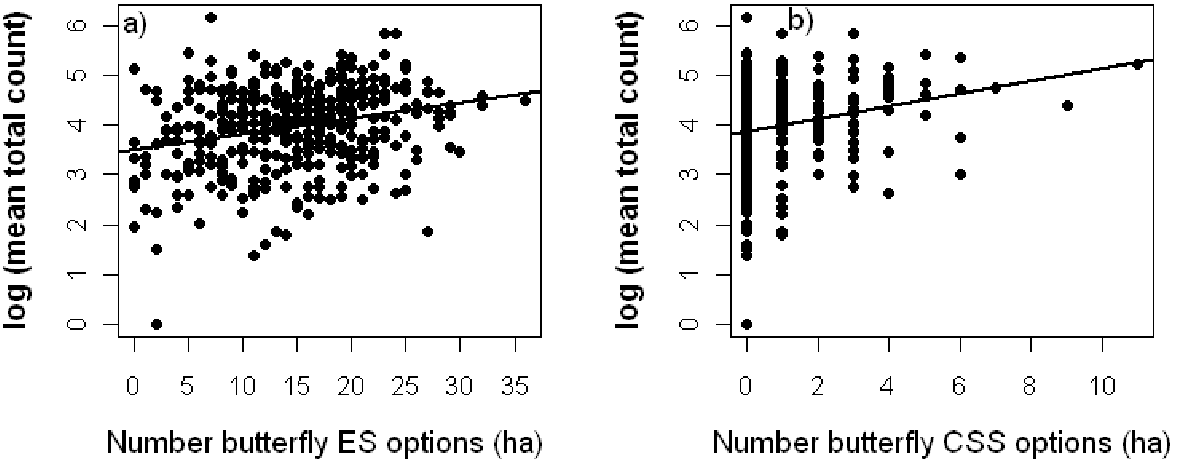
Variable	Coefficient	SE	T
Arable and horticulture area	0.0247	0.0080	**3.079**
Pesticide treated area 2010	0.0000	0.0001	0.117
Total count subset ES scheme options	0.0178	0.0065	**2.756**
Total count subset ESA scheme options	0.0182	0.0160	1.134
Total count subset CS scheme options	0.0794	0.0289	**2.749**
Proportion of protected areas	0.0038	0.0023	**1.66**

Table 7 Relationships between mean butterfly density (all species) between 2006-2011 on 443 UKBMS sites and characteristics of the surrounding landscape, in terms of arable/horticulture, pesticide treatment, AE schemes (which might benefit butterflies, assessed at 1km radius) and protected area cover (see methods for variable abbreviations). Significant coefficients ($p<0.05$) have t-values highlighted in bold font.

Variable	Coefficient	SE	T
Arable and horticulture area	0.1238	0.1307	0.95
Pesticide treated area 2010	0.0012	0.0016	0.78
Total count subset ES scheme options	0.0251	0.0177	1.42
Total count subset ESA scheme options	0.0390	0.0532	0.73
Total count subset CS scheme options	0.0939	0.0980	0.96
Proportion of protected areas	-0.0008	0.0022	-0.34

Table 8 Relationships between mean butterfly density (all species) between 2006-2011 on 451 UKBMS sites and characteristics of the surrounding landscape, in terms of arable/horticulture, pesticide treatment, AE schemes (which might benefit butterflies, assessed at 3km radius) and protected area cover (see methods for variable abbreviations). Significant coefficients ($p<0.05$) have t-values highlighted in bold font.

Variable	**Coefficient**	**SE**	**T**
Arable and horticulture area	0.0084	0.0173	0.483
Pesticide treated area 2010	0.0002	0.0002	1.115
Total count subset ES scheme options	0.0020	0.0087	0.234
Total count subset ESA scheme options	0.0165	0.0237	0.696
Total count subset CS scheme options	0.1047	0.0416	**2.518**
Proportion of protected areas	-0.0015	0.0021	-0.703



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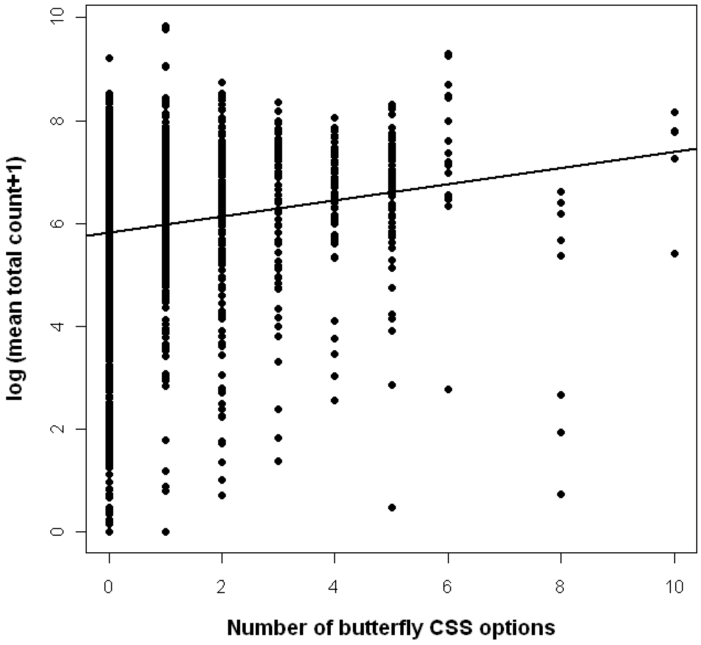

b

Figure 4a) Relationship between mean butterfly density (all species) from WCBMS sites in 2010 and a) the total count of selected ES scheme options hypothesised to benefit butterflies, b) the total count of selected CS scheme options hypothesised to benefit butterflies, both assessed at 3km radius around sites. **b)** Relationship between mean butterfly density (all species) between 2006-2011 on 443 UKBMS sites the total count of selected CS scheme options (which might benefit butterflies, assessed at 3km radius around sites).

4.2 Spatial Perspective – single species analysis

*4.2.1 Total area of **all** AE options in the local landscape*

Results from the single species analysis showed that species vary in their associations with the different land cover variables. However, interpretation of these single species results should be taken with caution for two reasons. Firstly, there are a large number of zero counts in these single-species data. In some particular cases, these might be better modelled using zero-inflated Poisson models. However, these models need to be tailored to the data, and this was not feasible for this automated analysis of many species. Second, when assessing species individually there are a larger number of statistical tests being carried out, and by chance we would expect some of these to be significant. The overall number of significant results here is greater than expected by chance (e.g. for the WCBMS assessing all AE option at 1km, 32 significant results out of 126 are significant at $p<0.05$, which is greater than the 6.3 out of 126 expected by chance alone). However, it is inadvisable to confer strong confidence on the significance of any individual result.

With these caveats in mind, the results do appear to make intuitive sense. For example, for the WCBMS assessing all AE options at 1km (Table A8), 16 out of 21 species showed positive associations between density and the total area of ESA. Five species showed individually significant relationships at $p<0.05$, all which were positive (Table 9). This mirrors the result for an overall significant effect of ESA scheme area on the total density of all butterfly species in the multispecies model (Table 1). Associations were also generally positive for the proportion of protected areas in landscapes and the total area of arable and horticultural landcover. Results for pesticides loadings were mixed. Some species showed negative effects, but others actually had positive relationships. This variable was also quite highly correlated with total area of arable and horticultural land cover (Tables A1-A4). Therefore, results should be interpreted with caution.

Table 9 Count of significant ($p<0.05$) species population responses to areas under agri-environment scheme agreements within 1km and 3km of WCBMS monitoring sites. Further detail for each of the 21 species modelled is given in Table A8 (1km) and A9 (3km).

		Response	
		+ve	-ve
1km	Area of Arable and Horticulture	4	
	Pesticide Loading	3	5
	Area under ES Agreement	1	2
	Area under ESA Agreement	5	
	Area under CSS Agreement	3	
	Protected Area	7	2
3km	Area of Arable and Horticulture	5	1
	Pesticide Loading	2	5
	Area under ES Agreement	3	2
	Area under ESA Agreement	3	
	Area under CSS Agreement	6	
	Protected Area	5	3

The results from assessing land cover at 3km also generally mirrored the multispecies models, with 18 out of 21 species showing positive associations between density and the area of CSS in the landscape. Six species showed individually significant relationships (at $p<0.05$), all of which were positive (Table A9). Some relatively mobile species showed significance for AE scheme area assessed at 3km but not at 1km radius. For example Meadow Brown butterfly density showed a positive association with area of ES scheme at 3km radius, whilst the Speckled Wood butterfly showed a negative relationship (Figure -5). Also again, the majority of species showed positive relationships with the total area of arable and horticultural land cover and the proportion of land covered by protected areas. Species which showed significant negative associations with protected areas were large white, green-veined white and comma, all species with food plants which still occur commonly in the wider countryside (food plants are as follows, large white: brassicas; green-veined white: garlic mustard and cuckoo flower; comma: nettles).

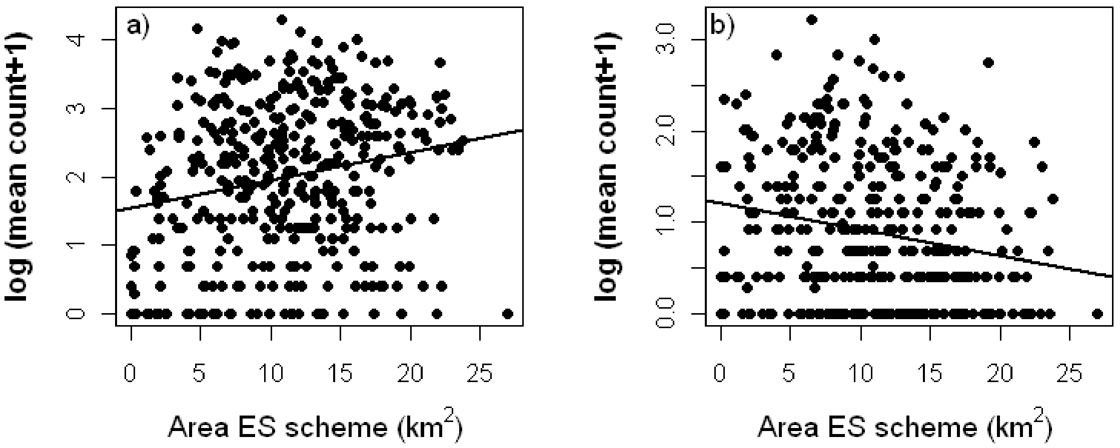

Figure 5 Relationships between mean density of a) Meadow Brown *Maniola jurtina* and b) Speckled Wood *Pararge aegeria* butterflies and the total area of ES scheme in 3km buffers around WCBMS sites in 2010.

*4.2.2 Total Count of **selected** AE options in the local landscape*

From the multispecies analysis, in light of the total count of selected individual AE options being a better predictor of butterfly densities than total area of these options, we proceeded to carry out the single species analyses on the total count of selected individual AE options. Results were qualitatively similar at both 1km (Table A10) and 3km (Table A11) and generally mirrored the multispecies model results. For example, the total number of CSS options at 3km radius had a positive association with butterfly densities for 19 out of 21 species. Eight species showed individually significant relationships (at $p<0.05$) with the count of CSS options, all of which were positive (Table A10).

Table 10 Count of significant (p<0.05) species population responses to counts of agri-environment scheme options within 1km and 3km of WCBMS monitoring sites. Further detail for each of the 21 species modelled is given in Table A10 (1km) and A11 (3km).

		Response	
		+ve	-ve
1km	Area of Arable and Horticulture	3	
	Pesticide Loading	3	4
	Count of ES Options	3	
	Count of ESA Options	3	
	Count of CSS Options	7	
	Protected Area	7	2
3km	Area of Arable and Horticulture	5	
	Pesticide Loading	2	5
	Count of ES Options	3	
	Count of ESA Options	3	
	Count of CSS Options	8	
	Protected Area	6	3

4.3 Temporal Perspective

We fitted regressions of population trend over time (between 1995-2011) for each species at each site and compared linear models with piecewise linear regression models with breakpoints either a) at the first commencement of an AE scheme in 1km radius, b) one year after first commencement of an AE scheme or c) three years after first commencement of an AE scheme. We did this considering the first start date of any ESA, CS, or ES scheme in the landscape (Table A12 for assessment of schemes at 1km radius around butterfly monitoring sites; Table A13 for assessment of schemes at 3km radius). We also repeated our analyses considering the first start date of only selected ESA, CS, or ES scheme options which were hypothesised as beneficial to butterflies (Table A14 for assessment of schemes at 1km radius; Table A15 at 3km radius). Because the more limited set of options (Set A, Tables A5-A7) were the best predictor of butterfly densities (see earlier results), we only considered this grouping of options in this temporal analysis.

We found that across all species, in nearly all cases the linear models most often gave the best fit (Tables A12-A2.15). This was more pronounced for options assessed at 3km radius around sites. For a few species, there were suggestions that piece-wise regressions gave a better fit than linear models, and this was more often the case at 1km radius and also when only selected AE options, that might be beneficial to butterflies, were considered. For example, for the Brown Argus butterfly, when considering selected CS scheme options, 39 sites were assessed for which models could be ranked in order of goodness of fit. Eleven models suggested that the population trend was best modelled by linear regression. In the majority of cases, however a piecewise linear model was better, and most often a model in which the break point was three years after the commencement of the CS scheme (13 cases).

In cases where a piecewise-linear model showed a better fit than the linear model, we assessed the change in population trend after the breakpoint. Under the hypothesis that the scheme had benefitted butterflies we would expect a ‘u’ shaped relationship, whereby the population trend after the breakpoint was more positive than beforehand. We carried this analysis out only for selected AE options that might be beneficial to butterflies assessed at 1km radius. We found that in most cases, there was no significant difference in the frequency of ‘u’ or ‘n’ shaped relationships (Table A16). In the four cases that were significant, ‘u’ shaped relationships were most common. However, we do emphasise that these results should be interpreted in the light that in most cases linear models were best suggesting no detectable effect of the AE scheme on butterfly population trend.

5. Discussion

This study investigated whether habitat enhancement options implemented as part of AE schemes have benefited butterfly species associated with those habitats. We first took a spatial perspective and asked whether densities were higher where there was more land in AE scheme agreement. We found evidence that AE schemes around WCBMS sites were associated with higher butterfly densities. There was no evidence that AE schemes around UKBMS sites affected butterfly densities, although we had less expectation for sites in this scheme, because they are more likely to be high quality sites with reasonable amounts of semi-natural habitat present. We found that total area of AE options for the ESA and CS schemes were associated with higher butterfly densities on WCBMS sites, with no significant effect across species of total area of ES schemes. This might indicate that schemes need to be in place for a number of years before observable effects are apparent in butterfly species. However, there were some effects of ES schemes on individual species (e.g. the Meadow Brown; Figure 5). The fact some butterflies, and those that we had *a priori* expectations for, were associated with AE schemes may be welcome news in light of criticisms that AE schemes have negligible beneficial effects on species (e.g. Kleijn *et al.* 2011). However, it does not necessarily suggest a direct causal link whereby uptake of scheme options increases butterfly densities. To provide more robust evidence for this link, a temporal perspective is necessary. Unfortunately, such an approach was only feasible for the UKBMS scheme, for which associations between butterflies and AE scheme areas in the surrounding landscape was weaker. Our temporal analysis did not suggest that uptake of AE schemes had led to changes in population trends of species on UKBMS sites. However, this analysis may have been very conservative because it may be difficult to detect non-linear trends (i.e. changes in population trajectory as a consequence of AE scheme uptake) in light of other factors affecting populations, such as inter-annual weather variation (Roy *et al.* 2001). Additionally, uptakes of AE schemes near to the start or end of the butterfly monitoring time series may make non-linear trends particularly difficult to detect. Therefore, a less conservative future analysis might focus only on time series where statistical power is greater (i.e. with a minimum number of years monitored before and after scheme uptake), might focus only on species which showed individually significant associations with AE schemes, and perhaps compare trends between sites with and without AE schemes (i.e. controlling for AE scheme area).

In addition to considering the total area of AE schemes in the landscape surrounding butterfly monitoring sites, we also considered the area of selected AE options hypothesised to benefit butterflies species. We found that the total count of these selected options was a better predictor of density than their total area. This might be due to errors in our assumptions about the width of certain options (e.g. where not explicitly specified we made assumptions about the width of hedgerows- see methods), or it could be because the total count of options integrates not just the total area, but also the diversity between option types and the age of different patches of the same option type, i.e. potentially providing heterogeneity in resources which might sustain species. Further research might investigate these differences further. We did assess whether the minimum age of selected options was related to butterfly densities but found no evidence of this (results not shown).

Comparisons between selected AE options hypothesised to benefit butterflies species versus total area of AE schemes, suggested that selected AE options gave a better fit to butterfly density. Of the different sets of selected options, the smallest subset (i.e. those options listed on the NE 'Farming for Wildlife' leaflet) was the best (see http://publications.naturalengland.org.uk/publication/35037?category=45001). Hence, to benefit butterflies, AE options need to be targeted, as shown for birds, bees and plants by Pywell et al. (2012). The fact that a selected subset of 'butterfly-friendly' options explains butterfly densities better than the total AE area may strengthen the evidence that AE schemes have a direct beneficial effect on butterfly populations. An initial concern in this 'spatial –perspective' analysis was that AE schemes might be aggregated in areas that are already good for butterflies (hence leading to positive associations, but not directly caused by AE scheme themselves). Our analysis already accounts for larger spatial patterns (e.g. regional differences in butterfly density), by including 100km region as a random effect in our statistical models. If, within these 100km^2 landscapes, the distribution of 'butterfly-friendly' AE options is random with respect to other aspects of landscape character that benefit butterflies (i.e. do not necessarily occur more on farms that are 'already good' for butterflies), then this would suggest a causal link between uptake of AE options and butterfly densities.

This investigation also considered other variables including extent of protected areas, area of arable/ horticultural land cover and extent of pesticide treatments. Perhaps counter intuitively, we found that extent of arable/ horticultural land cover was positively associated with butterfly densities. This result was also found in another Natural England-funded study, where the effect of spatial extent and configuration of a wide range of different (LCM 2000) land cover types on butterfly and bird populations was assessed (Oliver *et al.* 2012). The fact that the result is also found in the current study using LCM 2007 data suggests it is genuine. It is likely that this result occurs because linear features surrounding arable fields can provide good quality habitat (i.e. nectar and host resources and shelter). Also the relatively poor quality of surrounding habitat may concentrate butterflies in these linear features. Even though WCBMS transects are located in randomly selected 1km squares, by necessity, transect recorders will often use linear features such as footpaths and field edges. Therefore, we do not believe that the results obtained in this study suggest that arable land cover itself is high quality habitat. However, our results suggest that arable land with sufficient boundary features may result in landscapes that can house large densities of many butterfly species (but obviously not all specialist species). Further work assessing arable field sizes and the specific type of linear features may shed more light on the efficacy of different arable landscapes for conservation. The results found here suggest that AE options in these arable landscapes will also have additive positive effects, by increasing butterfly densities further.

It is also important to note that the positive result for arable land cover is a generalisation across many species. Not all species, had positive relationships (e.g. the Small Heath, although this result was non-significant; Table A10). Also, the species sampled best by the WCBM scheme tend to be those that can survive in an arable matrix. There are many rarer specialist butterfly species that are likely to have negative associations with arable land cover and tend to be restricted to woodlands or heathlands, for example. These species are likely to fare better in protected areas than AE schemes. Indeed, this study found that a large number of wider countryside specialist species also occur at higher densities where protected areas are present. This result was only significant for the WCBMS scheme and not the UKBMS. The reason for this could be that UKBMS sites are more likely to be historically higher quality wildlife sites (even if not SSSIs, they may be local Nature Reserves or simply managed by conservation-friendly private land owners), compared with WCBMS sites, which are randomly located in the countryside. Therefore, the effect of SSSI protection may be more marked for WCBMS sites.

Finally, we considered the effects of pesticide treatment on butterfly densities. We found little evidence that pesticide loadings had an effect on butterfly densities. Of course, this does not mean that pesticides are not necessarily harmful to these species. It may be the estimates of pesticide use are not sufficiently accurate to detect an effect or are too confounded with the total area of arable land cover. For example, although some species did show individually significant negative effects of pesticide loading on population density, other species showed positive effects. The species that we would expect to be most exposed to pesticides, such as the oil seed rape crop pests, the large and small white butterflies, actually showed positive relationships. Therefore, we can conclude that with the best possible pesticide data available we found no evidence for consistent negative effects on butterfly species.

To conclude, this investigation found reasonably robust evidence that AE schemes in England are associated with higher butterfly densities. We are less able to make firm conclusions regarding the direct effects of implementation of AE schemes on butterfly population trends. However, the fact that ‘butterfly friendly’ AE options were the best predictors of butterfly density does suggest that there may be a direct causal link between (selected) AE scheme options and butterfly density. Overall, our results suggest that AE schemes, along with protected areas and management of other semi-natural habitats, have had beneficial effects on butterfly populations, which are an indicator of the health of a wider range of invertebrate biodiversity (Thomas 2005).

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Appendix: Supporting Material

Table A1 Pearson's R correlations between explanatory variables assessed at 1km radius around the 387 WCBMS sites. See methods for abbreviations. Cells highlighted in pink have correlations greater than 0.7.

	AH	**Pesticide2010**	**ES_{area}**	**$ES_{option.count}$**	**ESA_{area}**	**$ESA_{option.count}$**	**CS_{area}**	**$CS_{option.count}$**	**PA**
AH	1	0.67	0.45	0.21	-0.17	-0.22	0.16	0.12	-0.26
sum.pesticide	0.67	1	0.40	0.16	-0.12	-0.15	0.15	0.02	-0.15
ES_Area	0.45	0.40	1	0.53	-0.16	-0.14	0.13	0.15	-0.12
ES.option.count	0.21	0.16	0.53	1	0.00	0.00	-0.03	0.12	-0.09
ESA_Area	-0.17	-0.12	-0.16	0.00	1	0.86	-0.09	-0.13	0.06
ESA.option.count	-0.22	-0.15	-0.14	0.00	0.86	1	-0.11	-0.13	0.13
CS_Area	0.16	0.15	0.13	-0.03	-0.09	-0.11	1	0.72	0.02
CS.option.count	0.12	0.02	0.15	0.12	-0.13	-0.13	0.72	1	-0.05
percent.PA	-0.26	-0.15	-0.12	-0.09	0.06	0.13	0.02	-0.05	1

Table A2 Pearson's R correlations between explanatory variables assessed at 3km radius around the 399 WCBMS sites. See methods for abbreviations. Cells highlighted in pink have correlations greater than 0.7.

	AH	**Pesticide2010**	**ES_{area}**	**$ES_{option.count}$**	**ESA_{area}**	**$ESA_{option.count}$**	**CS_{area}**	**$CS_{option.count}$**	**PA**
AH	1	0.71	0.53	0.30	-0.23	-0.22	0.24	0.23	-0.24
sum.pesticide	0.71	1	0.53	0.14	-0.18	-0.18	0.19	0.05	-0.15
ES_Area	0.53	0.53	1	0.57	-0.19	-0.15	0.34	0.28	-0.08
ES.option.count	0.30	0.14	0.57	1	-0.02	0.08	0.16	0.27	-0.09
ESA_Area	-0.23	-0.18	-0.19	-0.02	1	0.87	-0.16	-0.23	0.18
ESA.option.count	-0.22	-0.18	-0.15	0.08	0.87	1	-0.18	-0.24	0.15
CS_Area	0.24	0.19	0.34	0.16	-0.16	-0.18	1	0.70	0.01
CS.option.count	0.23	0.05	0.28	0.27	-0.23	-0.24	0.70	1	-0.05
percent.PA	-0.24	-0.15	-0.08	-0.09	0.18	0.15	0.01	-0.05	1

Table A3 Pearson's R correlations between explanatory variables assessed at 1km radius around 443 UKBMS sites. See methods for abbreviations. Cells highlighted in pink have correlations greater than 0.7.

	AH	**Pesticide2010**	**ES_{area}**	**$ES_{option.count}$**	**ESA_{area}**	**$ESA_{option.count}$**	**CS_{area}**	**$CS_{option.count}$**	**PA**
AH	1	0.71	0.29	0.15	-0.12	-0.13	0.22	0.18	-0.30
Pesticide2010	0.71	1	0.29	0.10	-0.08	-0.11	0.18	0.05	-0.19
ES_{area}	0.29	0.29	1	0.53	-0.08	-0.07	0.07	0.05	0.09
$ES_{option.count}$	0.15	0.10	0.53	1	0.02	0.06	0.07	0.13	-0.01
ESA_{area}	-0.12	-0.08	-0.08	0.02	1	0.88	-0.04	-0.06	0.10
$ESA_{option.count}$	-0.13	-0.11	-0.07	0.06	0.88	1	-0.05	-0.07	0.08
CS_{area}	0.22	0.18	0.07	0.07	-0.04	-0.05	1	0.76	-0.09
$CS_{option.count}$	0.18	0.05	0.05	0.13	-0.06	-0.07	0.76	1	-0.10
PA	-0.30	-0.19	0.09	-0.01	0.10	0.08	-0.09	-0.10	1

Table A4 Pearson's R correlations between explanatory variables assessed at 3km radius around 451 UKBMS sites. See methods for abbreviations. Cells highlighted in pink have correlations greater than 0.7.

	AH	**Pesticide2010**	**ES_{area}**	**$ES_{option.count}$**	**ESA_{area}**	**$ESA_{option.count}$**	**CS_{area}**	**$CS_{option.count}$**	**PA**
AH	1	0.76	0.42	0.23	-0.16	-0.13	0.27	0.17	-0.23
Pesticide2010	0.76	1	0.40	0.07	-0.15	-0.16	0.23	0.04	-0.14
ES_{area}	0.42	0.40	1	0.56	-0.10	-0.03	0.26	0.20	0.02
$ES_{option.count}$	0.23	0.07	0.56	1	0.08	0.12	0.13	0.25	0.03
ESA_{area}	-0.16	-0.15	-0.10	0.08	1	0.88	-0.09	-0.14	0.13
$ESA_{option.count}$	-0.13	-0.16	-0.03	0.12	0.88	1	-0.04	-0.11	0.11
CS_{area}	0.27	0.23	0.26	0.13	-0.09	-0.04	1	0.75	-0.11
$CS_{option.count}$	0.17	0.04	0.20	0.25	-0.14	-0.11	0.75	1	-0.08
PA	-0.23	-0.14	0.02	0.03	0.13	0.11	-0.11	-0.08	1

Table A5 Sets of CS scheme options hypothesised to benefit butterfly populations.

Code	Option Description	Set
CH2	Conservation headlands with no fertiliser	A
HP	Hedge planting	A
HR	Hedgerow Restoration	A
P4	Calcareous grassland	A
WM2	Pollen and nectar mixture	A
WM1	Wild bird seed mixture	B
CH1	Conservation headlands	C
HM	Creation of permanent grass margins	C
R3	Creation of permanent grass margins > 6m	C
R4	Creation of 2m grass margin or beetle bank	C
R5	Buffer Strips	C
R6	Wildlife Strips	C
R7	2m Arable Margin	C
R8	Beetle Banks	C
RR1	Recreating grassland on cultivated land (agreement renewals only)	C

Table A6 Sets of ESA scheme options hypothesised to benefit butterfly populations.

Code	Option Description	Set
1BM	Meadows	A
HLS	Traditional hedge management supplement	A
HMS	Hedgerow management supplement	A
HRS	Hedge and Hedgebank Restoration Supplement	A
HRS	Hedge restoration supplement	A
HRS	Hedgerow Restoration Supplement	A
O1B	Extensive Permanent Grassland	A
O1C	Extensive permanent grassland	A
O1C	Low-Input Permanent Grassland	A
O1G	Low input permanent grassland	A
O2A	Herb rich meadows	A
O2A	Meadows	A
O2A	Reversion of improved grassland to extensive permanent grassland	A
O2A	Species-Rich Hay Meadows	A
O2A	Traditional pastures	A
O2B	Traditional hay meadows	A
O3A	Reversion of arable land to chalk grassland	A
O3A	Reversion of arable land to extensive permanent grassland	A
OO2	Extensive grassland	A
OO2	Low input permanent grassland	A
OO2	Reversion of arable land to extensive permanent grassland	A
OO2	Species-Rich Hay Meadows	A
1AG	Ley Grasses under 5 years old	B
1AG	Tier 1 Grassland	B
1AG	Tier 1 Ley Grassland	B
1CG	Extensive permanent grassland that is not valley bottom grassland	B
1CV	Extensive Permanent Grassland which is valley bottom grassland	B
1DU	All unimproved pasture	B
4CA	Arable reversion to grassland (archaeological sites)	B
FMS	Field margin supplement	B
GMS	Grassland Field Margins Supplement	B
O1A	Extensive permanent grassland	B
O1A	Grassland (reverted under a previous ESA management agreement)	B
O1A	Permanent Grassland	B
O1B	Permanent Grassland	B
O1C	Enclosed unimproved permanent grassland	B
O2A	Arable reversion to permanent grassland	B
O2B	Buffer strips	B
O2B	Reversion of arable land to permanent grassland	B
O2C	Conservation headlands	B
O2D	Regeneration to extensive pastures	B
O3A	Reversion of arable land to permanent grassland	B

Code	**Option Description**	**Set**
O3B	Arable reversion to permanent grassland	B
O3B	Conservation Headlands	B
O3C	Arable Margin Buffer Strips	B
O4A	Arable reversion to permanent grassland	B
O4A	Uncropped wildlife strips	B
O4B	Arable grassland margins	B
O4B	Conservation headlands	B
O4C	Conservation headlands	B
OO1	Grassland	B
OO1	Permanent grassland	B
OO1	Permanent grassland on the chalk	B
OO2	Arable reversion to permanent grassland	B
OO3	Arable reversion to grassland	B
OO3	Arable reversion to permanent grassland	B

Table A7 Sets of ES scheme options hypothesised to benefit butterfly populations.

Code	Option Description	Set
EC4	Management of woodland edges	A
EF1	Field corner management	A
EF4	Nectar Flower mixture	A
EK3	Permanent grassland with very low inputs: outside SDA & ML	A
HF4	Nectar flower mixture	A
HF5	ASD to Dec 2008 Pollen & nectar flower mixture on set-aside land	A
HK3	Permanent grassland with very low inputs	A
HK6	Maintenance of species-rich, semi-natural grassland	A
HK7	Restoration of species-rich, semi-natural grassland	A
HK8	Creation of species-rich, semi-natural grassland	A
OB3	Enhanced Hedgerow management	A
OC4	Management of wood edges	A
OF1	Field corner management	A
OF4	Nectar Flower mixture	A
OG3	ASD to Jan 2010 Nectar flower mixture in grassland areas	A
OHC4	Management of woodland edges	A
OHF1	Management of field corners	A
OHK3	Permanent grassland with very low inputs	A
OK2	Permanent grassland with low inputs: outside SDA & ML(organic)	A
OK3	Permanent grassland with very low inputs:outside SDA&ML(organic)	A
EB3	Enhanced hedgerow management	A
OHF2	Wild bird seed mixture	B
OHF2NR	Wild bird seed mixture	B
EF2	Wild bird seed mixture	B
EF2NR	Wild bird seed mixture	B
HF12	Enhanced wild bird seed mix plots	B
HF12NR	Enhanced wild bird seed mix plots	B
HF2	Wild bird seed mixture	B
HF2NR	Wild bird seed mixture	B
OF2	Wild bird seed mixture	B
OF2NR	Wild bird seed mixture	B
OG2	ASD to Jan 2010 Wild bird seed mixture in grassland areas	B
OG2NR	ASD to Jan 2010 Wild bird seed mixture in grassland areas	B
OHF4	Nectar flower mixture	B
EE1	2m buffer strips on cultivated land	C
EE10	6m buffer strips on intensive grassland next to a watercourse	C
EE2	4m buffer strips on cultivated land	C
EE3	6m buffer strips on cultivated land	C
EE4	2m buffer strips on intensive grassland	C
EE5	4m buffer strips on intensive grassland	C
EE6	6m buffer strips on intensive grassland	C
EE7	Buffering in-field ponds in improved grassland	C

Code	Option Description	Set
EE8	Buffering in-field ponds in arable land	C
EE9	6m buffer strips on cultivated land next to a watercourse	C
EF10	Unharvested cereal headland within arable fields	C
EF5	ASD to Dec 2008 Pollen + nectar flower mixture on set-aside land	C
EF7	Beetle banks	C
EJ9	12m buffer strips for watercourses on cultivated land	C
EK1	Take field corners out of management: outside SDA & ML	C
EK2	Permanent grassland with low inputs: outside SDA & ML	C
HE1	2 m buffer strips on cultivated land	C
HE10	Floristically enhanced grass margin	C
HE11	Enhanced strips for target species on intensive grassland	C
HE2	4 m buffer strips on cultivated land	C
HE3	6 m buffer strips on cultivated land	C
HE4	2 m buffer strips on intensive grassland	C
HE5	4 m buffer strips on intensive grassland	C
HE6	6 m buffer strips on intensive grassland	C
HE7	Buffering in-field ponds in improved permanent grassland	C
HE8	Buffering in-field ponds in arable land	C
HJ3	Reversion to unfertilised grassland to prevent erosion/run-off	C
HJ4	Reversion to low input grassland to prevent erosion/run-off	C
HK1	Take field corners out of management	C
HK16	Restoration of grassland for target features	C
HK17	Creation of grassland for target features	C
HK2	Permanent grassland with low inputs	C
OE1	2m buffer strips on rotational land	C
OE10	6m buffer strip on organic grassland next to a watercourse	C
OE2	4m buffer strips on rotational land	C
OE3	6m buffer strips on rotational land	C
OE4	2m buffer strip on organic grassland	C
OE5	4m buffer strip on organic grassland	C
OE6	6m buffer strip on organic grassland	C
OF7	Beetle banks	C
OHE1	2 m buffer strips on rotational land	C
OHE2	4 m buffer strips on rotational land	C
OHE3	6 m buffer strips on rotational land	C
OHE4	2 m buffer strips on organic grassland	C
OHE5	4 m buffer strips on organic grassland	C
OHE6	6 m buffer strips on organic grassland	C
OHE7	Buffering in-field ponds in organic grassland	C
OHE8	Buffering in-field ponds in rotational land	C
OHF7	Beetle banks	C
OHJ9	12 m buffer strips for watercourses on rotational land	C
OHK2	Permanent grassland with low inputs	C
OJ9	12m buffer strips for watercourses on cultivated land	C

Code	**Option Description**	**Set**
OK1	Take field corners out of management: outside SDA & ML(organic)	C
UB14	Hedgerow restoration	C

Table A8 T-values for relationships between mean butterfly density in 2010 across 387 WCBMS scheme sites and characteristics of the surrounding landscape, in terms of arable/horticulture, pesticide treatment, AE schemes (in 1km landscape radius) and protected area cover (see methods for variable abbreviations). Significant relationships are highlighted (red positive; blue negative).

Latin name	**Common name**	**AH**	**Pesticide2010**	**ESarea**	**ESAarea**	**CSarea**	**PA**
Aglais urticae	Small tortoiseshell	1.04	0.21	0.97	2.45	1.79	-0.61
Aphantopus hyperantus	Ringlet	1.18	-0.68	1.60	-0.99	1.27	0.15
Aricia agestis	Brown argus	1.03	2.31	-0.12	0.57	1.40	0.63
Celastrina argiolus	Holly blue	0.17	0.83	-2.65	-0.44	0.85	0.35
Coenonympha pamphilus	Small heath	-1.30	0.52	1.72	1.44	2.08	10.09
Gonepteryx rhamni	Brimstone	0.58	0.96	-1.89	0.85	2.69	2.22
Lycaena phlaeas	Small copper	1.80	-3.56	0.78	0.43	0.99	2.43
Maniola jurtina	Meadow brown	1.89	-1.99	1.81	2.73	1.47	-0.71
Pyronia tithonus	Gatekeeper	3.70	-3.52	0.02	2.56	0.03	2.81
Melanargia galathea	Marbled white	-0.54	1.36	0.91	0.08	0.56	0.26
Inachis io	Peacock	1.59	0.55	-1.79	2.41	0.22	0.72
Ochlodes venata	Large skipper	-0.10	0.76	1.15	-0.15	0.36	2.76

Latin name	**Common name**	**AH**	**Pesticide2010**	**ESarea**	**ESAarea**	**CSarea**	**PA**
Pararge aegeria	Speckled wood	1.35	-3.37	-1.70	0.39	0.39	-0.16
Lasiommata megara	Wall brown	-0.66	-0.68	2.59	3.57	1.31	-0.80
Pieris brassicae	Large white	2.07	2.06	-1.37	0.74	-1.06	-1.97
Pieris napi	Green-veined white	1.70	-0.32	-0.44	1.27	3.03	-1.75
Pieris rapae	Small white	2.82	3.64	-2.22	-0.68	-0.34	-1.59
Polygonum c-album	Comma	0.82	-1.99	0.03	0.73	0.20	-2.26
Polyommatus icarus	Common blue	2.24	-0.11	-0.83	1.43	0.73	2.11
Thymelicus lineola	Essex skipper	-0.36	1.14	0.63	-0.64	0.83	1.13
Thymelicus sylvestris	Small skipper	0.01	-0.01	0.11	1.41	1.65	2.01

Table A9 T-values for relationships between mean butterfly density in 2010 across 399 WCBMS scheme sites and characteristics of the surrounding landscape, in terms of arable/horticulture, pesticide treatment, AE schemes (in 3km landscape radius) and protected area cover (see methods for variable abbreviations). Significant relationships are highlighted (red positive; blue negative).

Latin name	Common name	AH	Pesticide2010	ESarea	ESAarea	CSarea	PA
Aglais urticae	Small tortoiseshell	0.52	0.33	1.22	2.63	2.80	-1.20
Aphantopus hyperantus	Ringlet	1.24	-0.92	2.53	-0.25	2.18	-0.03
Aricia agestis	Brown argus	1.28	1.55	0.01	0.18	1.56	0.56
Celastrina argiolus	Holly blue	0.64	0.36	-2.02	-0.86	0.11	0.54
Coenonympha pamphilus	Small heath	-2.37	0.80	1.35	-0.28	3.97	9.55
Gonepteryx rhamni	Brimstone	0.95	0.12	-0.69	0.52	2.87	2.28
Lycaena phlaeas	Small copper	2.09	-4.30	2.09	0.11	0.61	2.18
Maniola jurtina	Meadow brown	2.66	-3.06	3.12	2.09	1.95	-1.12
Pyronia tithonus	Gatekeeper	4.30	-3.61	0.22	1.66	-0.16	2.44
Melanargia galathea	Marbled white	0.50	0.06	0.16	1.33	3.81	0.05
Inachis io	Peacock	1.40	0.13	-0.28	1.56	-0.15	0.49
Ochlodes venata	Large skipper	0.08	0.77	1.19	-0.08	0.92	2.64

Latin name	Common name	AH	Pesticide2010	ESarea	ESAarea	CSarea	PA
Pararge aegeria	Speckled wood	2.58	-4.72	-2.57	-0.28	0.97	-0.51
Lasiommata megara	Wall brown	-0.24	-0.75	1.75	2.42	0.84	-1.23
Pieris brassicae	Large white	1.16	2.73	-1.36	-0.36	-0.83	-2.19
Pieris napi	Green-veined white	1.96	-1.83	1.44	1.26	2.77	-2.22
Pieris rapae	Small white	2.27	3.86	-1.50	-1.18	0.80	-1.71
Polygonum c-album	Comma	1.59	-3.05	0.90	0.48	1.96	-2.43
Polyommatus icarus	Common blue	1.85	-0.22	0.03	1.10	1.81	1.77
Thymelicus lineola	Essex skipper	-0.27	1.28	0.08	-0.69	0.83	1.23
Thymelicus sylvestris	Small skipper	0.29	-0.22	-0.77	1.42	1.96	1.62

Table A10 T-values for relationships between mean butterfly density in 2010 across 387 WCBMS scheme sites and characteristics of the surrounding landscape, in terms of arable/horticulture, pesticide treatment, selected AE schemes (which might benefit butterflies, assessed at 1km radius) and protected area cover (see methods for variable abbreviations). Significant relationships are highlighted (red positive; blue negative).

Latin name	Common name	AH	Pesticide2010	ESoption count	ESAoption count	CSSoption count	PA
Aglais urticae	Small tortoiseshell	1.43	0.36	-1.12	2.04	3.33	-0.84
Aphantopus hyperantus	Ringlet	1.51	-0.74	2.01	-0.76	2.07	0.34
Aricia agestis	Brown argus	0.95	2.32	-0.21	-0.63	1.06	0.66
Celastrina argiolus	Holly blue	-0.53	0.49	-0.79	-0.77	1.46	0.27
Coenonympha pamphilus	Small heath	-1.03	0.68	1.68	0.45	0.71	10.22
Gonepteryx rhamni	Brimstone	0.14	0.65	-0.17	0.93	3.53	2.14
Lycaena phlaeas	Small copper	1.87	-3.51	0.51	-0.60	1.22	2.49
Maniola jurtina	Meadow brown	2.01	-1.90	2.77	1.58	1.17	-0.42
Pyronia tithonus	Gatekeeper	3.52	-3.44	0.46	1.33	0.38	2.77
Melanargia galathea	Marbled white	-0.52	1.26	1.15	0.27	2.56	0.26
Inachis io	Peacock	0.98	0.48	-1.50	0.71	1.28	0.49
Ochlodes venata	Large skipper	-0.06	0.72	2.54	0.01	0.17	3.03

Latin name	**Common name**	**AH**	**Pesticide2010**	**ESoption count**	**ESAoption count**	**CSSoption count**	**PA**
Pararge aegeria	Speckled wood	1.10	-3.55	-1.83	0.13	1.02	-0.37
Lasiommata megara	Wall brown	-0.20	-0.41	1.24	3.16	2.16	-0.81
Pieris brassicae	Large white	1.46	2.04	-1.02	-1.03	-0.74	-2.06
Pieris napi	Green-veined white	1.94	-0.44	0.01	1.98	1.82	-1.71
Pieris rapae	Small white	2.41	3.47	-1.69	-0.79	0.43	-1.77
Polygonum c-album	Comma	0.70	-2.22	0.59	0.75	2.15	-2.34
Polyommatus icarus	Common blue	1.57	-0.33	1.40	-0.10	2.39	2.17
Thymelicus lineola	Essex skipper	-0.17	1.23	-0.01	-0.65	1.03	1.15
Thymelicus sylvestris	Small skipper	0.05	0.13	-0.10	0.48	0.79	2.05

Table A11 T-values for relationships between mean butterfly density in 2010 across 399 WCBMS scheme sites and characteristics of the surrounding landscape, in terms of arable/horticulture, pesticide treatment, selected AE schemes (which might benefit butterflies, assessed at 3km radius) and protected area cover (see methods for variable abbreviations). Significant relationships are highlighted (orange positive; blue negative).

Latin name	**Common name**	**AH**	**Pesticide2010**	**ESoption count**	**ESAoption count**	**CSSoption count**	**PA**
Aglais urticae	Small tortoiseshell	0.92	0.56	0.32	2.32	2.57	-0.65
Aphantopus hyperantus	Ringlet	1.72	-0.59	1.92	0.33	2.35	0.41
Aricia agestis	Brown argus	1.17	1.52	0.16	-0.26	2.19	0.65
Celastrina argiolus	Holly blue	0.63	-0.07	-1.80	0.09	0.52	0.08
Coenonympha pamphilus	Small heath	-1.56	1.21	0.53	1.29	2.35	9.63
Gonepteryx rhamni	Brimstone	0.74	0.01	0.59	-0.01	1.96	2.53
Lycaena phlaeas	Small copper	1.71	-4.08	3.40	0.13	1.70	2.74
Maniola jurtina	Meadow brown	2.54	-2.65	4.70	2.33	1.63	-0.12
Pyronia tithonus	Gatekeeper	4.00	-3.57	1.38	1.14	-0.72	2.82
Melanargia galathea	Marbled white	0.46	0.09	1.43	0.98	2.43	0.58
Inachis io	Peacock	0.91	0.10	1.04	0.98	0.09	0.74

Latin name	Common name	AH	Pesticide2010	ESoption count	ESAoption count	CSSoption count	PA
Ochlodes venata	Large skipper	0.07	1.04	1.73	-0.11	0.24	2.98
Pararge aegeria	Speckled wood	2.52	-5.51	-1.31	0.80	0.55	-0.79
Lasiommata megara	Wall brown	0.14	-0.64	1.92	3.32	0.14	-0.64
Pieris brassicae	Large white	0.62	2.52	-0.04	-0.80	-0.55	-2.37
Pieris napi	Green-veined white	2.31	-1.64	1.86	1.53	1.08	-1.61
Pieris rapae	Small white	2.18	3.74	-0.94	-0.43	2.68	-2.07
Polygonum c-album	Comma	1.73	-3.00	1.18	0.90	1.61	-2.12
Polyommatus icarus	Common blue	1.17	-0.25	2.45	0.44	2.25	2.26
Thymelicus lineola	Essex skipper	-0.21	1.41	-0.64	-0.49	2.36	1.10
Thymelicus sylvestris	Small skipper	0.47	-0.18	-1.32	0.36	0.65	1.74

Table A12 Comparison of linear models with piecewise linear models with breakpoint at the either the first commencement of any AE scheme option in 1km radius (Break 0), or one to three years later (Break+1 and Break+3 respectively). Shown for each species are the number of sites for which each model was the best fit (lowest AIC score). Sites for which models had equal AIC scores were non-informative were excluded.

	ES scheme assessment				**ESA scheme assessment**				**CS scheme assessment**			
Species	**Linear**	**Break 0**	**Break+1**	**Break+3**	**Linear**	**Break 0**	**Break+1**	**Break+3**	**Linear**	**Break0**	**Break+1**	**Break+3**
Aglais urticae	**117**	21	0	4	**16**	7	1	0	**51**	20	4	0
Aphantopus hyperantus	**56**	30	14	35	**10**	2	4	5	**25**	18	12	16
Aricia agestis	**73**	48	43	50	11	9	1	**15**	36	22	16	**42**
Celastrina argiolus	**155**	62	43	54	**25**	7	5	9	**74**	30	29	21
Coenonympha pamphilus	**52**	20	6	24	**8**	5	5	3	**25**	13	9	10
Gonepteryx rhamni	**148**	67	52	53	**21**	11	10	10	**72**	40	30	30
Inachis io	**120**	72	78	91	20	8	5	**21**	**82**	23	18	62
Lasiommata megara	**65**	57	21	13	**18**	10	4	2	**33**	23	13	7
Lycaena phlaeas	**121**	90	49	57	**18**	13	8	13	**52**	44	30	34
Maniola jurtina	**83**	42	21	19	**15**	5	5	5	**43**	15	12	13
Melanargia galathea	**56**	23	13	19	**9**	4	8	2	**33**	10	9	11
Ochlodes venata	**71**	36	14	36	**9**	7	5	3	**32**	21	15	14

	ES scheme assessment				**ESA scheme assessment**				**CS scheme assessment**			
Species	**Linear**	**Break 0**	**Break+1**	**Break+3**	**Linear**	**Break 0**	**Break+1**	**Break+3**	**Linear**	**Break0**	**Break+1**	**Break+3**
Pararge aegeria	**58**	34	30	42	**12**	6	5	4	**31**	17	15	18
Pieris brassicae	135	62	53	**139**	**29**	13	5	9	**100**	40	26	35
Pieris napi	107	76	61	115	**24**	3	16	14	**64**	33	46	44
Pieris rapae	**160**	68	60	82	**18**	16	7	14	**75**	48	39	37
Polygonum c-album	**78**	28	20	34	**12**	6	4	3	**40**	13	10	17
Polyommatus icarus	**117**	62	80	92	16	10	6	**26**	65	38	28	**67**
Pyronia tithonus	**75**	30	30	14	5	**10**	7	2	**26**	**26**	10	18
Thymelicus lineola	**20**	7	4	1	2	1	0	0	**9**	6	3	2
Thymelicus sylvestris	**61**	27	12	7	**6**	**6**	3	1	18	**19**	5	5

Table A13 Comparison of linear models with piecewise linear models with breakpoint at the either the first commencement of any AE scheme option in 3km radius (Break 0), or one to three years later (Break+1 and Break+3 respectively). Shown for each species are the number of sites for which each model was the best fit (lowest AIC score). Sites for which models had equal AIC scores were non-informative were excluded.

	ES scheme assessment				**ESA scheme assessment**				**CS scheme assessment**			
Species	**Linear**	**Break 0**	**Break+1**	**Break+3**	**Linear**	**Break 0**	**Break+1**	**Break+3**	**Linear**	**Break0**	**Break+1**	**Break+3**
Aglais urticae	**111**	25	0	5	**32**	9	2	0	**74**	32	10	1
Aphantopus hyperantus	**51**	28	16	32	**13**	7	4	9	29	**32**	19	23
Aricia agestis	**65**	52	33	45	18	12	2	**24**	**45**	29	23	58
Celastrina argiolus	**157**	67	30	53	**46**	11	7	14	**110**	49	35	39
Coenonympha pamphilus	**49**	23	12	16	**14**	9	4	4	**40**	20	11	13
Gonepteryx rhamni	**142**	69	60	61	**37**	23	15	12	**112**	59	48	42
Inachis io	**141**	66	54	108	**35**	17	7	32	**105**	49	32	102
Lasiommata megara	**53**	55	23	13	**25**	11	8	5	**45**	29	17	16
Lycaena phlaeas	**113**	102	33	65	**31**	20	12	14	**70**	72	39	61
Maniola jurtina	**82**	41	24	16	**25**	5	7	7	**59**	28	19	23
Melanargia galathea	**53**	25	17	23	**16**	8	12	5	**40**	20	17	18
Ochlodes venata	**70**	44	9	34	**14**	11	6	7	**40**	35	15	31

	ES scheme assessment				**ESA scheme assessment**				**CS scheme assessment**			
Species	**Linear**	**Break 0**	**Break+1**	**Break+3**	**Linear**	**Break 0**	**Break+1**	**Break+3**	**Linear**	**Break0**	**Break+1**	**Break+3**
Pararge aegeria	**55**	34	17	52	**15**	7	3	10	**43**	28	23	33
Pieris brassicae	**153**	53	46	126	**48**	17	13	10	**149**	50	45	55
Pieris napi	**110**	80	63	94	**28**	13	27	19	**103**	53	66	69
Pieris rapae	**165**	81	56	73	**38**	19	14	20	**119**	71	47	63
Polygonum c-album	**89**	22	19	33	**24**	5	7	4	**68**	23	12	30
Polyommatus icarus	**140**	56	62	93	32	14	9	**37**	88	58	35	**117**
Pyronia tithonus	**79**	41	28	12	**16**	14	7	4	**42**	40	20	23
Thymelicus lineola	**18**	9	7	1	**2**	**2**	1	0	**15**	9	2	3
Thymelicus sylvestris	**59**	29	14	6	**13**	10	3	4	**36**	27	7	9

Table A14 Comparison of linear models with piecewise linear models with breakpoint at the either the first commencement of selected AE scheme options which might benefit butterflies in 1km radius (Break 0), or one to three years later (Break+1 and Break+3 respectively). Shown for each species are the number of sites for which each model was the best fit (lowest AIC score). Sites for which models had equal AIC scores were non-informative were excluded.

	ES scheme assessment				**ESA scheme assessment**				**CS scheme assessment**			
Species	**Linear**	**Break 0**	**Break+1**	**Break+3**	**Linear**	**Break 0**	**Break+1**	**Break+3**	**Linear**	**Break0**	**Break+1**	**Break+3**
Aglais urticae	**83**	9	1	3	**8**	5	0	0	**16**	2	2	0
Aphantopus hyperantus	**39**	21	18	21	**6**	0	2	4	**8**	7	2	3
Aricia agestis	**47**	**47**	32	32	4	**5**	0	10	11	8	7	**13**
Celastrina argiolus	**109**	56	34	31	**13**	3	3	6	**23**	5	4	4
Coenonympha pamphilus	**39**	12	9	13	**6**	3	2	1	**5**	3	4	**5**
Gonepteryx rhamni	**106**	58	47	29	**15**	5	6	6	**22**	8	7	6
Inachis io	**80**	76	55	63	11	4	5	**14**	**16**	9	4	**16**
Lasiommata megara	**56**	33	14	5	**9**	8	1	2	**6**	2	1	4
Lycaena phlaeas	**85**	74	44	25	7	7	5	**8**	**13**	8	8	6
Maniola jurtina	**62**	31	17	9	**8**	2	3	4	**15**	3	2	4
Melanargia galathea	**41**	20	12	10	**5**	3	4	2	**14**	5	4	0

	ES scheme assessment				**ESA scheme assessment**				**CS scheme assessment**			
Species	**Linear**	**Break 0**	**Break+1**	**Break+3**	**Linear**	**Break 0**	**Break+1**	**Break+3**	**Linear**	**Break0**	**Break+1**	**Break+3**
Ochlodes venata	**42**	30	14	24	2	**3**	**3**	**3**	**9**	3	5	3
Pararge aegeria	29	**35**	25	30	**6**	2	3	2	**9**	**9**	0	6
Pieris brassicae	93	66	37	**99**	**15**	8	2	7	**28**	7	6	11
Pieris napi	**80**	69	46	73	9	2	10	**12**	14	10	10	**15**
Pieris rapae	**111**	57	34	65	**12**	9	3	6	**17**	11	7	12
Polygonum c-album	**57**	24	18	18	**4**	**4**	3	2	**15**	2	3	4
Polyommatus icarus	**73**	60	67	63	6	5	4	**17**	14	10	6	**20**
Pyronia tithonus	**58**	23	16	7	1	**6**	3	1	**12**	8	2	2
Thymelicus lineola	**12**	8	3	0	**1**	**1**	0	0	1	0	0	0
Thymelicus sylvestris	**41**	23	7	7	**4**	2	3	2	5	4	2	1

Table A15 Comparison of linear models with piecewise linear models with breakpoint at the either the first commencement of selected AE scheme options which might benefit butterflies in 3km radius (Break 0), or one to three years later (Break+1 and Break+3 respectively). Shown for each species are the number of sites for which each model was the best fit (lowest AIC score). Sites for which models had equal AIC scores were non-informative were excluded.

	ES scheme assessment				**ESA scheme assessment**				**CS scheme assessment**			
Species	**Linear**	**Break 0**	**Break+1**	**Break+3**	**Linear**	**Break 0**	**Break+1**	**Break+3**	**Linear**	**Break0**	**Break+1**	**Break+3**
Aglais urticae	**108**	21	0	5	**27**	7	2	0	**35**	13	3	0
Aphantopus hyperantus	**51**	24	16	32	**10**	7	3	7	**20**	17	10	6
Aricia agestis	**66**	49	30	47	12	12	0	**21**	27	18	12	**28**
Celastrina argiolus	**148**	63	35	46	**35**	8	7	11	**45**	17	17	18
Coenonympha pamphilus	**46**	25	10	15	**11**	7	4	4	**17**	9	8	9
Gonepteryx rhamni	**137**	74	54	49	**31**	19	13	10	**48**	25	15	14
Inachis io	**125**	75	48	105	**27**	16	7	25	37	17	13	**45**
Lasiommata megara	**59**	52	16	13	**20**	10	5	3	**20**	8	4	6
Lycaena phlaeas	**110**	91	34	62	**21**	16	12	13	**28**	31	13	27
Maniola jurtina	**76**	38	24	15	**21**	4	7	7	**30**	9	7	7
Melanargia galathea	**52**	23	17	20	**12**	6	11	4	**21**	13	9	9
Ochlodes venata	**61**	42	11	33	**13**	5	6	7	**19**	15	9	11

	ES scheme assessment				**ESA scheme assessment**				**CS scheme assessment**			
Species	**Linear**	**Break 0**	**Break+1**	**Break+3**	**Linear**	**Break 0**	**Break+1**	**Break+3**	**Linear**	**Break0**	**Break+1**	**Break+3**
Pararge aegeria	**51**	32	18	47	**14**	6	3	7	**24**	10	5	15
Pieris brassicae	**143**	52	46	122	**38**	15	11	8	**64**	24	9	21
Pieris napi	**105**	82	53	97	**24**	12	23	13	**38**	26	24	23
Pieris rapae	**158**	79	44	76	**28**	17	13	16	**51**	23	21	23
Polygonum c-album	**79**	26	17	34	**19**	5	6	4	**33**	9	6	10
Polyommatus icarus	**128**	56	62	85	25	9	8	**33**	37	17	12	52
Pyronia tithonus	**74**	34	26	10	**13**	**13**	6	3	**19**	16	10	8
Thymelicus lineola	**15**	8	7	1	2	2	1	0	**5**	2	1	1
Thymelicus sylvestris	**52**	28	14	6	**12**	9	3	2	12	**14**	3	3

Table A16 Qualitative comparison of the direction of pre- and post-breakpoint population trends from analysis of selected AE scheme options which might benefit butterflies in 1km radius (i.e. from Table 2.16). Considered are species and AE schemes for which the a piecewise-regression more often gave a better fit than a linear model. **'**U-'shaped trends are where the post-breakpoint population trend is greater than the pre-breakpoint trends. Ticks indicate where the proportions are significantly different.

Species	**Model**	**'U-'shaped**	**'N'-shaped**	**P**
Aricia agestis	ES Break 0	21	26	NS
Aricia agestis	CS Break 0	12	1	0.0034
Coenonympha pamphilus	CS Break + 3	4	1	NS
Inachis io	ESA Break + 3	3	11	NS
Inachis io	CS Break + 3	5	11	NS
Lycaena phlaeas	ESA Break + 3	7	1	NS
Pararge aegeria	CS Break 0	4	5	NS
Pieris napi	ESA Break + 3	10	2	0.039
Pieris napi	CS Break + 3	9	6	NS
Polyommatus icarus	ESA Break + 3	14	3	0.013
Polyommatus icarus	CS Break + 3	19	1	<0.001
Pyronia tithonus	ESA Break 0	5	2	NS