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Evidence Project Final Report

Department for Environment Food & Rural Affairs

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Project identification

1. Defra Project code: WC1034
2. Project title: Farmland heterogeneity, biodiversity and ecosystem services
3. Contractor organisation(s):
   British Trust for Ornithology
   The Nunnery
   Thetford
   Norfolk
   IP24 2PU
4. Total Defra project costs (agreed fixed price): £ 148,480
5. Project: start date .... January 2012
   end date .... December 2014

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Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

1. This project constituted the UK component of an international research programme aiming to test the concepts introduced by Fahrig et al. (2011) that the biodiversity benefits from heterogeneous natural or semi-natural elements should be reflected in arable cropping: landscapes with more heterogeneous cropping should have higher biodiversity. The provision of ecosystem services by this biodiversity should also increase, so the manipulation of heterogeneity could form a new tool in the management of farmland to integrate improved environmental management and maintained (or increased) crop yields.

2. The wider research programme includes study regions in France (four), Germany, Spain and Canada (funded by BiodivERsA in Europe and the Canadian government in Canada). In each region, the same protocol, a landscape-scale field experiment, is being followed. The regions provide a range of cropping patterns and amounts of heterogeneity, rather than replicates. Hence, it is appropriate to consider the international study as a whole to reach conclusions. The European study is still in progress (to complete in Autumn 2015), including integrated analyses; final results and interpretation will be provided to Defra then, as an addendum to this report. The UK results presented here should be regarded as preliminary.

3. UK study sites (1km squares) were selected using the protocol used in the other regions (**Objective 1 - to identify study locations making up a mensurative experimental design**). Within East Anglia, 30 different 1km^2 landscapes were selected in each of 2012 and 2013. Survey squares were identified with consistent agricultural land cover (60-90% in 2012, following the Canadian study, and 90-100% in 2013) across spatial scales up to 7×7km. Indices of compositional (the Shannon diversity index of crop cover) and configurational (the total length of agricultural boundaries) heterogeneity were then calculated, using the best available proxies for cropping. Squares were selected to minimize spatial autocorrelation and to maximize variation in the heterogeneity variables along two independent gradients.

4. Crop habitat mapping in the field showed that the original square selections produced uncorrelated variation in the two key indices of heterogeneity: the correlations between the empirically measured indices were -0.204 in 2012 and -0.101 in 2013, indicating that the gradients were strongly independent.

5. Bespoke surveys were conducted for seven taxonomic groups (birds, bees, butterflies, hoverflies, ground beetles, spiders and plants), all at four survey points in each square, located on boundaries between two cropped fields (**Objective 2 – to characterize biodiversity-heterogeneity relationships in sample landscapes**). Invertebrates and plants were surveyed within the crop vegetation and along the

boundary. Bird surveys were also conducted using the BTO/JNCC/RSPB Breeding Bird Survey method, to make it possible to link the patterns in the study squares to the national scale, via the BBS.

6. All surveys were conducted successfully, with the exception of butterflies in 2012. The protocol for the latter was taken from the Canadian context, where butterfly abundance and species richness are much higher than in East Anglian farmland, so encounter rates were simply too low to generate usable data. A revised protocol was therefore employed in 2013.

7. As a preliminary analysis of the UK data alone, patterns of biodiversity in each group were summarized as species richness and the Simpson's diversity index. These indices were then analysed with respect to the two heterogeneity indices, controlling for the area of non-agricultural habitat in the survey square and crop type, which are both potentially important confounding variables.

8. Various patterns were detected for the UK context, suggesting that the study design provides sufficient power to reveal relationships should they exist within the ranges of heterogeneity found among the UK study areas. There were small numbers of clear patterns for associations between farmland heterogeneity indices and biodiversity measures in either year, and the patterns varied in direction. Compositional heterogeneity (the Shannon index of crop cover diversity) was positively associated with plant and spider species richness in 2013 and with bee richness in 2012, but was negatively associated with the latter measure and bird richness in 2013.There were only two associations between configurational heterogeneity (the total length of agricultural boundaries) and species richness, both in 2012: a positive relationship involving bird assemblages and a positive relationship with plant assemblages. The diversity of ground beetles and plants were negatively associated with compositional heterogeneity in 2012, but bees, spiders and butterflies showed positive associations in 2013. As with species richness, there were positive associations with bird point count and in-field plant diversity. The results support recent studies that suggest that greater heterogeneity in cropping or land-use is not necessarily a positive influence on biodiversity and suggest that effects of heterogeneity can be complex and variable between different taxonomic groups. Variation in relationships between years probably reflects non-linearities and the different covers of non-agricultural habitat in the annual samples.

9. Experiments were run to investigate the effects of the two heterogeneity indices on the ecosystems services of pollination and the predation of crop pests (**Objective 3 – To investigate the influence of heterogeneity on ecosystem service provision**). Pollination was investigated using a "phytometer" experiment in 2013, in which flowering radish and cornflower plants were presented in the field at the points used for biodiversity sampling under controlled conditions and the seed set from the exposed flowers measured. Losses of cornflower plants during husbandry prevented a sufficient sample being deployed for analysis of the UK data alone (although these data will still contribute internationally). Predation of pests was assessed using a standardized presentation of aphids, glued to cards, within the crops at each of the sample points in both study years. Both seed set and proportions of aphids predated were analysed with respect to the key heterogeneity variables for the 1km squares sampled.

10. There was no significant relationship between radish seed set and compositional heterogeneity (the Shannon index), but there was a strong, positive relationship with configurational heterogeneity (the total length of agricultural boundaries). Predation of crop pests showed contrasting patterns in 2012 and 2013, with configurational heterogeneity a significant, positive apparent influence in 2012 and compositional heterogeneity significant and positive in 2013. These results suggest that the spatial arrangement of crop covers is a determinant of pollination potential when non-agricultural habitats are relatively rare, whereas it is associated with predation of aphids when non-agricultural habitats are more common. The composition of local land cover was less important for pollination, but this was only tested in on landscape context, while it was a significant determinant of predation of aphids where non-agricultural habitats were rarer. However, these patterns refer only to the ranges of variation found in the UK and definitive analyses will require the integration of data from across Europe and Canada.

11. This project provides unique data on multiple taxa and the potential to investigate inter-relationships between the taxa that deliver different ecosystem services (**Objective 4 – To investigate relationships between elements of biodiversity providing different ecosystem services**). In general, carabid (ground) beetles and spiders potentially provide a pest control service, bees and syrphid flies (hoverflies) may be important for crop pollination and arable plants support the populations of pollinators and predators, while birds, butterflies and plants provide an aesthetic service. Multiple benefits might be realized by single manipulations of farmland heterogeneity if groups providing different services co-varied. The results of the biodiversity analyses under Objective 2 were used to investigate the inter-relationships between abundance, species richness and diversity of birds (conservation priority species), butterflies,

bees, syrphids, carabids, spiders and plants, as well as the effects of heterogeneity on the relationships.
12. As with other areas of this report, the results must be treated as preliminary, but they suggest that there are certain common responses to environmental variation among the different taxa, while further patterns may emerge in the pan-European data set. There was only limited evidence for a role of heterogeneity in modifying these relationships, but almost all of the patterns found indicated positive effects and more definitive tests will be possible once the integrated, international data set is analysed.
13. An important element of the European BiodivERsA project involves social science research into the attitudes of farmers and other stakeholders in the agricultural landscape to the functioning of that landscape, in order to inform research conclusions with respect to the feasibility and likely social reception to landscape management options suggested by the results. Here, the aim was only to collect relevant data to feed into analyses to be conducted in Montpellier during 2015. This was done via telephone interviews with project farmers to reveal their "mental models" of the landscape (**Objective 5 – to conduct farmer interviews to support a UK component of the wider BiodivERsA FarmLand project**) and via a workshop for farmers and stakeholders to consider the possible nature and practicality of management options, which was conducted at the BTO in Thetford on 9th December 2014. (**Objective 6 – to organize a stakeholder workshop for the UK to derive a collective conceptual model and socially feasible recommendations**).
14. It is not appropriate to reach final conclusions from this project until the results have been integrated with those from elsewhere in Europe and Canada. This process will also identify opportunities for further work, which may include field testing of management solutions for the maximization of biodiversity and ecosystem service provision suggested by the study's results.

Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:
   - the objectives as set out in the contract;
   - the extent to which the objectives set out in the contract have been met;
   - details of methods used and the results obtained, including statistical analysis (if appropriate);
   - a discussion of the results and their reliability;
   - the main implications of the findings;
   - possible future work; and
   - any action resulting from the research (e.g. IP, Knowledge Exchange).

Introduction

Agricultural intensification, including conversion of natural and semi-natural areas into cropped land, increasing use of agro-chemicals and general increases in efficiency, has resulted in significant losses of biodiversity worldwide, with associated negative effects on ecosystem services (Norris 2008, Carvalheiro et al. 2010). Intensification has also resulted in lower diversity of crop types and larger crop fields (fewer edges) in agricultural regions. In other words, agricultural landscapes have become more spatially homogeneous. The effects of this loss of heterogeneity on biodiversity have been studied little at the landscape scale, compared to the field or farm scales and, although some cross-scale extrapolation suggests that it may lead to reduced biodiversity (Benton et al. 2003), analyses of certain heterogeneity indices suggest complex, not uniformly positive effects across species (Pickett & Siriwardena 2011). If a significant portion of the loss of biodiversity associated with increasing agricultural intensity is due to the spatial homogenization of farming enterprises, then it may be possible to develop new policies for agriculture that could help restore to biodiversity and associated ecosystem services by enhancing landscape heterogeneity. This project seeks to inform how best to do this in order to benefit as many aspects of farmland biodiversity as possible, whilst both minimizing any negative influences on farm productivity – and the perception of this by farmers – and maximizing the beneficial services provided by biodiversity.

Previous research in this area has typically considered more heterogeneous agricultural landscapes to be those containing large areas of heterogeneous natural or semi-natural habitats, such as small wooded areas, hedgerows, herbaceous field borders, or wetlands (e.g., Thies et al. 2003, Doxa et al. 2010, Poggio et al. 2010). Agricultural landscapes containing these elements have higher biodiversity because, as more semi-natural habitats are added to a landscape, there is an accumulation of species associated with these additional habitats. A further increase in biodiversity occurs due to species whose presence or abundance is enhanced by the occurrence of more than one cover type (habitat or crop) in the landscape. For species that need (or prefer) different cover types at different times in their life cycle, or different resources such as food and nest sites at a particular time, landscapes with an inter-mixing of those different cover types have high "landscape complementation" (Dunning et al. 1992). For example, many amphibians need both aquatic and terrestrial habitats at different life stages, so they are more likely to occur in landscapes containing a mosaic of the two (Pope et al. 2000).

This automatically suggests a policy of insertion of natural and semi-natural elements into agricultural landscapes, but such a policy would mean that some farmed area had to be taken out of production, which is unlikely to be compatible with increasing demand for food from human society to be produced from less land area. It is also effectively the rationale behind much agri-environment management (the rest being a reduction in intensity of management of the cropped area), which has had some success in addressing environmental priorities but which has so far failed to achieve all of its aims, such as reversing the decline in the farmland bird index in England (Baker et al. 2012, Dallimer et al. 2010, Peach et al. 2001, Siriwardena et al. 2014). This leads to the question of whether there are other, novel ways of increasing heterogeneity and hence enhancing the farmland environment without reducing productivity. One such approach would be to increase the heterogeneity of the cropped area itself, which could potentially increase biodiversity within agricultural landscapes while maintaining the same total area of the landscape in agricultural production.

Fahrig et al. (2011) hypothesized that the same mechanisms that produce biodiversity benefits from heterogeneous natural or semi-natural elements should apply to the arable cropping: agricultural landscapes with more heterogeneous cropping should have higher biodiversity. A greater diversity of crop types should provide resources for more different species and when these different crops are more interspersed with each other (high edge density and high habitat diversity per unit area), species that use more than one crop field type (at different times, or benefiting from simultaneous complementarity) should benefit through landscape complementation. For example, some birds in intensive agricultural landscapes need particular adjacent contrasting land-uses to provide different resources needed for breeding (e.g. lapwing *Vanellus vanellus*: Galbraith 1988; little bustard *Tetrax tetrax*: Wolff et al. 2002).

As well as conservation of farmland biodiversity for its own sake, or “existence value”, the ecosystem services that it may deliver provide further incentives for considering manipulation of heterogeneity. Aspects of biodiversity may contribute to agricultural production by providing ecosystem services such as crop pollination and biological control of crop pests (regulating services) and soil quality (supporting services) that ultimately allow or support food provisioning (provisioning services). These effects may support increases in yield, reduce the need for agro-chemicals and/or promote system sustainability, and thus promote efficiency and profitability. Through charismatic, conspicuous or rare species, biodiversity may also contribute to the aesthetic and recreational value of farmland (cultural services). If greater heterogeneity of cropped fields results in a benefit to biodiversity, all these associated ecosystem services might also be increased. Moreover, particular components of biodiversity or indicators derivable from biodiversity data could have demonstrable correlations with ecosystem service provision due to shared drivers (notionally reflecting a healthy environment). Such indicators would be valuable tools for cost-effective assessment of ecosystem service provision, especially if they could be applied to existing data sources or using ongoing survey effort.

This project constituted the a UK component of an international research programme aiming to test these ideas and to convert the results into policy-relevant recommendations that are both socially acceptable and economically feasible, while providing benefits to biodiversity and ecosystem services. In the UK, this has particular importance for the identification both of potential management solutions that are independent of agri-environment scheme (AES) funding (potentially contributing to voluntary management under the Campaign for the Farmed Environment or in areas where AES management is no longer supported under Countryside Stewardship from 2016) and of mechanisms to manage components of Ecological Restoration Zones (*sensu* Lawton et al. 2010) without compromising agricultural productivity. In Europe, the programme has been funded as the BiodivERsA project **FARMLAND**, which includes study regions in France (four diverse regions), Germany and

Spain. This project is due to report in late 2015. In Canada, parallel work was conducted in 2011-2014 and the first results have recently been published (Fahrig et al. 2015). As a whole, the programme seeks to answer the research questions described and conceptualized in Fahrig et al. (2011), using a standardized research protocol.

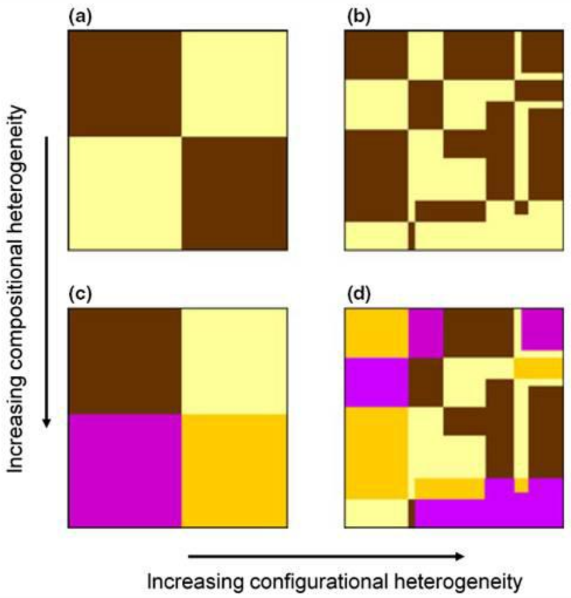

Fig. 1: Illustration of the two major axes of spatial heterogeneity: compositional and configurational heterogeneity. Each large square is a landscape and different colors represent different cover types within landscapes. Compositional heterogeneity increases with increasing number and/or evenenss of cover types. Configurational heterogeneity increases with increasing complexity of the spatial pattern.

The protocol explicitly divides heterogeneity into two components (Fig 1. after Fahrig et al., 2011): a more heterogeneous landscape is a landscape with a larger variety of different cover types (compositional heterogeneity) and/or a more complex spatial patterning of them (configurational heterogeneity).

Based on these concepts, the FarmLand programme has asked four questions, covering seven groups of organisms (plants, carabid beetles, spiders, bees, hoverflies, butterflies and birds):

1. How does farmland biodiversity change with increasing compositional heterogeneity of crop types in the landscape (measured using the Shannon diversity index)?
2. How does farmland biodiversity change with increasing configurational heterogeneity (edge density) of crop types in the landscape?
3. What measures of farmland biodiversity are most strongly related to provision of the ecosystem services provided by that biodiversity [regulating (pollination, pest control) and cultural services]?
4. How is agriculture linked to farmland heterogeneity and ecosystem services provided by biodiversity and how are these connections perceived by farmers? How can we build collectively acceptable guidelines that will create spatial patterns of farmland that promote biodiversity-based ecosystem services?

The common design allows direct comparisons of results across regions, which are expected to lie along gradients of heterogeneity and farmland character. The standardized protocol means that regional context will not have been confounded with methodology and that single statistical analyses can be conducted that integrate data across regions, maximizing both the power of the analyses and the ranges of the predictor variables evaluated: the international focus provides both added value from shared data and a broader range of landscape forms and cropping systems than would ever be possible in one country. In turn, this means that the UK-specific results are only a component of a larger picture and that the complete, final data analyses are being conducted at a European (and inter-continental) scale, led by collaborators in France and Germany. Fundamentally, therefore, the UK work described here only comprises data collection to contribute to analyses being done elsewhere and those analyses are still in progress, with completion expected in Autumn 2015. Additional reporting of the implications of the results for the UK will be provided then. Here, however, UK-specific results and interim conclusions are presented, with the caveat that they are intrinsically incomplete and should be regarded as interim. Final conclusions and recommendations should, therefore, not be drawn from the results presented in this report.

The remainder of this report describes the Objectives, Methods and Results of the UK work funded by Defra. Note that, because the design of the full project requires data from multiple regions, this Defra project aimed primarily to collect data for use in European-scale analyses, rather than to address the FarmLand questions above at regional scale in the UK.

Objectives

1. To identify study locations making up a mensurative experimental design;
2. To characterize biodiversity-heterogeneity relationships in sample landscapes;
3. To investigate the influence of heterogeneity on ecosystem service provision;
4. To investigate relationships between elements of biodiversity providing different ecosystem services;
5. To conduct farmer interviews to support a UK component of the wider BiodivERsA FarmLand project;
6. To organize a stakeholder workshop for the UK to derive a collective conceptual model and socially feasible recommendations.

The project was conducted via three work packages (WP), reflecting a system replicated in each study region internationally. WP1 investigated links between the structure of the farmed landscape and biodiversity, via Objectives 1 and 2. WP2 considered how these effects of landscape structure on biodiversity will affect ecosystem services, via Objectives 3 and 4. WP1 and WP2 were conducted in parallel, using the field study described below. WP3 concentrated on how individual farmers and land planning and management decision-makers perceive the effects of farmland heterogeneity and farm management on biodiversity and ecosystem services in farmland. Work towards WP3 in the UK, via Objectives 5 and 6, consisted only of data collection for our French partners (led by Dr Raphael Mathevet of CNRS, Montpellier), who are now processing and analysing the data and will write up the results, so only methods and meta-data are described below for the UK.

Work Package 1 – Objectives 1 & 2.

Objective 1 – To identify study locations making up a mensurative experimental design.

Introduction

Manipulating landscape content such as cropping is not feasible in practice because of the scale of land-use that would need to be controlled and the number of landowners involved, as well as the issues of possible requirements for compensation or compliance control. A mensurative experiment, in which study areas are selected that maximize the variation in the landscape properties of interest and provide uncorrelated gradients in these properties, provides an effective alternative for use with real landscapes, in which confounding variables are controlled the predictor variables of interest are isolated. This approach has been developed and verified by our Canadian partners (Pasher et al. 2013). It aims to minimize correlations between independent variables, to minimize spatial autocorrelation between sample sites and to maximize the variation between sites and thus the statistical power.

For the UK, 30 different $1km^2$ landscapes were selected for fieldwork in each of 2012 and 2013 from the 1km British National Grid for the 100km squares TF, TG, TL and TM, which cover East Anglia. Initial landscape selection in the UK was conducted in winter 2011-12, before common methods for the Biodiversa project had been finalized. Hence, the approach used previously in Canada was followed as closely as possible. Subsequently, lessons learned in 2012 and agreement across the Biodiversa consortium led to a change in approach for 2013. Details are provided in Appendices 1 and 2.

Methods

In both years, the strategy was to select squares in East Anglia, an area of arable-dominated farmland with reasonably consistent land-use, from the UK national grid such that the proportion of land covered by agriculture was as consistent as possible (i.e. covering a narrow range of percentage cover) and that this proportion was consistent across multiple spatial scales for each focal 1km square. The latter was done by calculating percentage cover for 1km squares and for areas delimited by progressively larger buffers around the focal square (in steps of 500m), up to 7km, and filtering the data such that only squares with the desired proportional cover of agriculture at all spatial scales were considered. These calculations were made using data from the Land Cover Map 2007 (LCM), with agricultural land being defined as that under the “arable and horticulture” or “improved grassland” “broad habitats”.

Indices of compositional and configurational heterogeneity were then calculated for the agricultural land in the candidate 1km squares, as described below. Ideally, these analyses would have been conducted using a comprehensive map of cropping and other land-use at the field scale, but such a map was not available, so the best available proxies were used instead. It is important to note that these proxy measures were used only in the landscape selection process, in order to achieve the maximum possible range and independence of heterogeneity gradients *a priori*. For final analyses (Obj. 2 & 3), all heterogeneity indices were re-calculated for the sampled squares using accurate field records of crops and other field contents.

The LCM provides accurate data on land-use within parcels, but many parcel boundaries do not match real field boundaries and crops are not distinguished. Real field boundaries were extracted from the Ordnance Survey MasterMap and LCM parcels falling within these fields were merged where the LCM broad habitats or “sub-classes” showed no evidence of the existence of crop boundaries within fields delimited in MasterMap. The best proxy for crop composition was provided by Landsat images (http://glovis.usgs.gov/) for two dates in 2011 (April and June), which effectively describe the colour of the land in 25×25m pixels (via the Normalized Difference Vegetation Index, NDVI). Pixel-specific NDVI values were extracted by arable field and averaged for each date. These field averages for April and June (effectively the colours of the land early and late in the growing season) were then plotted against one another, revealing four clear clusters, each of which was assumed to represent a crop type for calculations of heterogeneity indices (see below). This clearly involved an assumption about the equivalence of NDVI variation and crop type that was unlikely to hold in all circumstances. There were also many more than four crop types across the region. Nevertheless, this proxy was considered the best available guide to the variability in cropping available. Further, some ground-truthing was possible using 1km BTO/JNCC/RSPB Breeding Bird Survey squares in the region that had been covered by BTO staff in 2011 and for which true cropping was known. Comparison with the cluster classifications indicated that spring sugar beet appeared in one cluster, but that winter oilseed rape and (winter) cereals were in another, not sufficiently separated to be identifiable from each other. This indicates that the cluster results represent some, but not all, of the known variation in cropping, but also capture additional variation that could not be tested using the limited ground-truthing information available. It is likely that the crops covered by the latter include sparser winter-sown crops such as field beans and other spring-sown crops, of which potatoes, onions and spring cereals are notable locally. This means that the best possible land-use map available was less than perfect, but that it probably captured some of the ecologically most important factors in crop variation, such as timing of sowing.

Heterogeneity variables were calculated as described below for multiple spatial scales, in order to identify the optimum maximum spatial scale for summarizing local land-use patterns in potential survey squares. This scale was identified as that delimited by 3km buffers. Then, patterns of spatial auto-correlation were investigated for focal squares separated by distances up to 30km. This identified that auto-correlation approached a minimum (levelling off with respect to distance) between 5km and 10km for all variables, so 8km was chosen as a guideline inter-square minimum distance required for the sites to be effectively independent replicates and was used in square selection. Finally, plots of the heterogeneity variables were used to select equal numbers of squares each year from the extremes of the ranges covered by each index, thus minimizing the inter-correlation of the compositional and configurational heterogeneity indices and facilitating the identification of independent effects of these potential influences.

The details of the index calculations that were year-specific are described below.

2012

Following the approach taken in Canada, survey squares were sought in which 60-90% of the land cover was agricultural at all spatial scales. Heterogeneity was then calculated in terms of one index of compositional heterogeneity (the Shannon diversity index of “crop types” derived from NDVI values and improved grassland, with different “crops” being assumed wherever the LCM sub-class differed) and two indices of configurational heterogeneity (the total length of agricultural boundaries (i.e. the spatial “grain” of the agricultural landscape) and the diversity of boundaries – the Shannon index of boundary types defined by the “crop types” on either side, whereby each different combination of crops was considered to represent a different “species” in calculating diversity). A three-dimensional tri-plot of these variables was used to identify six corners of the cloud of possible survey squares and equal numbers of squares were selected from each corner.

It was challenging to select squares using this system both because the requirement for low inter-correlation of three variables was difficult to satisfy and because 1km square sites in East Anglia with 60-90% cover of farmland at multiple spatial scales were rather rare. This led to the selection of many sites with atypical areas of forestry or human habitation relative to the bulk of farmland in the region. Sites were selected in the TF (9), TG

(3), TL (14) and TM (4) 100km squares of the national grid, from south Lincolnshire south to Hertfordshire in the west and in Norfolk, Suffolk and north Essex.

2013

Given the problems with square selection and representativeness in 2012, there was a trade-off with site-selection for 2013, between the benefits of precise replication versus those of collecting better data in the second year. It was critical to sample variation in heterogeneity across a narrow range of variation in other habitat factors and comparison between years was never a target the project. The cost to changing the sample selection was, therefore, only that it became less straightforward to combine the annual samples into a single dataset (i.e. more consideration would need to be given to accounting for inter-annual differences in relationships with heterogeneity, which would be more likely to occur, *a priori*). Therefore, following discussions with the rest of the Biodiversa consortium, survey squares for 2013 were sought with 90-100% cover of farmland, which led to a coverage of squares that were much more typical of the East Anglian landscape than had been used in 2012. Note that the high figures for agricultural cover typically mask many small areas of semi-natural habitat, such as hedgerows, ditches, copses and patches of scrub, because the calculations were based on LCM data, which have a resolution of 25m. Hence, smaller semi-natural habitat patches will often have gone undetected.

Again to be consistent with our European partners, square selection for 2013 used just the Shannon diversity index of compositional heterogeneity and the total length of agricultural boundaries as an index of configurational heterogeneity. Thus, just a bi-plot of the variables was required to select a balanced sample of squares from the extremes of each distribution and it was considerably easier to find squares separated by the nominal 8km or more.

The final selection covered a similar spatial spread to the 2012 sample, with squares again in the TF (14), TG (3), TL (10) and TM (3) 100km squares.

Results

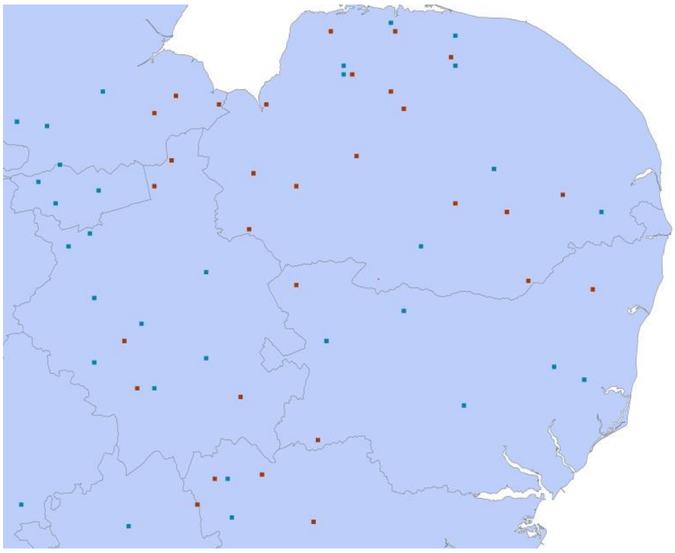

Fig. 2. Locations of survey 1km squares in East Anglia: 2012 (blue) and 2013 (brown).

The distributions of survey squares identified are shown in Figure 2. In the course of the field surveys described under Obj. 2, cropped habitats were mapped, allowing comparison of the heterogeneity indices used in square selection with their analogues identified on the ground (Table 1). These data showed that the original square selections produced both good and uncorrelated ranges of variation in the two key indices of heterogeneity: the Shannon diversity of agricultural land-use (compositional) and the total length of agricultural boundaries (configurational) in both years. The correlations between the empirically measured indices were -0.204 in 2012 and -0.101 in 2013, indicating that the gradients in compositional and configurational heterogeneity were strongly independent. Note, however, that the correlations between the remote-sensed and empirically measured variables nominally measuring the same landscape parameters were rather low

(Table 1). In part, this may reflect the comparison of indices derived from different spatial scales (1km^2 in the field and c. 9km^2 for landscape selection), but more important is likely to be the significant differences in the form of the cropping data available. Hence, the agreement between the two versions of agricultural boundary length was considerably stronger than was the case for cropping diversity, especially in 2013, when the areas considered were more dominated by agriculture. Nevertheless, the critical requirement for the rest of the study that uncorrelated gradients in heterogeneity were identified was satisfied.

Table 1. Correlations between landscape heterogeneity variables used in (a) 2012 and (b) 2013 for study landscape selection and as measured empirically in the field.

(a) 2012	Landscape selection variables (3km buffer)	
Empirically measured variables (1km square)	Shannon crop diversity	Total boundary length
Shannon crop diversity	-0.155	-0.044
Total boundary length	0.077	0.020

(b) 2013	Landscape selection variables (3km buffer)	
Empirically measured variables (1km square)	Shannon crop diversity	Total boundary length
Shannon crop diversity	-0.264	0.276
Total boundary length	0.478	0.528

Objective 2 – To characterize biodiversity-heterogeneity relationships in sample landscapes

Introduction

In order to relate variation in biodiversity to the variation in farmland heterogeneity among the survey squares, surveys of a range of taxa were undertaken following a protocol agreed across the international consortium. The aim was to assess the patterns of diversity (measured most simply as species richness) and abundance of each group and how they were affected by the two gradients of heterogeneity. Once again, there were minor changes to the protocol after a consortium meeting in Autumn 2012, at which the UK experience was used to improve the approaches to be employed in the other regions in 2013 and 2014. In 2013, the methods were aligned as closely as possible to those already used in Canada, while in 2014 they were adapted to be more specifically suited to the European context.

The data collection protocols are described below, with results in the form of meta-data and preliminary statistical analyses of the UK data. Final conclusions will be reached after integration and analysis of the various data sets at the European scale.

Methods

<u>Survey points</u>

The basic international survey design focused on four survey points within each selected 1km square. The points were selected to be a minimum of 500m apart and adjacent to crop-crop boundaries in farmland (i.e. not next to semi-natural or human habitat). Where possible, locations directly along roads or tracks were also avoided, but this was unavoidable in some instances because there were too few other crop-crop boundaries (where field sizes were large or there were large areas of non-agricultural habitat in the squares). Both point and locations and the side of the boundary on which to focus (the "survey crop") were chosen to represent the range of crops present in the square, with one or more points focusing on a winter wheat crop in all squares where wheat was found. Wheat was selected as a key crop because it is grown in the majority of survey squares across all the study regions. Bird and plant surveys were conducted at each of these points, while invertebrate surveys were conducted at three in each square; this was a decision taken across the whole consortium for logistical reasons. Transects of 50m in length were established at each survey point, one at the edge of the crop, with the actual survey point at the mid-point of the transect, and a parallel one within the crop, a minimum of 25m from the boundary (far enough for the local boundary vegetation to have minimal impact on invertebrate and plant occurrence). In-field transects were positioned along “tramlines” (tractor access paths) to avoid damage to crops during survey work; occasionally, when the tramlines ran perpendicular to the boundary at the survey point, the in-field transect therefore ran perpendicular to the boundary one as well. The transects were used for plant, hoverfly (but see below) and butterfly surveys; traps for ground invertebrates and pollinators were positioned at the 0, 25 and 50m points along the transect lines.

All surveys were conducted by single fieldworkers in each year: the survey squares were divided geographically and each of two multi-skilled field surveyors was assigned 15 squares, in which they were responsible for all of the survey work conducted. This maximized familiarity with the sites and standardization of the survey approaches taken.

<u>Birds</u>

Birds were surveyed at the survey points using 10-minute point counts, split into 1-minute sections, with each bird being recorded in ALL periods in which it was detected. All individuals seen or heard were recorded in distance bands of 10m, 25m, 50m, 100m and 250m, and as using habitat (including foraging by aerial insectivores) or flying over (e.g. crows or gulls flying overhead, not landing in fields or boundaries). Counts were conducted before 10am, avoiding rain, fog and strong winds, but recording weather conditions and the ambient noise level. At least one point count was conducted per point per season, in May-July 2012 and April-June 2013.

Further bird surveys were conducted in all squares in addition to the international protocol. These surveys followed BTO/JNCC/RSPB Breeding Bird Survey methods, comprising two 1km transects per 1km square, each walked twice, in May-July 2012 and April-June2013. As well as further analyses of effects of heterogeneity on birds using methods that may be more representative of square-level populations than point counts, the aim of these additional surveys was to collect data allowing links to be made between the multi-taxa field data collected under this project and national bird monitoring data in the UK. Results permitting, this would potentially allow the scaling up of the biodiversity patterns found here, as well as a more general investigation of the value of national bird data for deriving indices of the variation in other taxa. This work will be conducted outside the current project, in 2015.

<u>Plants</u>

Plants were surveyed along the two 50-m transects at each of the four survey points in each square. Two surveys were conducted per year, one early (late May to mid-July in 2012, April-May in 2013) and one later (mid-July to end of August in 2012, June to July in 2013). On each visit, the observer walked along the transect, identifying plant species and estimating percentage cover of each species (to the nearest 10%, or as “present”) within a 2m-wide strip of crop vegetation. This was done separately for five 10m sections of each transect (0-10m, etc.) in 2012 and for five 5m sections (0-5m, 10-15m, 20-25m, 30-35m and 40-45m). The cover of bare ground and previous crop residue was also given a percentage cover in each block, and the general character of the woody boundary vegetation was recorded (solid hedge, gappy hedge, hedge with trees or no hedge).

<u>Bees and hoverflies</u>

These pollinator groups were sampled at a random three of the four survey points per square, together with ground invertebrates (see below). The sampling used pan traps, i.e. coloured polystyrene cups (approx. 9cm in diameter and 11cm high) half-filled with water and a drop of detergent, presented in three pairs along each boundary and in-field transect at 0, 25 and 50m (so twelve traps per survey point). Traps were paired as blue-yellow, white-blue and white-yellow, with each pair mounted on a wooden batten and positioned just above the height of the crop vegetation. The traps were left in place for one or two four-day periods each year (one in 2012, mid-June to end of August, two in 2013, May to mid-June and mid-June to July).

On collection, traps were drained and the contents preserved in alcohol. The bee and hoverfly specimens were subsequently identified at the BTO headquarters in Thetford: hoverflies, bumblebees and honey bee were identified to the species level, but solitary bees (Andrenidae and Helictidae) were not identified further. Identification was conducted by an expert entomologist at the BTO.

The original Canadian protocol included net sampling of hoverflies, which consisted of a walk along the 50m transects at each point, capturing all hoverflies seen within 2m in a butterfly net. This was attempted in 2012 at the UK sites, but capture efficiency was low, especially where the vegetation was dense and/or rigid and there was concern about bias towards larger, slower species. This approach was, therefore, dropped from both the international protocol and the UK sampling after a consortium meeting in Autumn 2012 and is not considered further here.

<u>Ground (carabid) beetles and spiders</u>

These ground invertebrates were sampled using pitfall traps synchronized with the pan trapping. Two traps were set for each transect (four per point), one at 0 and one at 50m. Each trap consisted of a polystyrene cup (approx. 9cm in diameter and 11cm high) half-filled with water and a drop of detergent, set into the ground such that the lip was level with the soil surface and protected with a plywood roof on wire stakes that was set 1-2cm above the surface. Traps were set once in 2012 and twice in 2013, as with the pan traps; collection and identification also proceeded similarly. All carabids were identified to species, as were all adult spiders. Beetle identification was conducted the expert entomologist, but spiders were covered by a volunteer expert. Pressures on the volunteer's time meant that the processing of the 2013 spider samples was delayed and a small number were lost to desiccation before identification could be done.

<u>Butterflies</u>

In 2012, attempts were made to survey butterflies using the protocol used in Canada, namely using the same transects as were used for plants, recording all butterflies encountered within 5m of the transect line on two visits to each square and point. However, the species richness and abundance of butterflies in UK farmland are far lower than they are in Canada and encounter rates were prohibitively low, so no usable data were collected (all records were zeroes or sightings of the odd individual that was as likely to be passing through the survey area as actively using it and therefore subject to a high degree of stochasticity). The protocol was, therefore, changed for 2013, adding recording of all individuals seen during a 10-minute period walking along the transect lines, both inside the 5m buffer area and more broadly (in the area around the transect). Surveys were only conducted in suitable weather and butterflies were recorded separately in the crop and boundary vegetation, along with weather and basic cropping information. Two visits were made to three points in each square (May-June and July-August). Note that the encounter rate with butterflies remained low with this method, reflecting low butterfly densities relative to those in continental Europe, as well as in Canada, so the data collected are limited in quality. From a UK perspective, it would have been preferable to collect butterfly data in a different way, but this had to be traded off against the value of standardization across the wider consortium and available time and resources precluded additional UK-specific survey work.

<u>Boundary character</u>

The nature of the field boundary vegetation and its structure are likely to be important influences on all taxa surveyed, especially the more mobile animals and the species found along the boundary transect, so it may be important to apply appropriate controls during data analysis. Hence, key features of the field boundary adjacent to each survey point (i.e. along the 50m transect) were recorded. These features were: boundary type (solid hedge, gappy hedge, isolated bushes, herbaceous only [all with or without trees or a ditch], tree line or other), boundary width, boundary height, tree height, number of woody stems (estimated number of separate trees and bushes), key boundary plant species, sown margin width and the identities of the survey crop and that on the opposing side of the boundary.

<u>Farming practices</u>

An important potential influence on biodiversity, especially within crops, and therefore a factor that may need to be controlled in analyses, is the farming activity in the survey field, specifically the cropping practices employed. This may be particularly important for plants and ground invertebrates. As many farmers as possible who owned survey fields were therefore asked basic questions about agricultural practices, with the aim of at least characterizing average practices for each crop in the region for comparison with the other regions, internationally. For each crop in which surveys were conducted, farmers were asked:

(i) What rotation has been applied to this field in the last few years?

(ii) Approximately how many passes were made over the field with machinery (including soil preparation, sowing, inputs and harvest) in 2013?

(iii) What fertilizers did you use (chemical or organic) in 2013 and, if you can remember, on what dates were they applied?

(iv) What crop pests, if any, were you concerned about in this field in 2013?

(v) What type(s) of pesticides (herbicides, fungicides and/or insecticides) did you use in 2013 and, if you can remember, on what dates were they applied?

(vi) Were the seeds used coated with insecticide, fungicide or fertilizer?

(vii) Did you use any other weed or pest management measures?

These data have been submitted to the wider consortium for inclusion in the integrated, European-level analyses; consideration of these details was outside the scope of the preliminary analyses reported here. The wider analyses will consider farming-practice indicators informing about the nature and intensity of agricultural management.

UK data analysis

The principal aim of the UK work and this project in particular was to collect data to feed into the international consortium work, so only preliminary analyses are presented here. Further UK-specific analyses will be conducted during 2015, outside this project *per se*, and reporting will follow, together with the results of the integrated, Europe-wide project. These analyses will consider the dispersion of the data and other details of data structure to ensure that the final conclusions are not compromised by data issues.

To date, UK analyses have been conducted just to indicate the broad patterns of variation that occurred. Hence, broad, summary indices of the variation in the diversity of each taxonomic group considered have been analysed with respect to the target indices of farmland heterogeneity. Effects on each group were investigated using simple species richness and Simpson's diversity index. In both cases, "species" were defined for the diversity calculations as the maximum taxonomic resolution available from the identification processes. Thus, all animals and plants were considered at the species level except for bees (all solitary bees of the families Andrenidae or Helictidae considered as one "species") and immature spiders (which were identified only to the family level).

Indices for birds from the BBS-method surveys were calculated at the level of the whole 1km square, pooling all records after taking a maximum count per species across the two survey visits. For the other surveys, indices were calculated at the level of the survey point, these being treated as repeated measures of square-level values for the purposes of analysis. Further analyses, including the wider European data, will also consider beta-diversity (the complementarity of different survey locations within 1km squares in terms of generating square-level diversity), but this report considers only overall diversity values.

For these analyses, data were pooled at the point level, so species lists and relative abundances (for the Simpson's index) were constructed by combining records from individual pan traps, pitfall traps and sections of plant survey transect at each point location. However, data for the field edge and in-field (in-crop) traps and transects were analysed separately for bees, hoverflies, ground beetles, spiders and plants. For plants, "abundance" for diversity calculations was considered to be the percentage ground cover recorded in each section of transect (cover of sown crops was ignored). For birds (point counts) and butterflies, counts were summed per survey at each point and maxima taken across survey visits (where more than one count was undertaken).

Separate analyses were conducted for each study year, because the differences in square selection procedures between years meant that the annual samples could not usefully be considered to be replicates. Analyses were conducted using generalized linear mixed models, modelling species richness (count of species) with Poisson errors and a log link function and Simpson's index using an identity link and normal errors.

Parameter estimates then show the slope of the best-fitting linear relationship between the biodiversity response variable (species richness or Simpson's diversity) and increasing heterogeneity, i.e. conceptually equivalent to a simple linear regression. In practice, inference is best made on the basis of the sign (positive or negative) and significance (P-value, strength of confidence that the pattern is real). All models were fitted with the area of non-agricultural habitat in the survey square as a fixed control, to account for gross impacts of non-farmland factors. Where data were considered at the point level (all analyses except for the BBS bird tests), a random effect for "survey square" was used to account for the non-independence of survey points with squares. For the 2013 data, where two survey visits were available for each biodiversity target, a "survey point" random effect was nested within the square effect to account for the non-independence of repeat visits to the same survey point. For the pan trap, pitfall trap and plant data, survey point crop was included as an additional random effect because it is likely to provide an important influence on biodiversity local to survey points. It would be beneficial also to investigate the effects of further possible confounding factors, such as the field boundary structure local to survey points and details of farming practices such as pesticide use, as further controls, but there would be a concomitant analytical cost in loss of power due to the incorporation of more parameters in the models. Such more complex models would therefore best be fitted using larger data sets integrated across Europe. In the models fitted here, the effects of heterogeneity were assessed for each group by fitting separate models incorporating the indices of compositional and configurational heterogeneity that were measured in the field as continuous, fixed effects, and testing their significance using F-tests. All analyses were conducted using the GLIMMIX procedure in SAS 9.2 (SAS Institute, Inc. 2008).

Results

Summaries of the biodiversity collected for sharing with the wider European project are presented in Appendix 2 and summary statistics are shown in Table 2, with the intention of aiding interpretation of the statistical results and model parameter estimates reported below. Note that identification and processing of the spider data from 2013, which have been dependent on volunteer input from a taxon expert, have yet to be completed, so the test results presented are subject to change when more data are available. The data on farming practices collected from 22 farmers in the study areas, covering 73 study fields, are collated in Appendix 3. These data have not been analysed, but will be passed (anonymized) to our international collaborators for use in the integrated analyses.

Table 2. Summary statistics of species richness and Simpson's diversity variables for each taxon, year and (for all groups except birds and butterflies) location (edge or in-field). All statistics refer to whole survey squares, so the data were averaged across survey points in each square before calculating the values shown here.

Taxon	Trap Location	Mean	Minimum	5% CL	Median	95% CL	Maximum
Species Richness - 2012							
Birds - BBS		37.47	28.00	29.00	38.50	50.00	54.00
Birds - point counts		14.10	7.75	10.75	13.38	18.25	28.75
Bees	edge	3.05	1.00	1.00	3.00	5.67	6.00
Bees	field	2.51	0.00	1.00	2.33	5.67	7.00
Carabids	edge	3.77	0.50	0.75	3.33	8.00	17.00
Carabids	field	3.38	0.50	0.67	2.50	6.67	10.67
Plants	edge	22.83	8.25	8.50	22.38	37.25	39.00
Plants	field	10.12	0.50	1.00	7.13	28.50	32.75
Spiders	edge	24.82	0.00	1.25	33.75	45.00	45.00
Spiders	field	23.08	0.00	0.75	22.75	45.00	49.25
Syrphids	edge	2.44	0.00	0.67	2.00	5.50	12.33
Syrphids	field	1.83	0.00	0.00	1.50	4.50	9.00

Table 2, continued

Taxon	Trap Location	Mean	Minimum	5% CL	Median	95% CL	Maximum
Species Richness - 2013							
Birds - BBS		31.07	19.00	22.00	31.00	37.00	40.00
Birds - point counts		37.43	19.00	22.38	37.25	52.88	58.00
Bees	edge	4.42	1.33	2.17	3.80	9.20	10.83
Bees	field	3.43	0.83	1.33	3.33	6.50	7.33
Butterflies		2.66	0.43	0.50	2.67	4.83	6.00
Carabids	edge	3.73	0.17	1.17	3.33	6.67	7.83
Carabids	field	2.85	0.83	1.00	2.83	5.17	6.00
Plants	edge	18.95	4.17	5.25	17.06	37.75	37.88
Plants	field	6.23	0.00	1.25	5.50	14.25	16.88
Spiders	edge	2.64	0.50	1.00	2.80	4.83	5.33
Spiders	field	2.08	0.67	0.67	2.00	4.00	4.33
Syrphids	edge	1.59	0.00	0.00	1.42	3.67	4.00
Syrphids	field	1.27	0.00	0.00	1.00	3.50	3.67
Simpson's Diversity - 2012							
Birds - BBS		11.94	4.90	5.73	12.23	18.32	18.63
Birds - point counts		8.77	4.39	4.93	8.62	13.27	17.54
Bees	edge	2.24	0.93	1.00	2.28	3.96	3.99
Bees	field	2.03	0.00	0.76	1.99	3.66	5.72
Carabids	edge	2.47	0.50	1.00	2.44	3.65	6.90
Carabids	field	2.18	0.50	0.60	1.75	4.20	5.26
Plants	edge	7.50	4.94	5.35	6.57	12.79	15.56
Plants	field	6.39	4.83	5.03	5.28	13.57	15.26
Spiders	edge	2.75	0.33	0.46	2.38	6.34	7.34
Spiders	field	2.24	0.00	0.00	1.94	4.92	5.37
Syrphids	edge	1.75	0.00	0.33	1.60	3.48	6.48
Syrphids	field	1.31	0.00	0.00	1.00	3.79	4.52
Simpson's Diversity - 2013							
Birds - BBS		9.39	1.82	2.27	10.44	14.03	16.50
Birds - point counts		28.40	17.16	19.34	28.52	38.79	41.91
Bees	edge	3.64	1.33	1.89	3.24	7.49	8.79
Bees	field	2.96	0.83	1.33	2.77	4.43	6.33
Butterflies		2.03	0.35	0.43	2.03	3.54	4.20
Carabids	edge	2.80	0.17	0.86	2.76	4.75	5.47
Carabids	field	2.20	0.59	0.90	2.37	3.49	4.10
Plants	edge	6.82	4.90	4.90	6.64	10.92	12.65
Plants	field	5.34	4.40	4.74	4.99	7.10	8.55
Spiders	edge	2.24	0.5	0.91	2.38	3.49	3.90
Spiders	field	1.87	0.63	0.67	1.76	3.26	4.15
Syrphids	edge	1.28	0.00	0.00	1.24	3.05	3.31
Syrphids	field	1.08	0.00	0.00	0.86	2.83	2.90

Table 3. Relationships between compositional heterogeneity and species richness for different aspects of farmland biodiversity. Note that butterfly surveys were not conducted in 2012.

		2012		2013	
Group		Parameter estimate (SE)	F-test result	Parameter estimate (SE)	F-test result
Birds (BBS)		-0.1844 (0.2665)	$F_{1,27}$=0.48, P= 0.495	0.6003 (0.5595)	$F_{1,27}$=1.15, P=0.293
Birds (point counts)		-0.2529 (0.3730)	$F_{1,90}$=0.46, P=0.500	-1.3115 (0.5085)	$F_{1,118}$=6.65, P=0.011
Butterflies				1.9540 (1.3557)	$F_{1,68}$=2.08, P=0.154
Bees	Edge	3.3976 (1.7597)	$F_{1,39}$=3.73, P=0.061	-3.5355 (1.1689)	$F_{1,86}$=9.15, P=0.003
	In	2.6957 (1.9392)	$F_{1,42}$=1.39, P=0.172	-1.5356 (1.1057)	$F_{1,86}$=1.93, P=0.169
Hoverflies	Edge	3.4736 (2.1768)	$F_{1,40}$=2.55, P=0.118	-1.6629 (1.9531)	$F_{1,86}$=0.72, P=0.397
	In	3.2216 (1.9638)	$F_{1,43}$=2.69, P=0.108	-1.9014 (2.3535)	$F_{1,86}$=0.65, P=0.421
Ground beetles	Edge	0.4939 (0.6730)	$F_{1,47}$=0.54, P=0.467	-0.6759 (0.9965)	$F_{1,86}$=0.46, P=0.499
	In	-0.1579 (0.8603)	$F_{1,45}$=0.03, P=0.855	-1.6818 (1.0289)	$F_{1,86}$=2.67, P=0.106
Spiders	Edge	2.5469 (2.9754)	$F_{1,74}$=0.86, P=0.395	6.7916 (2.4212)	$F_{1,86}$=7.87, P= 0.006
	In	1.7216 (1.6745)	$F_{1,74}$=1.06, P=0.307	-0.9287 (2.5386)	$F_{1,86}$=0.13 , P=0.715
Plants	Edge	-1.1664 (0.8383)	$F_{1,74}$=1.94, P=0.168	2.7669 (1.1762)	$F_{1,103}$=5.53, P=0.021
	In	-1.9984 (1.2689)	$F_{1,74}$=2.48, P=0.120	0.8874 (1.7646)	$F_{1,103}$=0.25, P=0.616

Table 4. Relationships between configurational heterogeneity and species richness for different aspects of farmland biodiversity.

		2012		2013	
Group		Parameter estimate (SE)	F-test result	Parameter estimate (SE)	F-test result
Birds (BBS)		0.000004 (0.000011)	$F_{1,27}$=0.20, P=0.657	0.000007 (0.000012)	$F_{1,27}$=0.32, P=0.578
Birds (point counts)		0.000034 (0.000013)	$F_{1,89}$=6.55, P=0.012	-0.000002 (0.000011)	$F_{1,119}$=0.03, P=0.871
Butterflies				0.000008 (0.000026)	$F_{1,68}$=0.10, P=0.751
Bees	Edge	0.000035 (0.000080)	$F_{1,39}$=0.19, P=0.663	0.000003 (0.000025)	$F_{1,86}$=0.02, P=0.901
	In	0.000043 (0.000085)	$F_{1,42}$=0.26, P=0.612	0.000024 (0.000022)	$F_{1,86}$=1.22, P=0.273
Hoverflies	Edge	0.000078 (0.000094)	$F_{1,40}$=0.68, P=0.414	0.000037 (0.000038)	$F_{1,86}$=0.96, P=0.330
	In	0.000025 (0.000088)	$F_{1,43}$=0.08, P=0.775	0.000069 (0.000044)	$F_{1,86}$=2.53, P=0.115
Ground beetles	Edge	-0.00004 (0.000033)	$F_{1,47}$=1.44, P=0.236	-0.00002 (0.000022)	$F_{1,86}$=0.57, P=0.450
	In	-0.00004 (0.000038)	$F_{1,45}$=1.30, P=0.261	0.00023 (0.000022)	$F_{1,86}$=1.02, P=0.316
Spiders	Edge	0.000024 (0.000127)	$F_{1,73}$=0.04, P=0.850	-0.00006 (0.000052)	$F_{1,86}$=1.49, P=0.226
	In	0.000014 (0.000072)	$F_{1,73}$=0.04, P=0.843	-0.00005 (0.000053)	$F_{1,86}$=0.93, P=0.336
Plants	Edge	0.000043 (0.000036)	$F_{1,73}$=1.45, P=0.233	0.000022 (0.000023)	$F_{1,103}$=0.97, P=0.335
	In	0.000109 (0.000052)	$F_{1,73}$=4.37, P=0.040	0.000037 (0.000033)	$F_{1,103}$=1.24, P=0.268

Within the UK biodiversity data, the preliminary analyses revealed only a few clear patterns for associations between farmland heterogeneity indices and biodiversity measures in either year, and those patterns were not consistent in direction. Compositional heterogeneity (the Shannon index of crop cover diversity) was positively associated with plant and spider species richness at field edges in 2013 and (near-significantly) with bee richness at field edges in 2012, but was negatively associated with the latter measure and bird richness (from point counts) in 2013 (Table 3).There were only two associations between configurational heterogeneity (the total length of agricultural boundaries) and species richness, both in 2012: a positive relationship involving bird assemblages, measured using point counts, and a positive relationship with in-field plant assemblages (Table 4).

There was a similar number of significant associations between diversity and heterogeneity. Ground beetles in field edges and in-field plants (near-significantly) were negatively associated with compositional heterogeneity in 2012, but bees and spiders in field edges and butterflies (near-significantly) showed positive associations in 2013 (Table 5). Then, the same patterns apparent with species richness (Table 4) were detected again: positive associations with bird point count and in-field plant diversity (Table 6).

Table 5. Relationships between compositional heterogeneity and Simpson's diversity index for different aspects of farmland biodiversity.

		2012		2013	
Group		Parameter estimate (SE)	F-test result	Parameter estimate (SE)	F-test result
Birds (BBS)		3.9536 (6.4229)	$F_{1,27}$=0.38, P=0.543	1.9798 (12.2702)	$F_{1,27}$=0.03, P=0.873
Birds (point counts)		-3.0038 (4.4080)	$F_{1,90}$=0.46, P=0.497	-17.8893 (13.3851)	$F_{1,118}$=1.79, P=0.184
Butterflies				5.3016 (2.7445)	$F_{1,68}$=3.73, P=0.058
Bees	Edge	0.1063 (1.3817)	$F_{1,38}$=0.01, P=0.939	12.1740 (3.8373)	$F_{1,84}$=10.06, P=0.002
	In	-0.3160 (1.6558)	$F_{1,41}$=0.04, P=0.850	-2.5328 (3.0685)	$F_{1,85}$=0.68, P=0.411
Hoverflies	Edge	1.6381 (1.9829)	$F_{1,38}$=0.68, P=0.414	-2.3271 (2.2694)	$F_{1,84}$=1.05, P=0.308
	In	0.1519 (1.5831)	$F_{1,41}$=0.01, P=0.924	-0.9257 (2.0768)	$F_{1,85}$=0.20, P=0.657
Ground beetles	Edge	-4.0660 (1.7906)	$F_{1,43}$=5.16, P=0.028	-0.7534 (2.6983)	$F_{1,85}$=0.08, P=0.781
	In	-3.0052 (1.8210)	$F_{1,44}$=2.72, P=0.106	-2.9042 (1.9991)	$F_{1,85}$=2.11, P=0.150
Spiders	Edge	-1.9014 (2.9926)	$F_{1,38}$=0.40, P=0.529	4.6130 (1.8599)	$F_{1,85}$=6.15, P=0.015
	In	-0.05804 (2.2518)	$F_{1,42}$=0.00, P=0.980	-0.6482 (1.7827)	$F_{1,85}$= 0.13, P=0.717
Plants	Edge	-3.4206 (2.9598)	$F_{1,73}$=1.34, P=0.252	4.5670 (5.4329)	$F_{1,81}$=0.71, P=0.403
	In	-3.3456 (1.8186)	$F_{1,74}$=3.38, P=0.070	-2.0614 (2.1350)	$F_{1,91}$=0.93, P=0.337

Table 6. Relationships between configurational heterogeneity and Simpson's diversity index for different aspects of farmland biodiversity.

		2012		2013	
Group		Parameter estimate (SE)	F-test result	Parameter estimate (SE)	F-test result
Birds (BBS)		0.000022 (0.000272)	$F_{1,27}$=0.01, P=0.936	-0.00028 (0.000257)	$F_{1,27}$=1.19, P=0.280
Birds (point counts)		0.000430 (0.000168)	$F_{1,89}$=6.55, P=0.012	0.000065 (0.000288)	$F_{1,119}$=0.05, P=0.822
Butterflies				0.000033 (0.000050)	$F_{1,68}$=0.43, P=0.516
Bees	Edge	0.000006 (0.000059)	$F_{1,39}$=0.01, P=0.922	0.000008 (0.000082)	$F_{1,86}$=0.01, P=0.918
	In	0.000020 (0.000070)	$F_{1,42}$=0.08, P=0.779	0.000065 (0.000060)	$F_{1,86}$=1.16, P=0.285
Hoverflies	Edge	0.000027 (0.000085)	$F_{1,39}$=0.10, P=0.749	0.000026 (0.000047)	$F_{1,86}$=0.30, P=0.583
	In	-0.00005 (0.000066)	$F_{1,42}$=0.58, P=0.452	0.000037 (0.000042)	$F_{1,86}$=0.78, P=0.380
Ground beetles	Edge	-0.00006 (0.000082)	$F_{1,43}$=0.62, P=0.436	-0.00001 (0.000057)	$F_{1,86}$=0.04, P=0.840
	In	-0.00011 (0.000079)	$F_{1,44}$=1.77, P=0.190	0.000043 (0.000041)	$F_{1,86}$=1.12, P=0.292
Spiders	Edge	-0.00010 (0.000125)	$F_{1,39}$=0.77, P=0.447	-0.00005 (0.000040)	$F_{1,86}$=1.69, P=0.197
	In	-0.00010 (0.000093)	$F_{1,41}$=1.19, P=0.281	-0.00004 (0.000037)	$F_{1,86}$=0.90, P= 0.345
Plants	Edge	0.000071 (0.000126)	$F_{1,72}$=0.32, P=0.575	0.000083 (0.000102)	$F_{1,81}$=0.67, P=0.417
	In	0.000132 (0.000069)	$F_{1,73}$=3.64, P=0.060	0.000026 (0.000043)	$F_{1,91}$=0.38, P=0.542

Discussion

It must be stressed that the results presented above are strictly preliminary because they fundamentally represent just a contribution to a wider project, but some general conclusions can be drawn. First, although large numbers of significant results were not found, there were sufficient to suggest that the study design provides sufficient power to reveal relationships should they exist. Second, contrary to some older research (e.g. Benton et al. 2003), the results support more recent studies that suggest that greater heterogeneity in cropping or land-use is not necessarily a positive influence on biodiversity (e.g. Pickett & Siriwardena 2011). Third, again echoing some recent work, effects of heterogeneity can be complex and variable between different taxonomic groups. Beyond these concepts, it would be unwise to interpret the results in great detail before final analyses have been conducted across Europe and more comprehensive sets of controls have been applied.

In particular, pan-European data are expected to provide greater power, not just because there will be longer gradients of heterogeneity and land-use type, but also because biodiversity variables such as numbers of invertebrate species potentially found on farmland, which can be much greater in warmer climates further south, should vary over larger ranges. As a general rule, lower power might also be expected for in-field tests, because biodiversity within crops is often rather low, so the larger samples needed to detect effects may require internationally collated data. However, given the larger data sets, any patterns that exist may also be clearer than those in field edges because they should be influenced little by variations in local field boundary habitat.

It is not surprising that the relationships found contrasted between years, because the 2012 and 2013 survey squares were selected to have completely different covers of non-agricultural habitat. Moreover, heterogeneity within farmland might be expected to have different effects on biodiversity dependent upon the landscape context and therefore the availability of non-farm habitats nearby (whether they be positive or negative influences). Such non-linearities may be reflected in those patterns that are very inconsistent between 2012 and 2013 in this study.

All analyses reported here considered simple, assemblage-level indices of biodiversity. Clearly, these assemblages, even when constrained to a particular taxonomic group, consist of individual species, each of which probably interacts differently with environmental variation. Hence, the broad indices represent blunt instruments for characterizing effects of such variation and further effects might be apparent if individual species or smaller, functional groups of species were considered instead. In particular, it would be instructive to separate those species expected to benefit more from more heterogeneous landscapes from those that might do less well, perhaps because they respond to large expanses of homogeneous habitat. Such subtleties of response are obscured in multi-species indices, but may be critical to understanding general effects on biodiversity, especially if species with different types of response tend to have different levels of conservation priority. In addition, differences in assemblage composition with respect to the types of response to heterogeneity may explain variation in the patterns seen for species richness or diversity in different landscape contexts. More sophisticated, species-specific, analyses of the data collected here will follow outside this specific project.

One weakness with the assessment of biodiversity was that solitary bees (especially the species-rich Andrenidae) were not identified to species. This occurred because suitable keys for solitary bee identification were not available and because the sample processing required (e.g. dissection of genitalia) would have been prohibitively resource-intensive. It is likely that overall bee diversity was under-estimated significantly as a result, so various effects of heterogeneity on this group may have been missed. However, individual solitary bee species are, numerically, generally relatively rare compared to honey bees and bumblebees, so may be unlikely to provide a significant pollination service. Future work using the data collected for this project will attempt to investigate what can be done with the simple count data for solitary bees as a group in more detail, while some of the BiodivERsA farmland regions have also identified this group to species, so results will be available considering diversity more completely for a subset of the habitat range in the full project.

It may be surprising that the patterns revealed by bird point counts and BBS transects were not more similar. Both nominally sample the 1km square in standardized ways, but a key difference is that the point counts were targeted on specifically farmed areas, whereas the transects sampled squares more completely. This is likely to have affected assemblage indices particularly strongly because habitats such as gardens, scrub and woodland are likely to influence the species lists detected disproportionately to their area due to their value as bird habitat relative to open farmland. The point counts, being time- and space-limited, are also more standardized than transects: they are therefore less subject to variations such as those due to walking pace, for example, which might vary unavoidably with terrain or habitat and thus affect survey results. Closer agreement between the surveys might be provided by a focus on farmland-associated species, as opposed to total bird communities, or by dividing the BBS records by habitat. These options will be addressed in future research as part of investigations into the generalization of the results for non-avian taxa across the UK BBS data set and spatial extent.

Work Package 2 – Objectives 3 & 4.

Objective 3 – To investigate the influence of heterogeneity on ecosystem service provision

Introduction

Two experimental approaches were used to assess variation in ecosystem service delivery in the sample landscapes considered, investigating the predation of crop pests and pollination efficiency. Both experimental approaches were designed as assays of the potential services provided, not as direct measurements of any benefits received by the crops considered. This means that each experimental set-up could be used equally meaningfully in any cropping context.

Methods

Predation of crop pests

The potential of local predator communities to control crop pests was investigated by presenting aphids, under controlled conditions and for a set period of time, within the crop at the three survey locations in each square at which invertebrate trapping was carried out and, where possible, at the same time. Green pea aphids *Acyrthosiphon pisum*, raised and maintained on bean plants, were obtained from the John Innes Centre, Norwich, in both years. In 2012, the original Canadian protocol was followed, in which ten live aphids were attached to one side of pieces of cardboard (c. 10cm long) with eyelash glue. At each survey point, along the in-field transect, three of these cards were then folded into a tent (inverted V) shape and placed on the ground, with the glued aphids facing downwards, so that ground dwelling arthropod predators can detect them. The aphid cards were then retrieved after 24 hours, the number of aphids predated counted and the percentage of surviving aphids calculated. In 2013, after discussions amongst the wider consortium, aphids were frozen instead of being kept alive and ten cards each with three aphids attached were used (instead of three cards of ten). In both years, the aim was to conduct two aphid trials at each survey square, but problems with aphid supply and maintenance in 2012 limited the number of second visits that could be conducted. Two trials were completed in 2013, however (May to mid-June and mid-June to July).

Preliminary analyses to date have considered the influences of the two key variables describing compositional and configurational heterogeneity on predation probability. The models employed were similarly structured to those used for the biodiversity analyses, considering crop and survey point, nested within 1km square, as random effects and controlling for the area of non-agricultural habitat. Data points were numbers of aphids predated out of the three or ten on each card recovered, so the models were fitted using an events/trials syntax, using logit link and binomial errors. Significance was tested using F-tests.

Pollination potential

Pollination was investigated using a phytometer experiment. This logistically demanding protocol involved presenting pots of flowering plants at the survey points in each square for four days, ideally synchronized with the pollinator sampling. Only the local pollinator community could pollinate these flowers. Individual flowers were marked to identify those that opened or finished flowering before or during the period over which they were in the field. The relative numbers of seeds set from differently marked flowers then provided an index of pollination effectiveness local to the survey point.

Only small-scale trials of the pollination protocol were possible in 2012, due to logistical constraints. These involved sowing pots of radish *Raphanus sativus*, mustard *Sinapis alba* and poppy *Papaver rhoeas* and revealed good flowering and seed set in mustard and poppy, but problems with caterpillar infestation after flowering in radish. Nevertheless, discussion with the other consortium partners, including several researchers who are expert in phytometer experiments led to decision to focus on radish and cornflower *Centaurea cyanus* in 2013, with seeds supplied free of charge by Göttingen University (Germany). These species do not self-fertilize.

Seeds of radish and cornflower were sown in March 2013 and grown to flowering in June/July. The radish plants were initially more successful and a number of cornflowers were lost to a brood of pheasants that infiltrated the nursery area. Radishes could, therefore, be deployed at more sites than cornflowers. The plants were grown on and deployed as groups of three, similarly sized plants in 3l pots, with two pots of each species deployed simultaneously at each survey point where invertebrate trapping was conducted. Flowering plants were deployed as they became available, in survey squares where the invertebrate trapping was occurring at the same time. Thus, squares visited later in the season were more likely to have both plant species deployed. Plants were left in the field for four days, with every effort made to ensure an adequate water supply (including a water-retaining soil supplement). However, hot weather in July 2013 challenged the plants at several sites and logistics did not permit additional site visits to water them, so some plants were lost. Overall, 16 survey squares were sampled effectively with the radish phytometer and six with the cornflower one. The latter sample was too small for meaningful tests to be conducted for the UK alone, but the data will still contribute to the international, integrated study.

The radish flowers tended to last for around two days. Hence, it was common for flowers to open and die while plants were deployed, as well as to have opened before deployment and to be spent while in the field, or to have opened in the field and still to be open on retrieval. Flowers were marked differently for these three scenarios; it was not possible to isolate plants in the nursery area from pollinators, so the first category provided the best data pollination potential in the survey squares and this was reflected in the data analyses conducted. Cornflower flowers lasted longer, so such a clear classification was not possible, but flowers were, nevertheless, classified according to timing of opening and closing relative to deployment in the field. Numbers of flowers on plants of each species in each category of opening/closing time were recorded on deployment and retrieval.

After retrieval from the field, plants were returned to the nursery area and grown on to seed set. At the end of summer 2013, seed pods (on radish plants) and flower heads (cornflowers) were harvested and the seeds within counted when time allowed. For both species, as well as larger, apparently viable seeds, it was common to find undersized seeds in the pods/flower heads. These were also counted, but excluded from analysis.

Only preliminary analyses have been conducted to date for the UK (radish) data, but consisted of models of seed production per flower as a function of heterogeneity and key control variables. Numbers of seeds in pods produced by flowers that were exposed to potential pollination in the field formed response variables. Models were fitted treating each seed pod as a data point and summing the numbers of seeds produced per plant. All models fitted used a similar structure to those used for the biodiversity analyses, i.e. Generalized Linear Mixed Models incorporating sample point, nested within survey square identity, and crop type as random effects. A control for the area of non-agricultural habitat in the square was included, together, in the models using total seed numbers, with a second control for number of flowers exposed in the field. Predictor variables considered were the two key variables describing compositional and configurational heterogeneity and significance was tested using F-tests. In summary, the heterogeneity variables were fitted as predictors separately and their effects investigated by comparing models including them and the control and point/square random effect variables with models omitting them but retaining the rest of the variables. Thus, the analyses considered heterogeneity effects after accounting for the other, potentially confounding influences, and avoiding pseudoreplication from treating correlated data as independent samples.

Results

<u>Predation of crop pests</u>

The patterns of effect of heterogeneity differed between years, as might be expected given the likely variable additive effects of different types of habitat heterogeneity in different landscape contexts, where there will be correspondingly variable ambient communities of predators. In 2012, there was no significant relationship with compositional heterogeneity (Shannon habitat diversity parameter estimate (SE) = 1.41 (2.12), $F_{1,290}$=0.44, P=0.507), but a significant, positive association with the total length of agricultural boundary (parameter estimate (SE) = 0.00017 (0.00008), $F_{1,291}$=4.93, P=0.027). In 2013, the pattern was reversed, with no significant association being found with configurational heterogeneity (total length of boundary parameter estimate (SE) = 0.00002 (0.00005), $F_{1,1658}$=0.09, P=0.760) but a significant, positive effect of the Shannon index of compositional heterogeneity (parameter estimate (SE) = 6.33 (2.56) , $F_{1,1658}$=6.12, P=0.013).

It would be unwise to regard these results as definitive, because further controls and broader integration of the international data sets may change the patterns seen (as described above for biodiversity). However, they suggest that the data provide sufficient power to reveal relationships between heterogeneity and aphid predation and the results are indicative of positive effects, although there are indications that these effects are strongly context-specific.

<u>Pollination potential</u>

There was no effect of farmland compositional heterogeneity (the Shannon index) on pollination potential, but strong, positive effects of configuration (total boundary length) were found in both forms of analysis (Table 6). As elsewhere, it would be unwise to regard these results as definitive and they form only part of the larger, international picture, wherein more sophisticated analyses can be conducted, for example considering only flowers that opened and closed while plants were exposed in the field (as opposed to pooling all flowers exposed to some extent). A further caveat is that it was not possible to exclude the plants from pollinators completely before and after deployment to the field. There is no reason why this should have biased the results with respect to heterogeneity analyses because all plants were kept together, but it may have introduced noise and reduced power to detect effects, via pollination influences on flowers that opened before, or closed after, deployment. Nevertheless, the results are indicative of a role for configurational heterogeneity in determining pollination effectiveness, at least in a highly agricultural landscape context.

Table 6. Relationships between farmland heterogeneity and radish seed production.

Heterogeneity variable	Parameter estimate (SE)	F	DF	P
Individual seed pods				
Shannon - composition	-1.94 (1.22)	2.51	1,607	0.113
Total boundary length – configuration	0.000060 (0.000027)	4.89	1,608	0.028
Seeds pooled per plant				
Shannon - composition	-1.53 (2.60)	0.34	1,89	0.559
Total boundary length – configuration	0.000147 (0.000053)	7.73	1,89	0.007

Objective 4 – To investigate relationships between elements of biodiversity providing different ecosystem services

This project provides unique, comparable data on multiple taxa in farmland for the same study locations and at the landscape scale. It therefore provides new opportunities to investigate the inter-relationships between the taxa that deliver different ecosystem services in the farmed environment. In general, carabid (ground) beetles and spiders potentially provide a pest control service, bees and syrphid flies (hoverflies) may be important for crop pollination and arable plants support the populations of pollinators and predators, while birds, butterflies and plants provide a cultural or aesthetic service. Management options to promote multiple elements of this matrix of service benefits and providers would be valuable tools in designing future agricultural landscapes for multiple objectives. Note that it was beyond the scope of this project to consider the details of the delivery of services by each group, so inter-relationships between the groups that deliver the services, rather than between the services themselves, were the focus. The delivery of aspects of pollination and pest control were considered under Objective 3, but this work covered specific examples of these services (pollination of two plant species and predation of one potential pest), rather than a general summary of relevant effects.

To investigate where such potential multiple benefits might be realized by manipulations of farmland heterogeneity, the results of the biodiversity analyses under Objective 2 were used to investigate the inter-relationships between summary indices for the key taxonomic groups. Thus, abundance, species richness and diversity indices for birds, butterflies, bees, syrphids, carabids, spiders and plants were modelled against one another. All species recorded in each group were considered, except for birds, for which only species on the red and amber lists, denoting high and moderate conservation concern (see Appendix 2), were included in the index calculations (reflecting values held by human society). The dependence of the relationships revealed was then also investigated.

As elsewhere in this study, the results should be regarded as preliminary and the data as merely a part of those contributing to the wider international project. In this specific context, future analyses will consider refinement of the species lists considered for each group specifically to consider taxa more likely to provide particular services, such as predation of particular pest species or pollination of particular crops. In addition, associations involving particular individual species or genera providing specific services can be considered. These might include scavenging birds of the Corvidae, which potentially provide an important waste disposal service.

Methods

To produce spatially and temporally comparable indices of the diversity of each group, the data described under Objective 2 above were summarized and re-analysed at the sample point level. Maximum counts were therefore calculated per point, across survey visits, for birds (point counts) and butterflies, average cover per visit was calculated for plants and the total count of individuals was calculated for bees, syrphids, carabids and spiders. These data were then used to calculate species richness, Simpson's diversity index and total abundance/cover for each group at each point. Total abundance was added to the diversity indices because service provision is often likely to be determined by quantities of key animals or plants, rather than their diversity.

The analyses were conducted in two stages. First, each of each type of index was modelled as a linear function of each other index of that type, e.g. bird species richness as a function of butterfly species richness, etc.. Then, a main effect for one of the two key heterogeneity indices (Shannon habitat composition and configuration revealed by the total length of boundaries) was added, along with an interaction between this index and the biodiversity variable being considered as a predictor. The significance of the interaction term therefore indicated whether amounts of habitat heterogeneity modified the relationship between the two biodiversity variables: a positive parameter estimate would suggest that increasing farmland heterogeneity could enhance both groups synergistically. Analyses were conducted using Generalized Linear Models in SAS (SAS Institute, Inc. 2008), modelling each variable with an appropriate link function and error distribution (log and Poisson for species richness and total abundance, identity and normal for Simpson's diversity), and allowing for repeated measures among the four points in each square. Significance was assessed using score tests.

Results

There were several significant associations between the indices summarizing the assemblages in different groups that were recorded and almost all of these were positive (Tables 7-9), indicating that high diversity or abundance of certain groups tended also to be associated with high diversity or abundance of other groups. As would be expected, where a given index for a given group "A" was a significant predictor of variation in group "B", the converse was also usually true (although the patterns were not exactly symmetrical because of the controls applied in each model: the parameter estimates in the tables are not simple correlation coefficients). Across indices and the two study years, the strongest associations were between the two groups of pollinators, which were reciprocal, positive predictors of one another in respect of species richness, diversity and total abundance in one or both years (Tables 7-9). This pattern may show common responses to the quantity and diversity of floral resources. The lack of associations with the plants themselves in this analysis may not be inconsistent, because floral resources represent only a subset of the plant community present. Further analysis may reveal such connections more clearly by considering only plants selected for particular characteristics, such as flowering or native species. In general, plant diversity may be a parsimonious indicator of local land-use (agricultural) intensity, as s proxy for the combined effects of fertilizer and herbicide, or other weed control, use. This will be considered in more detail (for example, considering the omission of species that respond positively to high nitrogen levels) in future analyses.

Spiders and carabids were positively associated with one another in 2012, particularly in respect of diversity and abundance (Tables 7-9), perhaps reflecting common dependence on soil surface habitat conditions beneath crops. There were also reciprocal positive associations between butterfly and plant species richness and bird and butterfly diversity in 2013, as well as a weak such relationship between bee and carabid total abundance in 2012 (Tables 7-9). These patterns may be more noteworthy because they involve groups sampled in different ways and so reflect broader common influences of environmental variation, although associations between bees/syrphids and carabids/spiders may be promoted by the precise spatio-temporal coincidence of the sampling for these groups. Rather specific elements of the habitat can vary to drive common changes in ecologically similar components of the community, such as floral resources and pollinator groups, such that each group is a good indicator of the other. However, for more ecologically different groups to co-vary implies more general variation in environmental quality. Birds and butterflies respond to the environment at somewhat larger scales than most of the other groups, so common responses to environmental variation with these other groups might not be expected, unless the latter variation is even with respect to scale. However, the bird-butterfly relationship may reflect environmental conditions at the larger spatial scales, suggesting different roles for different taxa as indicators of biodiversity at different scales. The association between butterflies and plants suggests that plant resource richness can be a significant predictor of habitat suitability for butterflies, perhaps reflecting the availability of larval and nectar food resources. In general, the differences between the results from 2012 and 2013 suggest dependence on landscape context may be important, i.e. perhaps that different factors are important where there are different amounts of non-agricultural habitat.

Table 7. Relationships between the species richness of different groups in (a) 2012 and (b) 2013. Figures show parameter estimates for the effects of the *predictors* on the *responses*. Figures in bold are statistically significant at P<0.05 and those in italics at P<0.1.

(a)	Predictors					
Responses	Bees	Birds	Carabids	Plants	Spiders	Syrphids
Bees		-0.031	0.022	0.017	*-0.008*	*0.052*
Birds	-0.030		-0.014	-0.006	0.000	0.012
Carabids	0.064	-0.035		0.001	-0.011	0.021
Plants	0.076	-0.027	0.021		0.000	0.017
Spiders	-0.002	0.000	*0.005*	*0.003*		0.000
Syrphids	*0.081*	0.021	0.022	0.004	0.000	

(b)	Predictors					
Responses	Bees	Butterflies	Birds	Carabids	Plants	Syrphids
Bees		0.0060	0.0149	0.0038	0.0019	**0.0560**
Butterflies	0.0304		0.0373	0.0246	**0.0218**	-0.0488
Birds	0.0135	0.0003		0.0120	0.0043	-0.0005
Carabids	0.0173	0.0247	0.0245		0.0078	-0.0113
Plants	0.0293	**0.0944**	*0.0598*	0.0431		-0.0438
Syrphids	**0.1105**	-0.0432	-0.0110	-0.0123	-0.0119	

Table 8. Relationships between the Simpson's diversity index of different groups (a) 2012 and (b) 2013. Figures show parameter estimates for the effects of the *predictors* on the *responses*. Figures in bold are statistically significant at P<0.05 and those in italics at P<0.1.

(a)	Predictors					
Responses	Bees	Birds	Carabids	Plants	Spiders	Syrphids
Bees		-0.084	0.103	0.008	0.033	0.196
Birds	-0.120		-0.095	-0.028	-0.048	-0.030
Carabids	0.360	-0.294		0.069	**0.380**	0.145
Plants	-0.066	-0.127	0.110		0.016	0.010
Spiders	0.152	-0.198	**0.461**	-0.006		0.119
Syrphids	*0.221*	-0.022	0.089	0.003	0.048	

(b)	Predictors					
Responses	Bees	Butterflies	Birds	Carabids	Plants	Syrphids
Bees		-0.0202	0.0678	-0.0077	0.0284	**0.3280**
Butterflies	-0.0094		**0.4094**	0.0684	-0.0887	-0.0968
Birds	0.0638	*0.1996*		-0.0624	0.0163	-0.0256
Carabids	-0.0246	0.1471	-0.0677		-0.0131	0.0290
Plants	-0.0310	-0.1127	0.0707	-0.0048		0.1121
Syrphids	**0.2773**	-0.0389	0.0039	0.0085	0.0160	

Patterns of variation with respect to the effects of interactions with heterogeneity were less clear, with fewer significant, reciprocal effects. Full results are provided in Appendix 4; positive associations suggest that the two groups concerned were more diverse or abundant where farmland heterogeneity was higher, while negative relationships suggest that greater heterogeneity has an opposite effect on the two groups concerned. Therefore, the results should indicate where increasing heterogeneity could multiply ecosystem service co-benefits and where it might reduce the co-occurrence of different groups, suggesting that independent management solutions would be required to promote different service types.

Table 9. Relationships between the total sampled abundance of different groups in (a) 2012 and (b) 2013. Figures show parameter estimates for the effects of the *predictors* on the *responses*. Figures in bold are statistically significant at P<0.05 and those in italics at P<0.1.

(a)	Predictors					
Responses	Bees	Birds	Carabids	Plants	Spiders	Syrphids
Bees		-0.007	*0.027*	0.000	**0.031**	0.043
Birds	-0.017		-0.006	0.000	-0.003	0.015
Carabids	*0.069*	-0.003		0.000	**0.059**	0.013
Plants	0.132	-0.003	0.035		0.037	-0.012
Spiders	**0.080**	-0.018	**0.059**	0.001		0.026
Syrphids	0.069	0.014	0.005	0.000	0.018	

(b)	Predictors					
Responses	Bees	Butterflies	Birds	Carabids	Plants	Syrphids
Bees		0.0001	0.0001	0.0083	0.0004	**0.0355**
Butterflies	-0.0065		-0.0009	-0.0145	-0.0006	-0.0022
Birds	0.0388	-0.0541		-0.0223	0.0029	0.0720
Carabids	0.0061	-0.0015	-0.0002		-0.0002	0.0135
Plants	0.0256	-0.0177	0.0010	-0.0131		0.0375
Syrphids	**0.0428**	-0.0043	0.0001	0.0215	0.0005	

Overall, heterogeneity indices were more often negative influences on the associations between biodiversity measures than positive ones. The Shannon index of compositional heterogeneity was a negative modifier of the plant-bee species richness relationship and weakly of the carabid-plant one in 2012, but was not associated with any significant effects in 2013 (Table 4.1). It was also a negative modifier of bee-spider diversity and abundance relationships, as well as of the spider diversity response to carabids and the carabid abundance response to spiders in 2012 (Table 4.2-3). Conversely, the Shannon index was a positive modifier of the carabid diversity response to syrphids (Table 4.2) and of the bird abundance response to spiders and carabid abundance response to birds (Table 4.3). There were no significant associations between the Shannon index and Simpson's diversity relationships between biodiversity groups in 2013 (Table 4.2), but there were several such patterns in total abundance (Table 4.3). Bee and carabid abundance showed a reciprocal, negative association with heterogeneity, but plants and butterflies a reciprocal positive association; heterogeneity was a negative modifier of bee and bird abundance effects on carabids and a positive modifier of bird and plant effects on syrphids (Table 4.3).

There were similarly variable relationships between years in respect of interactions with the total agricultural boundary length (configurational heterogeneity). In 2012, heterogeneity was a weakly positive modifier of the associations between syrphid species richness and that of each of bees and birds, while, in 2013, there was a reciprocal, positive relationship with the heterogeneity influences on the relationship between plant and carabid richness, while total boundary length was also a positive modifier on the butterfly richness association with that of carabids (Table 4.4). In terms of Simpson's diversity, there were only negative, reciprocal relationships in 2012, involving the heterogeneity effects on the associations between each of syrphids and spiders and spiders and carabids, but there was a positive, reciprocal relationship involving the relationship between plants and birds in 2013 (Table 4.5). Heterogeneity was also a weakly positive modifier of the syrphid relationship with bee diversity and a weakly negative one of the bird relationship with carabid diversity in 2013 (Table 4.5). Total boundary length was a negative modifier of both the carabid and plant abundance effects on spiders in 2012, while the spider abundance effect on bees was also negatively affected; conversely, the syrphid association with bird abundance was positively affected (Table 4.6). In 2013, heterogeneity positively affected the plant and syrphid effects on bird abundance, but affected the carabid association negatively (Table 4.6). Oddly, however, heterogeneity was a negative influence on the bird effect on syrphid abundance, i.e. contrary to the reverse relationship. Finally, heterogeneity was also a weakly positive modifier of the bee abundance association with plant cover (Table 4.6).

As with other areas of this report, these results must be treated as preliminary, but they suggest that there are certain common responses to environmental variation among the different taxa considered within Britain, while further evidence of such patterns may well emerge once a greater range of variation is considered in the pan-European data set. Correspondingly similar responses to the heterogeneity indices considered under

Objective 2 were probably not found because heterogeneity is just one of a wide range of habitat influences affecting the different taxa. There was only limited evidence for a role of heterogeneity in enhancing these inter-relationships, but almost all of the patterns found indicated positive effects and more definitive tests will be possible once the complete, integrated, international data set is analysed. These may include consideration of the inter-relationships of different types of biodiversity index (there is no reason why the diversity, say, of one taxonomic groups providing a critical ecosystem service might not be best predicted by the abundance of another), as well as of different subsets of the different groups (e.g. flowering plants or predatory beetles only).

Work Package 3 – Objectives 5 & 6.

Objectives 5 and 6 represent a UK data-collection component for a social science component of the wider international project. Specifically, this area of work, led by Raphael Mathevet and Carole Vuillot of CNRS, Montpellier, France, aims (i) to map the diversity of land-uses and management represented by the farming systems within the study sites; (ii) to describe and to compare the farmers' mental models of the functioning of their farms and its relationship to biodiversity dynamics, in order to build an understanding of the social, cultural and economic constraints or opportunities, at different organizational levels, that could affect potential guidelines for farmland biodiversity and heterogeneity; (iii) collectively to build and to discuss (among farmers, farm organizations, governmental institutions, scientists and conservationists) a site-specific conceptual model linking the spatial patterning of farmland, the biodiversity and ecological processes present and the farmers' and stake-holders' activities or decisions (Deconchat et al. 2007). The aim is to refine research conclusions about the implications of the management of farmland heterogeneity, in order to maximize practical effectiveness. For the present project, this meant a contribution of data collection to (ii) and (iii) from the UK study region in East Anglia. No analysis was planned as part of the UK work.

Objective 5 – To conduct farmer interviews to support a UK component of the wider BiodivERsA FarmLand project.

The Montpellier approach for deriving farmers' mental models of the environment was developed in detail after the inception of the current project and involved a two-hour face-to-face meeting with each subject. Resources did not permit this approach in the UK, so a simplified protocol was developed by Carole Vuillot (Montpellier), in collaboration with BTO staff, for use as a telephone survey. As a matter of course, all farmers who had cooperated by allowing access to land for survey work were contacted by letter in 2014 and provided with summary data describing what biodiversity had been recorded in their area, relative to the averages from the other study areas for context (thus preserving confidentiality of data to people from particular locations). In these letters, farmers were asked whether they might be interested in taking the phone, "mental model" survey (as well as in attending the workshop under Objective 6, and the letters were followed up by phone calls to answer this question.

The aim was to interview 24 farmers drawn from those already contacted about land access in the 1km^2 field study landscapes, but it proved difficult to secure cooperation from many farmers, even for a short phone survey, and it subsequently proved impossible to confirm a time for an interview session with some initially interested farmers. Thus, interviews were conducted by BTO researchers with only 18 farmers, despite considerable effort to secure six further participants. The precise interview protocol used is presented in Appendix 5 and the data collected are presented in summary (anonymized) in Appendix 6. It is likely that the data collected were biased in the respect of the types of farmer who were willing to contribute as a sample of the whole farming community in the region, but this was probably inevitable in a study such as this and this caveat has been communicated to the project partners in Montpellier, along with the data themselves. The limited sample size available here will, therefore, form a part of a larger data set, thus contributing to inference at the European scale, rather than within the UK.

Objective 6 – To organize a stakeholder workshop for the UK to derive a collective conceptual model and socially feasible recommendations.

For the international project, the original aim was to hold a workshop for farmers and stakeholders in each study region in order to build on farmers' individual mental models to produce a mutually agreed collective model. However, the plans of the Montpellier social scientists changed after the inception of the present project for Defra when it became clear that ensuring the involvement of a sufficient range of farmers and stakeholders in practice would be extremely difficult. Subsequently, therefore, workshop plans have focused on the social and human-behavioural context, with a view to informing the feasibility of any recommendations made (where appropriate for the regional policy context in the country concerned) and to acting as a “sense check” for the results. The ultimate intention is to filter the recommendations from the purely biological research through social and policy realities introduced by farmers and stakeholders in order to deliver final recommendations that both produce biodiversity and ecosystem service benefits and are acceptable to the farming industry. Once again, the present project has merely collected data to contribute to this process internationally and the results will be analysed and interpreted at a pan-European level by the social scientists at Montpellier.

All farmers contacted as described above were offered the opportunity to show interest in the workshop and around 30 did so. However, confirming attendance on a specific day proved difficult, despite re-scheduling from an initial date in August 2014 to 9th December 2014. Key stakeholders proved similarly difficult to confirm, but representatives from the Country Land and Business Association, Farming and Wildlife Advisory Group and local conservation-minded farming operations were able to attend, along with seven farmers who had helped directly with the project. This led to a total attendance of twelve externals, which was somewhat lower than would have been ideal (the aim was to attract a group of 20). As with the phone surveys, it is likely that this group was somewhat biased in terms of attitudes relative to the wider farming and stakeholder community, but this was again probably inevitable and the organizers from Montpellier are aware of it. A list of attendees is provided in Appendix 7.

The workshop was convened at the BTO offices in Thetford by two of the Montpellier team, with assistance from BTO staff. The protocol applied used open questions to elicit ideas and to characterize attitudes to the landscape in East Anglia, drivers of change within it and options for management. The programme and protocol followed are presented as Appendix 8. The data generated were in the form of lists of ideas, priorities and concepts, and are being analysed in Montpellier. Final conclusions will follow the integration of data from across the range of partners in the European collaborative. [It may be possible to provide some preliminary summaries of the UK data here, or in a further Appendix.]

List of Appendices

Appendix 1. Detailed methods for landscape (1km sample square) selection.
Appendix 2. Biodiversity metadata: species lists and numbers of squares where recorded each year.
Appendix 3. Metadata on farming practice information collected.
Appendix 4. Detailed tables for relationships between summary indices for different taxa.
Appendix 5. Protocol for phone interviews to derive mental models.
Appendix 6. Mental model data derived from phone interviews.
Appendix 7. Attendance list for the Workshop held at the BTO in Thetford, 9th December 2014.
Appendix 8. Protocol and programme for the farmer and stakeholder workshop.

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

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