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Project identification

1. Defra Project code: NF0440
2. Project title: Modelling the Landscape Scale Impacts of Biomass Crops on Biodiversity
3. Contractor organisation(s):
   WarwickHRI
   University of Warwick
   Wellesbourne
   Warwick
   CV35 9EF
4. Total Defra project costs (agreed fixed price): £ 158,748
5. Project: start date .... 01 April 2007
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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.

Modelling the Landscape Scale Impacts of Biomass Crops on Biodiversity

Background

Increasing the production frequency of biomass or bioenergy crops presents a major new challenge for the development of UK agriculture. Little is known, at present, about the impacts on biodiversity of converting land from arable crops or other current uses to the production of biomass crops.. The predicted increases in the frequency of production of biomass crops over the next 5 to 10 years (up to 1 million hectares in the UK) could result in potentially large impacts on biodiversity, possibly leading to a failure to meet Defra biodiversity targets for a number of key indicator species. This project addressed the need to understand the effects that large-scale production of biomass crops will have on biodiversity at a landscape scale, and predicted the impacts of the introduction of these crops on key indicator species and overall measures of biodiversity at local, regional and national level

Aims and objectives

The aim of this project was to determine how biodiversity would be affected by the conversion of arable land to biomass cropping.

The project built on work from previous Defra-funded projects to develop a quantitative scientific model to assess the impacts of biomass crops on biodiversity, with reference to general measures of biodiversity and the potential for a species to move through a landscape. The work on the project was split into the following four objectives:

1. *Development of "plausible future" scenarios for the conversion of arable land to biomass crops within the UK.*
2. *Identification of data available for the modelling of the impact of conversion of arable land to biomass cropping on biodiversity*
3. *Development of ecosystem modelling approaches and prediction of the effects of the "plausible future" scenarios on biodiversity*
4. *Identify the major impacts on biodiversity of conversion of arable land to biomass cropping*

Approach used

This project has produced a set of models, operating at a Joint Character Area (JCA) level, that examine the impacts of land-use changes on biodiversity. The models use GIS based land-use data converted to a 100m by 100m (hectare) resolution as input.

Three models have been developed:

- *Land allocation*
  This model identifies arable land parcels that are suitable for conversion to biomass cropping, and then allocates biomass crops to these arable land parcels.
- *Landscape heterogeneity*
  This model calculates the overall heterogeneity of the land-use within a JCA. Heterogeneity is assumed to act as a surrogate measure for biodiversity, and was chosen as providing the most pragmatic approach due to a paucity of data on the direct impacts of biomasss cropping on biodiversity.
- *Habitat permeability*
  As increased landscape heterogeneity can lead to habitat fragmentation, which is bad for biodiversity, the permeability algorithm uses land-use suitability and dispersal thresholds to quantify the connectivity of the landscape for the movement of generic arable and woodland species with varying degrees of preference for habitats and dispersal abilities.

The models have been run for 90 scenarios that investigate the impacts of 3 scales of planting (small patches, intermediate patches and a single patch), 5 crop planting scenarios (single crops of either species, or 3 scales of mixed cropping), 3 miscanthus harvesting strategies (dependent upon land quality) and 2 options for the timescale of conversion (by 2020 or 2050). The land allocation and heterogeneity models were run for 6 JCAs and the permeability model for the shorter conversion timescale for 3 JCAs.

Key findings

Networks of small clusters are most beneficial for heterogeneity and permeability.
Small clusters minimise the fragmentation of habitat in arable crops and result in an increasing connectivity in woodland crops. This is not surprising, since a single large cluster is generally just replacing one monocrop with another monocrop, whilst at the same time increasing the likelihood of fragmenting the landscape for species that prefer the land type being converted. Further work is required to determine the optimal cluster size for minimizing fragmentation in arable habitat and enhancing connectivity in woodland habitat.

Conversion of arable land is always detrimental to the connectivity between patches of suitable arable habitat.
However, the impact is much reduced where small clusters are converted to biomass crops. In all JCAs examined, the proportion of land suitable for arable species was high, and the impact of this loss of habitat was therefore minimal (under the assumptions used in the project – including that grassland is considered as suitable for arable species).

Biomass crops not harvested on an annual basis introduce a much greater element of biodiversity into a landscape compared to one that is harvested annually.
This effect is most clearly seen for SRC willow which introduces much greater levels of heterogeneity into the landscape compared to miscanthus, due to its 3 year harvest cycle. The results suggest either that willow should be predominantly chosen as the biomass crop to be grown or that miscanthus should be chosen to be grown on lower grade land (which potentially leads to a longer harvest cycle). However, there is a need to understand the economic and social implications associated with the move to longer harvest cycles, to assess whether this is a feasible way to enhance biodiversity.

Conversion over a longer timescale has less benefit in terms of heterogeneity.
This is related to the proportion of land in different years of the harvest cycle, with greater synchronisation of harvest cycles over a longer time period.

The effects of changing land-use on biodiversity are dependent upon the initial spatial distribution of convertible land-use types and the proportion of land to be converted.
This is particularly important for permeability, where the initial spatial distribution of the convertible land, relative to the existing suitable habitats, determines whether fragmentation is increased or reduced.

Key Recommendations
In this project we have developed an approach that is able to simulate the impacts of changing land-use on biodiversity. However, the approach could be improved to provide better predictions of these impacts. The key recommendations for improvements are:

Simulation of conversion of arable land to biomass crops in more JCAs is necessary to fully understand the impacts that biomass crops could have on biodiversity.
Greater information is required on how the spatial arrangement of land-use types interacts with conversion of land to biomass crops to influence the fragmentation or connection of habitats. This could lead to the identification of areas where conversion of land to biomass crops is not acceptable due to the potential for

fragmentation of habitats

Economic factors, that will influence decisions about land-use, should be included within the model.
Various economic factors will drive the conversion of land to biomass crops, and therefore the land allocation model could be greatly improved by allowing these factors to drive the simulated conversion process

The models should allocate land-use change at a field level, with decisions made at a farm level.
In most cases, decisions will be made to convert whole fields rather than specific hectares (as simulated in this study), and included within farm management strategies. Therefore there is a need to incorporate information on both fields/land-parcels and farm structures into the models to allow for the impacts of these structures

The models need to capture more detail on the spatial arrangement of land-use types
The spatial arrangement of land-use types is a key factor in determining whether habitat patches become fragmented or connected by land-use change. A scale-independent approach, that is able to work not only at the JCA level, but at smaller or larger scales, is required. Understanding how the spatial arrangement of land-use influences fragmentation would allow the identification of specific land-use arrangements where altering land-use has the greatest positive impacts, and those that would have the least negative impacts.

The heterogeneity and permeability measures should utilise more objective data.
Both algorithms could be improved through the inclusion of data on the species associated with different habitat types, as this would provide more objective measures of both the similarity of different land-use types for biodiversity and the suitability of land-use types for particular species.

Future projects using this approach should address more focussed questions (relating to specific species or groups of species).
The approach used in this project has been able to give some broad answers about the impacts of land-use change on biodiversity. By using it to address focussed questions, there is the potential to provide a greater level of information. The permeability algorithms are highly dependent on the parameters describing both the suitability of the land type and the dispersal distance for a species, and therefore have limited value when being used to simulate responses for generic species. By providing focussed information on specific species or groups of species, more informative conclusions on the effects on habitat patch connectivity of land-use change can be obtained.

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:
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   - 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 Transfer).

Modelling the Landscape Scale Impacts of Biomass Crops on Biodiversity

Aims and objectives

The aim of the project was to determine how biodiversity would be affected by the conversion of arable land to biomass cropping. The objectives of the project were:

- To develop “plausible future” scenarios for the conversion of arable land to biomass crops within the UK.
- To identify the key data available for the modelling of the impact of conversion of arable land to biomass cropping on biodiversity
- To integrate the available data with GIS and ecosystem modelling approaches and predict the effects of the “plausible future” scenarios on biodiversity
- To identify the major impacts on biodiversity of conversion of arable land to biomass cropping

Objective 1: To develop “plausible future” scenarios for the conversion of arable land to biomass crops within the UK.

In consultation with key stakeholders and Defra, a set of plausible future scenarios for the location of biomass crops was developed. These were based on the identification of potential cropping environments and alternative options for the rapidity of land conversion, together with constraints associated with the location of biomass cropping. They provided a framework for the development of the modelling approach and for the collation of appropriate data for inclusion within the model.

The list of factors initially considered was:

- Scale of planting – 3 options: a single patch, a few intermediate sized patches, many small patches;
- Crop composition – 5 options: a single crop (2 options: either SRC willow or miscanthus) or mixed cropping (3 options: 25% SRC & 75% miscanthus, 50% of both crops, 75% SRC & 25% miscanthus);
- Cropping cycle – 2 options: crops grown (harvested) in phase or grown out of phase with each other;
- Land type to be converted – 2 options: arable (cereal) cropped land only or all annual arable/horticultural cropped land;
- Crop management practices – 2 options: current best practice or more intensive management;
- Harvest timing – 2 options: single or multiple harvests;
- Land availability constraints – 2 options: all land suitable can be converted or only land within 25km of a power station can be converted;
- Land conversion rate – 2 options: rapid (50000ha by 2013 the further 300000ha by 2020 for the whole of the UK) or slow (50000ha by 2013, the further 300000ha by 2050);
- Land reversion after lifetime of biomass crops – 2 options: land reverts to arable after 30 years or stays in biomass crops indefinitely.

The combination of these factor options gave a total of 1920 potential scenarios to be investigated. It was also considered essential to include multiple realisations of each scenario because of variability in the distribution of suitable land. As the project progressed it became clear that it would not be possible to consider all the scenarios if we were also to include these multiple realisations of each scenario. It was therefore necessary to identify those factors (and options) that should be included in the simulation study.

A lack of GIS-based information on the locations of power stations that would be capable of burning biomass crops over the time periods being simulated (2009 - 2080), and comments from stakeholders suggesting that limiting conversion to areas immediately around power stations was not realistic, resulted in the omission of this factor from the simulated scenarios.

As research into the improvement of cropping practices for Short Rotation Coppice (SRC) willow and miscanthus are ongoing, there was little available information on the effect of more intensive growing practices on the biodiversity value of these crops. Therefore, it was decided to focus on the current best practice scenario and omit the option of more intensive crop management.

Whilst the land reversion option was relatively straightforward to include in the land allocation algorithm (see Objective 3), it resulted in a significant increase in processing time, and due to the time constraints associated with running the models, it was decided not to include this option, but to assume that crops did not revert back to arable after 30 years, but remained in biomass cropping throughout the remaining duration of the simulation.

The current best practice guidelines for the growing of SRC willow suggest a harvest interval of 4 years, with no flexibility in this interval across different land qualities. For miscanthus, however, the harvest interval is partially dependent on the quality (agricultural land-class) of the land on which the crop is grown, with a longer interval needed to build yield between harvests on poorer quality land. We therefore proposed 3 harvesting scenarios for miscanthus: an annual harvest irrespective of the agricultural land class; an annual harvest for agricultural land class 3 and a harvest interval of 2 years for agricultural land class 4; or a 2-year harvest interval for agricultural land class 3 and a 3-year harvest interval for agricultural land class 4. In all cases the first harvest would not happen until the third year after conversion, with the appropriate cycle being followed thereafter.

The definitions of the planting scales were revised, based on the percentage of land available for conversion, to aid implementation in the model. The revised options were: a single cluster; intermediate sized clusters, with each cluster containing approximately 5% of the land area available for conversion; and small clusters, with each cluster containing approximately 2% of the land area available for conversion.

A decision to include all annual arable/horticultural cropped land as suitable for conversion was taken after considering the available areas of land suitable for conversion from the summary of each JCA (see Objective 2).

These revisions resulted in 90 scenarios to be simulated, all of which focussed on key aspects of biomass crop production and conversion of arable land to biomass cropping.

Objective 2: Identification of key data available for the modelling of the impact of conversion of arable land to biomass cropping on biodiversity

Over the years many ecologists have tried to define the term diversity – however no generally accepted definition has emerged. Hurlbert (1971) concluded that “diversity per se does not exist”. Eberhardt (1969) suggested that diversity “mostly suggests a considerable confusion of concepts, models, definitions and measures (or indices)”. As an attempt at defining biodiversity we look at the notion that it is the variety of all living things. The term most commonly refers to the number of different species in a defined area. The planting of large scale crops creates a new and often different biodiversity, thus being detrimental to some species and beneficial to others.

In order to develop the models to assess the impacts of large-scale land-use change on biodiversity, it was necessary to obtain data relating to the impacts of land-use on biodiversity, and the changes in biodiversity associated with the growing of biomass crops. In this objective we reviewed the literature to determine whether there was a sufficient pool of data on the biodiversity consequences of growing biomass crops, so that we could extract appropriate data for use within the models.

Data available in the literature

Although there are many publications on biomass cropping, few include data about impacts on biodiversity. Those that do tend to be reports on specific projects (e.g. DTI URN 04/961 ARBRE Monitoring – ecology of short rotation coppice, DTI URN 05/1307 – The effects of energy grass plantations on biodiversity) though these are few in number and of limited value in developing the modelling approaches within this project. The majority of work on biodiversity concentrates on birds, and information about arthropod and mammal taxa is very limited. There was insufficient data on the biodiversity impacts of biomass cropping for parameterisation of a model for specific indicator species, and therefore an approach was taken using landscape heterogeneity and habitat permeability as surrogate measures for biodiversity. A summary of the key data on the biodiversity impacts of biomass crops, and the evidence for the use of landscape heterogeneity as a surrogate measure of biodiversity, are given below.

Impacts of biomass crops on biodiversity

For SRC willow there is some evidence of benefits for biodiversity,. Sage and Robertson (1994) suggested that SRC plantations could attract similar bird populations to those found in coppiced woodlands in the UK. There is also evidence to suggest that farmland birds are not completely displaced by the planting of SRC willow (Sage *et al*., 2006), and that more individuals and species of birds are recorded in or around SRC compared to arable or grassland. The ARBRE project (DTI URN 04/961) examined the ecology of SRC plantations and showed that there was a significant increase in both bird density and the number of bird species during the first two years of establishment, possibly associated with the increased vegetation cover during this time. Sage & Tucker (1998) demonstrated that the canopy of SRC willow has at least three times the number of bird species compared to conventionally grown arable crops.

The case for biodiversity benefits of miscanthus is less clear, although there is a suggestion that the weediness associated with the establishment of the crop can lead to an increased diversity of invertebrates and bird species, but that this declines as the canopy cover increases close to harvest. Semere & Slater (2007) showed that the majority of invertebrates were found in field margins around miscanthus crops, rather than in the crops themselves, and that differences in biodiversity between miscanthus and reed canary grass were attributable to the weed vegetation within the miscanthus crop.

Landscape heterogeneity as a surrogate measure of biodiversity

Biodiversity is a complex ecological concept, and includes the ideas of species richness, species evenness and species composition across a range of spatial scales. Landscape heterogeneity provides a measure of the diversity of habitat types in the landscape, and may also account for the spatial arrangement of the habitat types within the landscape. It is important to consider both the spatial scale at which heterogeneity is measured, and whether or not spatial structure is accounted for, as different landscape or habitat factors will influence biodiversity at a range of spatial scales.

At a local scale (e.g. within a field or farm), the structure of the landscape may not have much impact on species richness or species composition. Weibull and Östman (2003) showed that habitat type was the most important factor in explaining species composition at a farm level, with little effect of wider landscape factors, although landscape features did impact on the number of species (species richness). However, they did not take account of the spatial structure of the landscape within their analysis, considering only the number of habitat types within a given geographical area. The approach of considering only the number of habitat types, rather than their spatial distribution and size, has been used in a number of studies (Jeanneret *et al*., 2003; Wagner *et al.*, 2000; Hendrickx *et al*., 2007, Dauber *et al.*, 2003), all of which suggest that the influence of landscape features is limited. In addition, these studies tend to only consider the local landscape, and so it is possible that, at a local scale, the landscape structure is less important than the habitat types and quality. However, Hendrickx et *al.* (2007) do concede that for more mobile species, such as spiders, landscape features have a greater influence on species richness.

At a larger geographical scale, and accounting for the spatial structure of the landscape, there is a generally accepted relationship between heterogeneity and species diversity (richness). Tews *et al*. (2004) reviewed the literature on animal species diversity and habitat/landscape heterogeneity, and concluded that there is generally a positive relationship between species diversity and structural habitat heterogeneity, with most results in the literature being at larger spatial scales (greater than 1km^2). For agricultural landscapes, the literature suggests that the greater the habitat or landscape heterogeneity, the greater the diversity of species within the landscape (Bianchi *et al.,* 2006; Clough *et al*., 2007; Dramstad *et al.*, 2001; Fjellstad *et al*., 2001; Herzon & O'Hara, 2007).

Within this project we examined the impacts of land use changes at the JCA level, covering areas greater than 50km^2, and so restricted our definition of biodiversity to species richness, as this is most commonly associated with changes in landscape heterogeneity at larger geographical scales. The approach used to calculate heterogeneity is an extension of that used by Dramstad *et al*. (2001) and Fjellstad *et al*. (2001). The method used information on not only the number of habitat types within our region of interest, but also the spatial structure of the habitat types within the landscape. Dramstad *et al.* (2001) and Fjellstad e*t al*. (2001) showed that their heterogeneity index correlated extremely well with the species richness of breeding birds (a key indicator of biodiversity for the UK) and vascular plants, but was less suitable for insects (although there was only limited spatial coverage of insects in the field sampling of these studies). They also showed that the number of habitat types (the most common measure of habitat heterogeneity) added little explanatory power to the relationship between their index of heterogeneity and the diversity of species.

We are therefore confident that our approach, of using landscape heterogeneity as a surrogate measure for biodiversity, is valid for the scale at which we examined the landscape (JCA), but are well aware that we have limited our definition of biodiversity to species richness. As the project focussed on the large-scale impacts of changes in land use on biodiversity across a JCA, we feel that this was a suitable and valid approach.

The importance of permeability

Although heterogeneity can be used a surrogate for species richness, there is a potential negative impact of increased heterogeneity in terms of habitat fragmentation. In their review of heterogeneity and species diversity, Tews *et al.* (2004) state that too much heterogeneity can potentially cause increased fragmentation, which disrupts the dispersal of species and resource acquisition. The effects of fragmentation will depend on the scale at which a species perceives heterogeneity of the landscape. For example, forest gaps increase heterogeneity for butterflies and birds, but may fragment the habitats of ground beetles (Tews *et al*., 2004). The balance between heterogeneity and fragmentation will depend on the existing spatial structure of the landscape, e.g. in agricultural landscapes, increasing the amount of woodland patches is likely to be beneficial for species diversity as more habitat is being added, but in a tropical forest canopy, the addition of new habitat patches is likely to be detrimental as a result of habitat fragmentation. To fully understand the impact of biomass cropping on biodiversity, it was therefore essential to assess the impacts of land-use change on permeability as well as heterogeneity, as the two measures work together to provide an overall picture of the biodiversity of a landscape.

Capture and processing of GIS datasets

The GIS datasets used in the project

A range of data sources were identified as providing the background data required by the models developed as part of this project. Over twenty sets of georeferenced data were obtained and evaluated. Five were identified as being essential for the modelling work:

- Land Cover Map 2000 (LCM2000): this provided the background land-use information for the land allocation algorithm. It describes the habitat uses of different land parcels, based on remote sensing. A potential drawback with this information concerns the limited ground-truthing of the data, as the remote sensing approach used to generate this data-set inherently results in errors in land-use allocation. However, the estimated accuracy of the data-set is between 80 and 90%, which was considered adequate for the illustrative nature of the project. The data are available at two scales – on 1km squares or 25m squares – with land cover information recorded either as broad habitat classes (level 2) or as more detailed sub-categories (level 3). It was considered necessary to use the data at a 25m spatial scale to provide sufficient spatial resolution, and to use the level 3 LCM classification to provide sufficient land-use resolution for the assessments of both landscape heterogeneity and habitat permeability.
- Miscanthus Yield Potential Map: this describes the potential yield of miscanthus in each 5km square of the UK. The underlying model uses climatic data to predict the yield potential, which has then been classified as high, medium or low. These data were essential for the selection of land parcels which were suitable for miscanthus, although a higher resolution (e.g. land-parcel level of 1km squares or better) for the data would have been preferable.
- SRC Willow Yield Potential Map: this is a similar map to that for miscanthus yield, using the same spatial resolution of 5km squares. The underlying model includes more environmental data than in the miscanthus yield model, such as soil Ph and soil texture. These data were essential for the selection of land parcels suitable for conversion to SRC willow. As with the miscanthus yield potential data, the resolution of this dataset is a potential limitation, as it is coarser than the scale used for the simulation of the allocation of land-parcels to be converted to biomass crops.
- Agricultural Land Class Map: this provides information on the quality of the land for agricultural production in the UK, and agricultural land class was a key parameter used in the selection of arable land parcels to be converted to biomass crops. The data was at the resolution of 1 hectare, which was compatible with the resolution used in the simulation models.
- Joint Character Area (JCA) Boundaries Map: this defines the JCA boundaries and was essential to the modelling, as the simulations were run for specific JCAs.

Processing of the data for JCA selection

To aid with the selection of JCAs to be used in the simulation of the plausible future scenarios, the data within the GIS system were analysed and manipulated to produce maps for each JCA of the suitability of land areas for the production of miscanthus or SRC willow. Suitable land parcels were defined to be currently used for arable/horticultural crops, with agricultural land class values of 3 or 4, and with high or medium potential yields of miscanthus or SRC willow (as predicted from the yield maps). The JCA boundaries were then overlaid on these maps.

Processing of data for use in the simulation models

To use the GIS information within the simulation models, it was necessary to extract the data for individual JCAs. As the majority of the datasets were in a “vector” format, to allow maximum compression, these had to be converted to “raster” datasets before they could be exported. During the conversion of the datasets, it was discovered that the different maps did not align correctly due to the use of different points of origin. This meant that the analysis tool within ArcGIS would not operate correctly, and so the data had to be resampled to generate data at an appropriate spatial resolution for the integration of the datasets within the simulation models.

Due to the size of the JCAs, and the decision to acquire the data at a resolution of 100m by 100m to integrate the LCM200 level 3 land parcel data (25m by 25m resolution) with the other datasets (all at a lower resolution), the ArcGIS export tool exceeded the upper limits of the software for data creation and export. A manual process was therefore used to create and export the datasets for each JCA (including a 1km buffer zone around each JCA), with most JCAs also having to be split into sub-grids (18000 cells per sub-grid) to allow processing. The exported data sets for each of these sub-JCAs were then re-assembled within the simulation model.

The work with the GIS system highlighted some major issues associated with operating with large volumes of data at a high spatial resolution using proprietary GIS software, and future projects will need to develop appropriate methodologies to cope with the GIS issues encountered within this project.

Selection of JCAs for simulation of plausible future scenarios

The first step in the selection of JCAs to be included in the simulation study was to identify those JCAs with sufficient land area currently in arable cropping that was suitable for the growth of both miscanthus and SRC willow. Cells were defined as being suitable for conversion to biomass cropping if they satisfied the following criteria:

- LCM2000 level 2 values of 4.1 (arable and horticulture: cereals) or 4.2 (arable and horticulture: horticulture/non-cereal)
- Agricultural Land Class values of 3 or 4
- Miscanthus Yield Potential values of “high” or “medium”
- SRC Willow Yield Potential values of “high” or “medium”

Many cells were defined as being suitable for both crops, but in some JCAs cells were only defined as being suitable for one or the other of the crops. Where this distinction occurred, the suitability of land for the different crops was accounted for in the land allocation algorithm

As part of the initial collation of the GIS datasets into MatLab datasets for each JCA, summaries of the JCA size and the percentages of cells suitable for conversion to each of the biomass crops, and from either only cereal cropped land or all annual arable/horticultural cropped land were calculated. Based on the Defra targets for the land area to be converted to biomass crops, it was determined that, on average, 15% of the available land would need to be converted. Rather than just focussing on those JCAs with large areas of available land, we decided to run all simulations with a conversion rate of 15%. Thus all JCAs with a reasonable area of land suitable for conversion could be included in the simulation study.

However, the time constraints associated with the project meant that it would not have been possible to include all 159 JCAs in the land allocation simulation study and subsequent analysis. It was therefore necessary to select a subset of JCAs for inclusion, hopefully providing an illustration of the potential effects of a number of different JCA traits on the impact of the introduction of biomass crops. To aid the selection process we first classified the JCAs based on:

- The overall area of the JCA
- The available area of JCA suitable for conversion to either miscanthus or SRC willow

To make best use of the computing resources available, we further restricted the selection process to only include JCAs including sufficient land suitable for conversion to both crops. A further constraint on the selection process was that many of the larger JCAs were of such a size that the land allocation and biodiversity summary processes would have taken more computing time/power than was available.

A final consideration in the selection of JCAs for inclusion in the process was the geographical location of each JCA. It was considered appropriate to select JCAs from across different geographical regions of England, again to provide an illustration of the potential effects of different topographies on the impact of the introduction of biomass crops.

Six JCAs were selected for inclusion in the study, providing a broad geographical coverage and combinations of different overall JCA areas and different (percentage) areas of available land suitable for conversion to biomass crops. Summary information about the selected JCAs is provided in Appendix 1, Table 1.

Objective 3: To integrate the available data within GIS software to provide baseline information for ecosystem models and to predict the effects of the “plausible future” scenarios on habitat heterogeneity, landscape permeability and generic species distributions

All algorithms developed in this project were coded using MatLab, a software package specifically designed for working with grid style (or array/matrix) data, such as the baseline data provided by the LCM2000. MatLab also provided suitable programming and calculation tools to aid the development of the analysis approaches used to summarise biodiversity in terms of the landscape heterogeneity and habitat permeability

Algorithm development

Land allocation algorithm

After first combining the data from the required sources into a single file for each of the JCAs, land allocation datasets were constructed for each of the 90 scenarios for each of the 6 JCAs. For each scenario, 100 random allocation patterns were simulated for each JCA. As previously noted, an average of 15% of the available arable land in England would need to be converted to biomass crops to meet the Defra targets, and so in each simulation, 15% of the available land within the JCA was converted over the period from 2009 to either 2020 and 2050. Both higher and lower conversion levels were initially considered, but the inclusions of scenarios with alternative conversion levels would have resulted in an impractical increase in the total number of scenarios to be considered. Similarly, a number of different conversion rate functions were considered – these included a linear rate function (meaning that the same proportion of land would be converted in each year), an exponentially increasing rate function (so that a steadily increasing proportion of land would be converted in each subsequent year), and an exponentially decreasing rate function (so that a steadily decreasing proportion of land would be converted in each subsequent year). Again, it was not considered practical to simulate land allocations for all of these rates, and so all simulations used a sigmoidal rate function (so that initially a small proportion of land was converted in each year, gradually increasing to a maximum level at the mid-point of the conversion period, and then decreasing again, so that a small proportion of land was converted in the last year).

In addition to the conversion timescale (to 2020 or 2050), other differences in the land allocation algorithm related to cluster size, proportion of land allocated to each crop (miscanthus or SRC willow) and cropping cycle for miscanthus. For scenarios with a single cluster, an initial suitable cell was first randomly selected from all available cells, with further cells to be converted initially selected from the suitable cells within a specified neighbourhood (a 2km square centred on this initial conversion point). Once all suitable cells within this neighbourhood were converted, the neighbourhood was expanded incrementally by 100m in each direction until sufficient cells were converted. For the scenarios with multiple clusters, the algorithm initially allowed either 20 clusters (intermediate) or 50 clusters (small) to be formed. For each cluster a nominal maximum cluster size was then randomly drawn from a Normal distribution. For each subsequent allocation, either existing clusters were expanded (following a similar pattern to that described for the single cluster above, but with a smaller neighbourhood based on the nominal maximum cluster size), or a new cluster was initiated (with the centre point selected at random from available cells not in close proximity to existing clusters). This choice between cluster expansion and cluster initiation was determined at random, and influenced by the number of existing clusters (as the number of existing clusters increased, expansion of existing clusters was more likely). For these multiple cluster simulations, clusters were not expanded if no further suitable cells were found within a defined search area, with additional clusters initiated until the required number of cells were converted.

For scenarios where conversion to either crop was allowed, a simplifying assumption was made that each cluster would only include cells converted to one of the crops. So when new clusters were initiated, a random allocation to either miscanthus or SRC willow was made based on the nominal proportion of cells to be converted to each crop. For the single cluster scenarios, this meant that each simulation considered allocation to either miscanthus or to SRC willow, but not to both. In contrast, the multiple cluster scenarios resulted in proportions of clusters approximately following the required nominal proportions. Following the initial conversion to biomass crops, cells progressed through the defined harvest cycles in subsequent years. For SRC willow this was a standard 3-year cycle with the first harvest taking place in the fourth year after establishment and further harvests every three years thereafter. For miscanthus, the defined cycles depended on the selected harvest scenario and on the agricultural land class value for each cell, as indicated under Objective 1.

For each simulation of each scenario for each JCA, MatLab datasets recording both the land allocation (choice of biomass crop, time since conversion) and the Land Cover Map 2000 values (both LCM level 2 and LCM level 3 data) were generated for each year upto 2080. Each LCM scale was extended to include new land cover classes for each of the biomass crops (LCM level 2 code 23.1 for miscanthus and LCM level 2 code 23.2 for SRC willow, with separate LCM level 3 values for each year in the harvest cycle). These datasets were used in the calculation of both landscape heterogeneity and habitat permeability indices, using the algorithms described below, and to produce visual "maps" of the simulated land allocation processes.

Heterogeneity algorithm

As noted above, our calculation of heterogeneity indices to assess the impact of the simulated land allocation scenarios followed the approach used by Dramstad *et al.* (2001) and Fjellstat *et al.* (2001). This approach is based on constructing an "adjacency matrix" summarising the land types (we focussed on the LCM level 3 data) in neighbouring cells. At the simplest level this approach can just be applied to the immediate horizontal and vertical neighbours of each cell (referred to as the "first rook" neighbours – "first" because they are in the immediate ring of cells surrounding the focal cell, and "rook" following the movement patterns of chess pieces). Extensions include the consideration of "first bishop" neighbours (the immediate diagonal neighbours), of "second rook" and "second bishop" neighbours (as above but in the second ring), of "second knight" neighbours (the 8 cells reached following a "knight's chess move" from the focal cell), and of similarly defined cells in the third ring of cells (see Appendix 1, Figure 1).

For a given land class map, separate adjacency matrices could be calculated for each defined neighbour category (e.g. "first rook", "second bishop", etc.) across all the cells within the JCA, and these adjacency matrices then summarised further (see below). Alternatively, these matrices could be combined, for example, for all 8 cells in the innermost ring ("first rook" and "first bishop" neighbours), for all 24 cells in the innermost two rings, or for all 48 cells in the three rings). In combining the adjacency matrices we considered it appropriate to weight the contributions relative to the distance of each neighbour from the focal cell, so that "first rook" neighbours had a weighting of 1, "first bishop" neighbour a weighting of $1/(\sqrt{2})$, "second rook" neighbours a weighting of ½, and so on (see Appendix 1, Figure 1).

Two approaches were taken for the further summary of these adjacency matrices to provide a single index of heterogeneity. The first approach simply calculated the trace of each matrix, that is the sum of elements on the diagonal of the matrix, representing the number of neighbours having the same land class as the focal cell. To provide an index that was comparable between JCAs (which are of different sizes and therefore have different numbers of neighbour comparisons), the trace was scaled as a percentage of the total number of neighbour comparisons (the sum of the values in each matrix). A potential disadvantage of this first approach is that it treats all land class levels as being equally different. The second summary approach adjusts for this by multiplying each adjacency count between two land classes by an estimate of the similarity between the two land classes. The project team generated a matrix of subjective similarities between all LCM level 3 land classes based on a comparison of anticipated plant composition and structure, as shown in Appendix 1, Table 2 (more objective similarities were calculated based on the PLANTATT database (http://www.brc.ac.uk/resources.htm) for LCM level 2 land classifications, but similar data are not available for LCM level 3 land classes). Land classes perceived to have identical plant composition and structure have a similarity of 1.0, whilst those with nothing in common have a similarity of zero. All values were estimated to the nearest 10%. Summing all the values obtained from an element-wise multiplication of this matrix of similarities and each adjacency matrix provides an overall measure of the similarity of adjacent cells across the JCA, and scaling this value as a percentage of the total number of neighbour comparisons provides an index that is comparable between JCAs.

Analyses focussed on the summary measures obtained for the neighbours in different rings around each focal cell – referred to as "first trace", "second trace" or "third trace" for the simpler approach, and "first similarity", "second similarity" or "third similarity" for the approach based on the subjective similarities between land classes. In all cases percentages closer to 100% indicate a more homogeneous landscape (associated with lower biodiversity) and percentages closer to 0% indicate a more heterogeneous landscape (associated with higher biodiversity). However, at present we have not been able to calibrate specific levels of the indices with particular levels of biodiversity.

Permeability algorithm

To assess the impact of land use changes on the balance between heterogeneity and fragmentation, we developed an algorithm to calculate the permeability of a landscape for a range of generic species. Careful selection of parameters allowed the generic species to represent different habitat requirements (from generalist to specialist) and a range of dispersal abilities (short range to long range). This allowed us to asses the impact of land-use changes on the habitat networks perceived by different species, and the potential for dispersal of these species through the landscape.

We assume that a more connected habitat network is beneficial in allowing species to colonise previously fragmented landscapes, and that this will also enhance biodiversity.

In developing an algorithm to measure changes in the suitability of the landscape due to changes in land-use, the first step was to generate suitability indices for each land-use type. To allow the algorithm to be applicable for a wide range of species, a set of generic suitabilities were developed for both arable and woodland species. The suitabilities were on a zero to one scale, where zero means that the land-use is completely unsuitable and one means that it is completely suitable. By varying the suitability threshold within the permeability algorithm, we can then simulate varying degrees of specialism in the use of arable and woodland habitats.

A number of different methods for calculating permeability indices were considered during the development of the algorithm. The method described below was chosen as it provided the most realistic assessment of the connectivity of patches of suitable land, as would be experienced by dispersing or moving organisms, by considering the distances between the edges of patches, as opposed to other methods which consider the distances between the centres of patches.

The algorithm first generates a suitability map, based on the land-use map produced by the land allocation algorithm (for each year of each plausible scenario), and the list of land-use suitabilities (arable or woodland) generated for each land-use (LCM level 3). The defined suitability threshold is then used to turn this map into a binary map, with cells with suitability values above the threshold having a value of one and those below having a value of zero. This map is stored and can be displayed graphically.

Using the image analysis toolbox within MatLab, we can then identify patches of contiguous suitable cells within the JCA (those above the suitability threshold), with cells within each patch being given an index to indicate the patch to which they belong. This information is stored as an initial patch matrix. A patch dilation technique is then used to determine the connectivity between patches (illustrated graphically in Appendix 1, Figure 2). This technique places a circular mask of a given radius (the dispersal radius for the species) over each cell within the binary suitability map, and all cells within the mask are included in the dilated patch. The dilated suitability map is then re-analysed using the image analysis toolbox, to identify the patches as before. The resulting matrix is then re-calculated so that all unsuitable cells are reclassified, producing a matrix identifying the suitable cells that are effectively connected through a dispersal distance smaller than twice the specified radius. The number and size of patches of connected habitat is then stored for later analysis. By varying the dispersal radius, the effect of sedentary or migratory species can be simulated.

As currently configured the permeability algorithm will only simulate landscape permeability assuming that there are no barriers to movement within the landscape. This means that the permeability results are probably more useful for species that disperse aerially rather than those that disperse terrestrially.

The algorithm produces the following output statistics:

- Total area of suitable land
- Area of largest patch of connected (permeable) habitat
- Number of patches of connected (permeable) habitat
- The number of patches smaller than 10ha as a percentage of the total number of patches
- The total area of patches smaller than 10ha as a percentage of the total area of suitable land

Simulation output

Land allocation

For each of the six selected JCAs (see Appendix 1, Table 1), the land allocation algorithm was run for each of the 90 scenarios, with 100 separate realisations produced for each scenario. Each realisation used a different random number seed, resulting in a different selection of focal points for clusters, and hence in a different land re-allocation pattern. Land-allocation data sets identify the 100m by 100m cells suitable for conversion at each time point (year) and those allocated to biomass crops (either miscanthus of SRC willow), with information also provided about the number of years since conversion. Land-use data sets identify the land use associated with each 100m by 100m cell for each year within the simulation, with separate data sets for LCM level 2 and LCM level 3 values. Each of these data sets can be displayed graphically as a map of the JCA.

In Appendix 2, figures 1 to 6 show the initial (assumed to be 2009) land-use and land-allocation maps for the six JCAs. The left-hand map in each figure shows the LCM level 2 classification of each cell, essentially using the colours as defined on the LCM 200 web-site (http://www.ceh.ac.uk/sections/seo/lcm2000_home.html) though with some minor modifications to highlight the differences between the different arable and horticulture classifications (different shades of brown). Other key colours are two darker shades of green (coniferous woodland, improved grassland), red (broad-leaved or mixed woodland), orange and two lighter shades of green (various other grassland categories), and black and grey (urban and suburban developments). The right-hand map in each figure shows the land-allocation, with yellow cells being unsuitable for conversion, darker blue cells being suitable for conversion to either miscanthus or SRC willow, lighter blue cells only being suitable for conversion to miscanthus, and purple cells only being suitable for conversion to SRC willow. As the conversion process is simulated, those cells converted to miscanthus are coloured green, and those converted to SRC willow are coloured red. Similar colours are used to show the converted cells in the land use (LCM level 2) maps. The land-allocation maps show the variability in the density of land areas suitable for conversion to each of the crops, as summarised as percentages in Appendix 1, Table 1.

Figures 7 to 19 of Appendix 2 show the progression of land allocation (and changes in the simulated land-use) for a single randomisation of the simulation of a single cluster of miscanthus in JCA 62 (Cheshire Sandstone Ridge), with re-allocation of land completed by the end of 2020, and the first miscanthus harvest regime (referred to as “Scenario 01”). Each map shows the land-allocation and land-use at the start of each year, so that the maps for 2021 are after the completion of the re-allocation process. The cluster is initiated at coordinates of approximately (x = 125, y =175), and gradually spreads to occupy all suitable cells in the central segment of the JCA. Figures 20 and 21 of Appendix 2 summarise the same sequence of 13 years for land-allocation and land use respectively. As already noted, each randomisation produces a different pattern of land-allocation/land-use, and figures 22 and 23 of Appendix 2 show the variability in the location of single clusters of miscanthus Scenario 01) as simulated for JCA 62 in the first 10 randomisations (the map in the bottom left corner is for the initial (2009) land-use/land-allocation). Note that differences in the land-use values, as generated for the different years within each miscanthus harvest regime, cannot be seen in these LCM level 2 land-use maps, but only in the LCM level 3 data sets (which are more difficult to show graphically as they require 79 unique colours!).

The next four figures of Appendix 2 show examples of the year-by-year sequences of land-allocation and land-use changes over the shorter allocation timescale (to 2020) for scenario 04 – miscanthus in intermediate sized clusters – (figures 24 and 25) and scenario 07 – miscanthus in small clusters – (figures 26 and 27). The following six figures of Appendix 3 show examples of sequences of land-allocation and land-use changes over the longer allocation timescale (to 2050), though here the maps are only shown for every third year. Figures 28 and 29 show the patterns for scenario 10 (miscanthus in a single cluster), figures 30 and 31 for scenario 13 (miscanthus in intermediate sized clusters), and figures 32 and 33 for scenario 16 (miscanthus in small clusters).

Finally, figures 34 and 35 of Appendix 2 attempt to illustrate the variety of different patterns produced by the whole range of simulated scenarios. In each figure, the two maps in the bottom row are for single clusters of re-allocated land areas, the left-hand map being for 100% miscanthus and the right-hand map for 100% SRC willow. As the land-allocation algorithm specified that each cluster should have all cells converted to the same crop, the maps for scenarios specifying single clusters for mixed cropping regimes are similar to these, with a proportion of the randomisations being for miscanthus and a proportion for SRC willow (the proportions roughly corresponding to the proportions of each crop as specified in the scenario). The middle and upper rows of maps in each figure then illustrate the patterns for scenarios specifying intermediate sized and small clusters respectively, with the cropping factor varying from 100% miscanthus on the left to 100% SRC willow on the right, via (75% miscanthus, 25% SRC willow), (50% miscanthus, 50% SRC willow) in the middle column, and (25% miscanthus, 75% SRC willow).

Similar maps can be generated for each randomisation of each of the land allocation scenarios runs for each of the six JCAs.

Landscape heterogeneity

As noted above, summaries of the effects of the different land allocation scenarios on heterogeneity focussed on six measures – the trace of the adjacency matrices across the innermost ring of 8 neighbours (first trace), across the two innermost rings of 24 neighbours (second trace) and across all three rings of 48 neighbours (third trace), and the equivalent values obtained from the sum of values from the element-wise multiplication of the same adjacency matrices by the land-use similarity matrix (first similarity, second similarity, third similarity), in all instances scaled by the total number of comparisons in the adjacency matrices and expressed as a percentage between 0 and 100%.

A summary of the initial values of each of these statistics for the six selected JCAs, together with the distribution of values across all JCAs, is given in Table 1 of Appendix 3. It is not surprising that the similarity indices are consistently higher than the trace indices, as the former include contributions from off-diagonal elements of the adjacency matrices as well as the diagonal elements that provide all the contributions to the latter. Similarly, the consistent reduction in the values of the indices moving from the innermost ring of 8 neighbours (first trace, first similarity) to the three rings of 48 neighbours (third trace, third similarity) is expected, as cells for each land-use generally occur in contiguous patches so that first neighbours are more likely to have the same land-use than third neighbours. Of the six JCAs selected for the simulation study, JCA 101 is the most heterogeneous initially, with all values substantially less than the 1st (lower) quartile, though this JCA appears to be less extreme for the similarity indices than for the trace indices. Conversely, JCA 93 is the most homogeneous initially, with values towards the 3rd (upper) quartile, and is relatively more homogeneous for the similarity indices than for the trace indices. The other four JCAs have fairly similar values to each other, though these tend to be towards the lower end (more heterogeneous) of the distribution across all JCAs. Inspection of the initial land-use maps for JCAs 93 and 101 (Appendix 2, Figures 4 and 5) possibly suggests larger patches of particular land-uses in JCA 93 (more homogeneous) with a generally more fragmented landscape in JCA 101 (more heterogeneous).

Further information on the potential differences between these JCAs can be obtained by considering the initial (non-spatial) distribution of land parcels between the different LCM 2000 classes. Table 2 of Appendix 3 lists the initial numbers of 100m by 100m cells in each JCA allocated to each of the 72 LCM level 3 land-use classes (including totals for each LCM level 2 land-use class). The LCM level 2 data is graphically summarised on Figures 1 to 6 of Appendix 3. JCAs 14 and 62 have a relatively small proportion of arable and horticulture land (27% and 26% respectively), with JCAs 29, 93 and 146 being dominated by these land-uses (55%, 47% and 46% respectively). Four of the selected JCAs have high proportions of improved grassland, ranging from JCAs 62 and 101 with 43% and 39% respectively to JCAs 146 and 93 with 29% and 27% respectively, with JCA 14 only having 7% of land allocated to this use. Percentage areas of woodland vary from a high of 16% for JCA 29 down to a low of just 7% for JCA 146. Finally JCA 14 is dominated by urban and suburban development (42% of the total area) with JCA 146 having the next highest percentage (10%) and the other JCAs having between 3% and 6%.

Figures 7 to 14 of Appendix 3 illustrate the responses of the different heterogeneity indices over time for the different treatment combinations, using the output from JCA 14 as an example. Figures 7 and 8 show the impact of planting scale (single, intermediate, small) and miscanthus harvest regime (MH1, MH2, MH3) for scenarios with conversion to either 100% miscanthus or 100% SRC willow. For all indices there are obvious effects of planting scale, with the small clusters resulting in lower indices (more heterogeneity) and the single clusters resulting in higher indices (less heterogeneity). There are obviously no effects of miscanthus harvest regime on the SRC willow responses, and only limited effects on the miscanthus responses, with differences only seen for the trace indices between MH3 and the other two regimes (Figure 7). For the trace indices (Figure 7) there is a bigger difference between the single cluster and multiple clusters for SRC willow than for miscanthus, with a greater separation of the intermediate-sized and small cluster scenarios for miscanthus. For the similarity indices (Figure 8), all scenarios result in a more heterogeneous landscape at the end of the re-allocation process, whereas for the trace indices, the single and intermediate-sized cluster scenarios result in a more homogeneous landscape. Figure 9 illustrates the impacts of the different monocrops on the heterogeneity indices, with a substantial final difference seen for the first trace (upper graphs) after similar responses for the first 5 years or so, and the third miscanthus harvest regime giving a response more similar to that for the SRC willow scenarios than for the other miscanthus scenarios. The patterns for the first similarity index are more similar in shape, though diverge earlier, and maintain the divergence from around 2015 onwards. Figure 10 illustrates the effects of planting scale and crop choice (monocrops only) for each of the three miscanthus harvest regimes. The patterns of response are very similar for the first similarity index, showing larger effects of planting scale and smaller effects of crop, with a similar pattern for the first trace index with miscanthus harvest regime 3. For the other two miscanthus harvest regimes (MH1, MH2) the difference between crops dominates, with small clusters of miscanthus having similar heterogeneity levels to single clusters of SRC willow.

Figure 11 shows the impact across the five crop compositions of the two multiple cluster size scenarios and the miscanthus harvest regimes. For the first trace index, the difference between planting scales decreases as the proportion of SRC willow increases, with the difference between miscanthus harvest regime 3 and the other regimes similarly decreasing. For the first similarity index there is relatively little change in pattern across the crop compositions, with small clusters always creating more heterogeneous landscapes than intermediate-sized clusters. Figure 12 highlights the comparisons between crop compositions for each cluster size and the three trace indices, with consistent patterns across all six graphs. Figure 13 provides a similar summary for the similarity indices, with relatively small differences between crop compositions, but an interesting “pause” in the reduction in indices for the intermediate-sized cluster scenarios. Figure 14 compares crop compositions and cluster sizes for each miscanthus harvest regime, with the first trace index showing large effects of both crop composition and planting scale for the first two miscanthus harvest regimes, and smaller differences for the third, and the first similarity index showing a consistent effect of cluster size across all three miscanthus harvest regimes.

Figures 15 to 28 of Appendix 3 provide comparisons across the six JCAs of the effects of a number of treatment subsets, using the first trace index as an illustration. Figure 15 considers the effect of different planting scales and miscanthus harvest regimes on heterogeneity when allocating 100% miscanthus. Major differences are in the size of the initial reduction in index (increase in heterogeneity), and in the timing and levels of the minimum index value for the intermediate-sized and small cluster scenarios. Some JCAs show evidence of some class 4 agricultural land being allocated with the small differences between the first two miscanthus harvest regime scenarios. Figure 16 shows similar responses for SRC willow, with less variability in the shapes of response curves between JCAs. Figures 17 to 19 provide comparisons of the differences in response between crops across JCAs. For single clusters (Figure 17) differences are concerned with the size of the initial reduction in heterogeneity index, the size of the eventual increase for the miscanthus crops, and the size of the eventual reduction for the SRC willow crops. Note how the response for the third miscanthus regime for miscanthus is more similar to the response for SRC willow than for the other miscanthus scenarios. Similar differences between crops and miscanthus harvest regimes are seen for the other planting scales (Figures 18 and 19).

Figures 20 to 24 show the differences between JCAs in the responses for the different multiple cluster sizes and miscanthus harvest regimes, for each of the five crop compositions. As noted above, the primary differences here are in the relative timings of the minimum heterogeneity index values, in the sizes of these initial reductions, and in the eventual change in index value. Figures 25 and 26 provide direct comparisons of the different cropping regimes for intermediate-sized (Figure 25) and small (Figure 26) clusters respectively, showing fairly consistent differences between crop compositions, but differences between JCAs in the size of the initial index reduction and in the levels for the crop compositions relative to the initial heterogeneity.

Finally, Figures 27 and 28 provide a brief insight into the variability between repeat simulation runs of the same scenario (again using JCA14 as an example), showing the standard deviation between randomisations for particular treatment sets. For the trace indices (Figure 27), the intermediate-sized and small cluster scenarios show similar patterns of between-randomisation variability for both 100% miscanthus and 100% SRC willow, with the variability gradually increasing until around 2016. The single cluster scenarios show a much greater initial increase in variability, with this variability declining to a steady level for 100% miscanthus, but staying high for 100% SRC willow. For the similarity indices (Figure 28), similar patterns are seen for the multiple cluster scenarios, and the same initial increase in variability is seen for the single cluster scenarios, though these peak earlier than for the trace indices, and return to a level more similar to that for the multiple cluster scenarios for both crops.

Substantially more data on heterogeneity has been produced than it is possible to show here, but the figures in Appendix 3 and descriptions above hopefully provide an insight into the patterns seen.

The effects of the different simulation factors on each of the heterogeneity indices were formally assessed using ANOVA, with separate analyses for each of the six indices. Initially analyses concentrated on single JCAs, with analyses assessing the differences between the two monocrop scenarios (100% miscanthus, 100% SRC willow) across three planting scales (single cluster, intermediate sized clusters, small clusters) and three miscanthus harvest regimes, or the differences between the five cropping scenarios across two scales (omitting the single cluster treatment) and three miscanthus harvest regimes, in both cases just considering the simulations with an allocation completion date of 2020. Further within-JCA analyses compared values of the heterogeneity indices between the two allocation timescales (2020, 2050) either at equivalent proportions of the allocation timescale (every 2 years towards the 2020 completion date is equivalent to 7 years towards the 2050 completion date), or at equal periods of time (years) after the start of the re-allocation process. A final set of analyses assessed for differences between JCAs in the change in the values of the heterogeneity indices over time, potentially providing an insight into the effects of different JCA characteristics (including JCA size, proportion of land available for conversion, initial level of heterogeneity, etc.) on the impact of different allocation scenarios on landscape heterogeneity.

Habitat permeability

The calculation of the potential habitat permeability focussed on 3 JCAs (14, 62 and 93) and considered only the scenarios where land allocation was completed by 2020. The simulations assumed that a species had a preference for either arable habitats or woodland habitats and the assumed suitabilities for all LCM3 land use classifications for the two types of preference are shown in Appendix 4 Table 1. It is important to note that grassland was considered to be of similar suitability to arable crops. The simulations examined the impact of three different suitability thresholds (0.5, 0.75 and 1.0 to simulate a generalist, a partial specialist and a specialist species) and three different dispersal distances (using distances of 400m, 1000m and 2000m to simulate short, medium and long range dispersal) on the potential permeability of the landscape for each of the habitat types (arable, woodland). A huge amount of data has been produced by the permeability model (4 maps for each of 21 years in the 100 runs of 45 scenarios for each of 3 JCAs) and so it is not possible to present everything within this report. The figures in Appendix 4 are intended to provide an illustration of the types of output that the model can produce.

The initial distributions of suitable arable or woodland habitat for the three JCAs at the three suitability thresholds are shown in Figures 1, 2 and 3 of Appendix 4 and demonstrate how increasing the suitability threshold affects the number of suitable patches for an arable species. The number and size of woodland patches is unaffected by the suitability thresholds as all woodland is suitable at a high suitability level (greater than 0.75).

Appendix 4 Figure 4 illustrates the impact of conversion of land to miscanthus on the connectivity of arable land at the three dispersal distances. For all three JCAs, conversion of arable land to biomass cropping leads to a reduction in the amount of suitable habitat, with potential fragmentation depending upon where the clusters of biomass cropping are located. The impact of conversion to SRC willow on the connectivity of woodland habitats is illustrated in Appendix 4 Figure 5 for all three dispersal distances. Conversion of arable land to willow increases the amount of suitable woodland habitat, leading to increased connectivity of the landscape for woodland preferring species, dependent upon the spatial location of the clusters of conversion. In both figures, maps are shown for 2009, where conversion is just beginning, and for 2021, where conversion has been completed. Suitable habitat patches with the same colour in the figures are within the dispersal distance of each other, and are assumed to be connected to each other, forming a single permeable habitat (i.e. a species is able to move freely between the patches of suitable habitat).

Objective 4: The impact of conversion of arable land to biomass cropping on biodiversity

The key impacts of conversion of arable land to biomass cropping on heterogeneity and permeability

Analysis of variance was used to examine the effects of the scenario parameters on both heterogeneity and permeability. The most important impacts of the factors are described below.

Planting scale

There is an almost immediate significant effect of planting scale on heterogeneity, increasing in size and significance until around 2017 in all JCAs, and then declining slightly in most cases (JCA 14 is the exception here). In all cases, small cluster scenarios result in the greatest heterogeneity (smallest index) and single cluster scenarios in the lowest heterogeneity. All JCAs show a small interaction between planting scale and crop composition, with a larger effect of planting scale for miscanthus than for SRC willow.

For permeability of arable habitats, there is a significant effect of planting scale in JCAs 14 and 93. For the single crop clusters (miscanthus only or SRC willow only), small clusters lead to less fragmentation of the arable habitat (there are fewer patches, with a larger patch size). The effect of the intermediate-sized and single cluster scenarios is dependent upon the JCA, indicating that both the spatial arrangement of land-use, and the total area to be converted (actual patch size), are important in determining how larger patch sizes affect fragmentation. In JCA 62, there is no effect of planting scale, with only a single patch throughout each simulation. In the split cropping scenarios, intermediate sized patches lead to greater fragmentation than smaller patches, with an increased number of patches and a greater percentage of smaller patches. The maximum patch size was smaller for scenarios with intermediate sized clusters.

For the woodland permeability, there is a significant effect of planting scale for all JCAs. For the single crop scenarios, the single large cluster is least beneficial as it leads to greater fragmentation of the habitat (as seen by the larger number of patches and the higher percentage of small patches in single large cluster scenarios). Small or intermediate-sized cluster scenarios lead to greater connectivity of the woodland habitat, though dependent upon JCA, indicating that the initial spatial distribution of suitable habitat is a key factor in determining the ability of small or intermediate-sized clusters to reduce fragmentation. For the split crop scenarios, whether intermediate-sized or small clusters are better at reducing fragmentation (lower number of patches, decreased percentage of small patches, increased maximum patch size) varies between JCAs, with intermediate-sized clusters being better in JCA 62, whilst small clusters are more beneficial in JCAs 14 and 93. Note, however, that an intermediate-sized cluster in JCA 62 is of the same size as a small cluster in JCA 14 (Appendix 2 Table 1), suggesting that the intermediate clusters for JCA62 could be considered as small clusters from an absolute size point of view. From Appendix 4 Figures 1, 2 and 3, it can be seen that the initial distribution of woodland is reasonably even for JCAs 14 and 93, whilst it is more clustered in JCA 62, and this may be the explanation for the different effects of intermediate-sized and small clusters in these JCAs.

Crop composition

Significant effects of crop composition are generally observed by 2013 or 2014, with the size and significance of the effects growing consistently until the completion of the allocation and establishment phase in about 2022 (allocation phase to 2020). The sizes of differences vary quite considerably between JCAs, but the pattern is consistent, with the 100% miscanthus scenarios resulting in the highest indices (least heterogeneous) and the 100% SRC willow scenarios resulting in the lowest indices (most heterogeneous), and the mixed crops following in sequence between these levels. All JCAs show an expected interaction with miscanthus harvest regime, as there is no effect for SRC willow and, usually, a large difference between the third miscanthus harvest regime and the other two for miscanthus.

Crop composition had no effect on the permeability of arable habitats, since the suitabilities of both crops (except during the establishment phase of miscanthus) fell below the suitability thresholds used in the simulations. There was a significant interaction between planting scale and crop composition in the permeability of woodland habitats. The interaction was caused by the fact that miscanthus is not a suitable woodland habitat, and hence that the 100% miscanthus scenarios resulted in all planting scales predicting the same lack of effect.

Harvest regime (Miscanthus only)

Significant effects of harvest regime are generally observed by 2013 or 2014 (the point at which the first miscanthus harvest is simulated), with the size and significance of the effects growing until the completion of the allocation and establishment phase in about 2022 (allocation phase to 2020). Consistently lower index values are seen for miscanthus harvest regime 3 (two-year harvest interval on agricultural land class 3), with little difference between the other two harvest regimes (probably because of relatively little availability of agricultural land class 4 in the selected JCAs).

There was no effect of harvest regime on either permeability measure (arable or woodland) due to the fact that miscanthus did not have a suitability that was above the suitability thresholds used in the models.

Timescale of conversion

There is a significant effect of timescale on heterogeneity for all JCAs, with a lower heterogeneity (higher index value) for the 2050 timescale compared to the 2020 timescale. There is a significant interaction between timescale and scale of planting, with consistently smaller decreases in the heterogeneity for the 2050 timescale, as the cluster sizes changes from single to intermediate-sized to small, compared to the 2020 timescale. A significant interaction between timescale and crop composition is observed with consistently smaller decreases in heterogeneity for the 2050 timescale as the proportion of miscanthus changes from 100% to 0%.

Timescale of conversion was not investigated for permeability so there are no results to report.

Dispersal distance and habitat suitability threshold

The analysis of the outputs from the permeability simulations showed significant effects of both dispersal distance and suitability threshold. These effects were predictable *a priori* and consistent across all JCAs. Increasing the dispersal distance reduced both the number of patches and the percentage of small patches and increased the maximum patch size, due to increased connectivity of suitable habitat. Increasing the suitability threshold led to an increase in the number of patches and the percentage of small patches and reduced the maximum patch size, due to there being less suitable habitat which was more fragmented. For the arable land, increasing the threshold from 0.75 to 1.0 had no effect due to a lack of land type suitability values between 0.75 and 0.99. For woodland, increasing the threshold from 0.5 to 0.75 had little effect since there were few land types with suitabilities between 0.5 and 0.75, and these land-types did not appear in all JCAs.

Between JCAs

Initial heterogeneity levels vary quite markedly between JCAs, and formal analysis of the patterns between JCAs showed significant differences in the changes from these initial levels from start of the re-allocation process. However, it does not appear that these differences in changes in heterogeneity are related to the initial level. There may be other JCA characteristics that are influencing the sizes of these changes, such as the initial spatial structure of the different land-uses. Relative to the sizes of the main effects of these factors, the effects of crop composition, planting scale and miscanthus harvest regime appear to be fairly consistent across JCAs.

The predictions from the permeability model are heavily dependent upon the spatial arrangement of land-use types within the JCA, and there appears to be little consistency in the effect of crop scale and its interactions with dispersal distance and suitability threshold across the JCAs, particularly for woodland. There is consistency across the JCAs for the main effects of dispersal distance and suitability threshold, but this is entirely predictable, since these are model parameters that are not JCA dependent. The variable size of the intermediate-sized and small clusters between the JCAs could be one reason for the lack of consistency, and future work should perhaps focus on using absolute cluster sizes rather than sizes relative to the area of convertible land within a JCA.

The implications of the key impacts for conversion of arable land to biomass crops

The most important implication of the analysis of the predictions form the model is that **networks of small clusters are most beneficial for both heterogeneity and permeability** (both in terms of minimising the fragmentation in arable crops and in increasing connectivity in woodland crops). This is not surprising since a single large cluster is just replacing one monocrop with another monocrop, whilst at the same time increasing the likelihood of fragmenting the landscape for species that prefer the land type being converted. From the results of this project it is not possible to provide a recommendation as to the most appropriate size for the clusters. However the permeability results from JCA 62 suggest that there is a minimum cluster size below which the impact on permeability is reduced. Therefore, we suggest that there is a need to understand exactly how the size of a cluster of biomass crops influences both heterogeneity and permeability (and how this relates to the cluster sizes for existing crops), and from this understanding it should be possible to determine a cluster size (or relationship with the existing habitat distribution) that has maximum potential positive impact on biodiversity**.**

Conversion of arable land is always detrimental to the connectivity between patches of suitable arable habitat, but this is much reduced when small cluster sizes are used for conversion. However, in all selected JCAs, the proportion of arable land is high, and therefore the impact of this loss of habitat is minimal (based on the suitabilities used in this project, which considers grassland to be as suitable as arable land for arable species).

For the measure of heterogeneity used in this project, a **biomass crop that is not harvested on an annual basis is likely to introduce a much greater element of biodiversity into a landscape compared to one that is harvested annually**, which suggests that conversion of lower grade agricultural land to biomass cropping may be preferable from a biodiversity standpoint. However, whether this would be economically acceptable (viable) to land managers is unclear, and the economic aspects need further investigation. The effect of a non-annual harvest is most clearly seen for SRC willow, which introduces greater levels of heterogeneity into the landscape, compared to miscanthus, due to its 4 year harvest cycle. It could therefore be suggested that SRC willow is preferred as a biomass crop, due to its increased benefits on biodiversity (relative to miscanthus), both through the increase in landscape heterogeneity and the increased permeability of the landscape for woodland species, with limited detrimental impact on the permeability of the landscape for arable species. However, this project does not consider the social and economic factors which may also influence crop production decisions, and these would need to be taken into account before a recommendation to plant SRC willow in preference to miscanthus could be given.

The comparison of the two timescales for conversion suggests that **conversion over a longer timescale has less benefit in terms of heterogeneity**. This is related to the proportion of land in different years of the harvest cycle, with greater synchronisation of harvest cycles over a longer time period. It may also be influenced by the land allocation strategy that simulated land conversion within an area with an ever increasing radius around the focal point of the cluster. Moving to a model that converts fields as opposed to individual hectares should provide a more realistic assessment of the effect of timescale of conversion. Further modifications may also be necessary with regards to the strategy for expanding the converted areas.

The lack of consistency in the effects of land allocation on heterogeneity and permeability across JCAs indicates that **the effects of changing land-use on biodiversity are dependent upon the initial spatial distribution of convertible land-use types and the proportion of land to be converted**. This is particularly important for permeability, where the initial spatial distribution of the convertible land relative to the existing suitable habitats will determine whether fragmentation is increased or reduced.

Further research required

Due to the limited time available to run the simulations, once the appropriate data had been sourced, this project was only able to process a small subset of the JCAs in England. Therefore, to obtain a full picture of the impact of growing biomass crops on biodiversity in England, it is essential to run the models developed within this project for a much larger set of JCAs. However, some prioritisation of the JCAs is probably necessary, so that further simulations can concentrate on those areas where biomass crops are more likely to be grown, as running the simulations for every JCA in England would take an extremely large amount of computing time. It would also be beneficial to select JCAs based on the spatial arrangement of different land-use types, as opposed to the amount of land available for conversion, as this would give a better appreciation of the impact of converting land to biomass crop production on the fragmentation and connectivity of the landscape. Note that the current study was only able to source complete data sets for England and not for the rest of the UK,

With the increasing emphasis on how the UK will respond to environmental change, the modelling approach developed within this project has the potential to be applied to a much wider range of policy questions that fall under the Living With Environmental Change banner, specifically in relating how land use needs to change to benefit conservation or to allow the UK to adapt or mitigate the effects of environmental change, including climatic change.

Land allocation

The land allocation algorithm used in this project assigns land-use to hectare cells, and therefore may not realistically represent how land would be converted in practice, since land managers are more likely to convert fields rather than part fields, probably within a whole-farm management strategy. There is therefore a need to modify the land allocation algorithm to convert fields (within a farm structure) as opposed to hectare cells, since this would provide a more realistic assessment of the impact of changes in land-use on biodiversity. This has further implications for both the heterogeneity and permeability algorithms, which currently utilise the hectare squares to determine neighbours and connectedness. A move to field-level simulation would require the development of methods to account for the number of neighbours that a field has and the area that a field occupies. Alternatively, the land-allocation data set would need to be converted back to hectare (or smaller) cells for assessment of these characteristics.

The model currently assumes a sigmoidal rate function for the conversion of land to biomass crops – the conversion starts slowly, increasing to a maximum rate before slowing down again towards the end of the conversion period. It is unknown whether this is a realistic assumption for the take-up of the conversion of land to biomass crops by land managers (which may depend on a number of economic factors), and there is the potential to investigate a number of different rate functions (as suggested in Objective 3 above) and to examine how these impact on heterogeneity and permeability. This could be extremely important as the model predictions have shown that a slower conversion rate leads to less heterogeneity (and hence a lower biodiversity) than a fast conversion rate.

The model also assumes that the proportion of land available to be converted is fixed at 15% (based on the average requirement across England). However, the proportion of land that is converted within any JCA could vary, probably being related to the initial spatial distribution of land-use within the JCA. For example, in JCA 62, the arable landscape is sufficiently connected to remain as a single patch, even when 15% of the arable land available for conversion is converted to biomass cropping. Therefore, it might be possible to increase the proportion of land converted within this JCA without negatively impacting the connectivity of the arable landscape. An extension of the modelling approach could allow the assessment of the proportion of land that could be converted within each JCA before significant negative impacts on biodiversity occur, allowing a much greater flexibility in the allocation of biomass crops across different JCAs.

Landscape Heterogeneity

The heterogeneity algorithm currently only considers a global heterogeneity at the scale of the JCA, and only considers nearest neighbours up to a set radius of 3 cells from the cell of interest. Given that the landscape is a continuous mosaic of different land-uses, and that species will perceive the mosaic at different spatial scales, there is a need to extend this approach to allow the assessment of heterogeneity at a range of spatial scales, and to examine how the heterogeneity of the landscape changes with spatial scale. An increased understanding of how heterogeneity varies at smaller spatial scales than whole JCAs is important as the results from this project have suggested that the spatial arrangement of the patches of biomass, and other, crops within a JCA can have significant effects on the heterogeneity as measured at the whole JCA scale. By understanding the relationships between heterogeneity at smaller spatial scales within the JCA, heterogeneity at a whole JCA scale, and heterogeneity at even greater spatial scales, it should be possible to determine those areas both within and between JCAs where conversion from arable crops to biomass crops will have both beneficial and detrimental impacts on biodiversity.

One potential basis for an approach for measuring landscape heterogeneity in a scale-independent manner is lacunarity (Plotnick *et al.*, 1993). Lacunarity is used as a method for measuring the filling of space by different habitats (using a mean to variance ratio principle), but currently only copes with binary data, and so is not immediately appropriate for the multinomial data being considered here. There is a need to extend the lacunarity approach to cope with this multinomial data on land-use, further linking the spatial distribution of land-use types into the heterogeneity measure than is achieved by the current method. This would then allow the effects of land-use change to be measured at a range of spatial scales from local through to catchment, JCA and even region.

If landscape heterogeneity is to be used as a surrogate for biodiversity in models such as have been developed within this project, there is also a need to experimentally verify that it is an appropriate surrogate. This should include determination of the spatial scale at which heterogeneity needs to be measured, as this will be related to the distribution of dispersal distances of the populations of organisms of interest. We therefore recommend that experimental work be done to confirm the appropriateness of using habitat heterogeneity as a surrogate measure for biodiversity as a matter of urgency. Ideally this will include the calibration of similarity indices, as used in this project, with direct measures of biodiversity, to ensure that the similarity indices accurately reflect the similarities between land-use types in terms of the biodiversity that they support. By directly linking the similarity indices with biodiversity data, we will have a more accurate measure of the heterogeneity of the landscape, which reflects real differences in biodiversity. Such a measure can then be utilised to aid our understanding of how to adapt landscapes to maintain and promote biodiversity, and to allow the movement of species in response to environmental change.

The model developed in this project utilises the LCM3 land cover classes, and it is possible that this classification may not be detailed enough to accurately reflect the real heterogeneity within the landscape. There is therefore a need to understand the impact of the detail of the land classification on the predictions of the model. Although other classifications exist, such as the National Vegetation Classification (which has 10 times the number of classifications used in this project), and the Phase 1 habitat classification (twice as many classifications, including boundaries) there is limited data available in appropriate electronic formats for the UK using these classifications. A complete phase 1 habitat survey of Wales exists electronically, and might prove informative in investigating the impact of a more detailed classification of land use, assuming that appropriate land classification similarity matrices can be developed for the more detailed land classifications.

Habitat Permeability

As already noted, the current permeability algorithm does not allow for land-uses that form barriers to the movement of terrestrial organisms, and there is therefore a need to extend the algorithm to cope with such land-uses. This is relatively straightforward computationally, though requires a more iterative and gradual approach to patch dilation, checking for potential barrier land-uses at each incremental expansion step. Developing such a permeability algorithm for terrestrial species would allow a much greater range of generic species to be simulated, and could identify the potential impacts of land-use changes not found using the existing algorithm.

The habitat suitabilities used in the current study were subjective estimates based on best available knowledge, and were not specific to an individual identifiable species. In this project, the chosen suitability values (including the definition of managed grassland to be as suitable as arable land for arable species) meant that there was little impact of converting arable land-use to biomass cropping with most of the selected JCAs having a high proportion of grassland. This highlights the importance of calculating appropriate land-use suitabilities for use in the permeability model, as incorrect choices will potentially provide misleading conclusions. This limitation of the algorithm would be reduced by developing more realistic land-use suitabilities for different types of species, and defining suitability thresholds and dispersal distances for specific species of interest. However, this was beyond the scope of this project. Using existing data on feeding, nesting and overwintering habitats (French & Picozzi, 2002), it would be possible to develop some specific suitabilities for bird species within the UK, which if combined with suitable dispersal information would allow the prediction of the impacts of land-use changes on the habitat permeability for bird species within the UK. This information could then be linked to models of climate or environmental change to assess how land-use within the UK needs to be adapted to allow species to move to new habitats under the influence of climate or environmental change.

Scenarios

As already indicated, the models developed in this project have the potential to address a wide range of issues relating to changes in land-use and the impact of these changes on biodiversity and species movement (and other ecosystem services). The scenarios considered in this project were fairly general, as the remit of the project was to assess the impacts on biodiversity of replacing arable land with biomass crops. Although the project has produced some meaningful results, they are quite general results, and it is clear from the simulations that the initial spatial structure of the landscape has a significant impact on the results. This suggests that there is a need to consider more specific scenarios, addressing more specific questions relating to the effects of land-use. Some examples of the more specific scenarios/questions that could be examined are:

1. *What is the impact on biodiversity of growing biomass crops for local production of heat and power?*
   There is increasing interest in the local production of heat and power through the burning of biomass crops. This is likely to lead to small scale planting of biomass crops, clustered around small-scale heat and power production units. The modelling approach developed in this project could be used to assess how this could impact on biodiversity in comparison with plantations aimed at supplying large power stations.
2. *What is the impact on biodiversity of allowing conversion of any land-use type?*
   The scenarios in the current project were limited to only examining the conversion of arable land to biomass cropping. With the loss of set-aside in the UK, and an increasing interest in food security, there is a need to examine how the conversion of other land-use types, in conjunction with arable land, would affect biodiversity. This needs to be considered in combination with economic and social factors, with the potential greater need in the future for keeping land in food crop production to increase food security.
3. *Can the conservation of a species be enhanced by changing land-use?*
   By examining the impact of land-use on the movement of a specific species, the modelling approach could be used to determine the most appropriate arrangement of new land-use options to allow a species to move between currently fragmented habitats, or the most appropriate spatial arrangement for the creation of new habitats for a species of conservation interest. By linking the movement models for multiple species, then the impacts of these conservation measures on biodiversity in general could also be examined and predicted.

In summary, the models and algorithms developed within this project have the potential to be used to answer many policy questions relating to the impacts of changing land-use on biodiversity, the movement of species, and other ecosystem services. The research has particular relevance for questions that fall under the banner of the NERC led Living with Environmental Change programme. With further development, the algorithms could be improved to have relevance at a range of spatial scales, from individual fields and farms through to JCA or regional levels. However, for the models to have the most impact it will be essential to test, through experimental work, the current common assumption that heterogeneity can act as a surrogate for biodiversity, and to determine the most appropriate spatial scales at which to measure heterogeneity for different taxa.

Recommendations to Defra

This project has produced a modelling framework than can be used to assess the implications of land-use changes for biodiversity. However, the approach has only been used to examine a small subset of the landscape of the UK, and addresses a very broad question. If this approach is to be taken further for the development of policy within Defra, then we would recommend the following:

The simulation of the conversion of arable land to biomass crops in more JCAs is necessary to fully understand the impacts that the introduction of biomass crops could have on biodiversity.

As described above, due to the short timescale of this project we have been able to examine only a small subset of the JCAs in the UK (6 for heterogeneity and 3 for permeability, out of over 159). Although we have demonstrated the usefulness of the modelling approach for determining the impacts of land-use change on biodiversity, this small subset is not fully representative of the range of land-use mosaics within the UK. We would suggest that a further project is funded focused on selecting JCAs based on the distribution of land-use types within them, allowing simulation of the conversion of a wider range of land-use types, and with the permeability study focused on some specific species of interest as well as taking a more generic approach. This would provide a more comprehensive assessment of the potential impacts on biodiversity of growing biomass crops in the UK, with the ability to determine whether there are particular spatial distributions of land-use that are particularly suitable or unsuitable for the introduction of biomass crops. The main requirements for this would be computing time and resources, rather than staff time, making it cost-effective.

The land allocation model should be modified to be more realistic, with land-use change decisions driven by appropriate economic factors, and applied to whole fields within a farm management framework.

As this project was primarily focused on the impacts on biodiversity of introducing biomass crops, the simulated scenarios did not consider the economic factors that would influence decisions about land-use changes. However, a more realistic model could be achieved by incorporating appropriate economic factors in the land allocation process, so that land is only converted where it is economically viable to do so. In addition, it is more realistic to expect that whole fields will be converted to biomass crops, rather than hectare cells, within the context of a whole farm management strategy, and so the model should be modified to allocate land-use changes within such a structure.

Development is required of improved methods for the assessment of landscape heterogeneity and permeability.

As described above, the methods used to measure heterogeneity and permeability, although fit for purpose, are limited in their scope, and do not fully capture the spatial arrangement of land-use types within the landscape. To fully understand the impacts of land-use changes on biodiversity, measures are needed that fully capture the spatial relationships between land-use types at a range of spatial scales. Further, the current permeability algorithm does not fully account for physical barriers to movement, and is therefore of limited utility in describing the permeability of the landscape for terrestrial species. There is a need to develop permeability approaches that can account for barriers to terrestrial movement, so that the true connectivity of the landscape for terrestrial species can be predicted.

Objective measures of the similarity between land-use types and the suitability of land-use types for species are required.

The similarity and suitability parameters used in the model were based on subjective assessments by the project team. In order to fully understand how heterogeneity relates to biodiversity more objective similarity parameters are needed that reflect the differences and similarities between land-use types. For permeability assessments, there is a need for suitability parameters for specific species, rather than generic parameters for a range of species. There is limited data available to develop objective measures, and to do so would require extensive investigation of species distribution records from the Biological Records Centre and other monitoring data that is held by agencies such as the Centre for Ecology and Hydrology, Countryside Council for Wales and Scottish Natural Heritage. However, as a starting point, the paper by French and Picozzi (2002) provides information on the habitat types used by bird species for food, nesting and breeding, and this could be used to provide objective measures for both similarity and suitability parameters (assuming that bird species act as reliable indicators of general biodiversity within habitats). This would then allow the model to predict the impact of land-use changes on bird species within the UK, which has relevance to the indicators used by Defra to assess the state of biodiversity in the UK.

Future projects using this modelling approach should address more focussed questions (relating to specific species or groups of species).

Focussing on specific species would enable the development of suitability parameters that are directly relevant to the species of interest, and this approach would then provide appropriate predictions of the impacts of land-use changes on these species. Some example questions have been provided above in the scenarios section of the description of potential future work.

Collection and collation of datasets that can be used for simulation of land-use change needs to be co-ordinated.

A major issue for this project was the lack of co-ordination amongst the datasets required in our modelling approach. There is also a lack of appropriate data to allow the development of the similarity and suitability matrices for heterogeneity and permeability respectively. Without this data any approach examining the impacts of land-use change is limited in what it is able to provide in the way of predictions. Although models can be developed for specific species, where data is available, this will not provide good indications of the impacts on overall biodiversity. There is the potential to mine data from the biological records centre, countryside survey and other biodiversity monitoring schemes, but this will need appropriate methods to de developed for dealing with the uncertainty associated with the data.

An existing Defra project (IF0143) is currently developing a modelling approach that incorporates economic and agronomic factors into land-use decision making at a field level, focussed on examining the economic incentives that would be needed to drive land-use changes in a specific direction (i.e. addressing the first two recommendations). **There is therefore the potential to build on the work being done in IF0143, through the development of improved measures for heterogeneity and permeability to be linked to the models being developed in IF0143.** These models could then address questions about the impact of land-use change on either general biodiversity, or the distribution of specific species under a range of different economic scenarios for biomass or bioenergy crops.

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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Datasets used by the project
Land Cover Map 2000
(http://www.ceh.ac.uk/sections/seo/lcm2000_home.html)

Miscanthus Yield Potential Map
(http://www.defra.gov.uk/farm/crops/industrial/energy/opportunities/miscanthus-yield.htm)

SRC Willow Yield Potential Map
(http://www.defra.gov.uk/farm/crops/industrial/energy/opportunities/src-yield.htm)

Agricultural Land Class Map
(http://www.magic.gov.uk/datadoc/metadata.asp?dataset=2&x=16&y=9)

Joint Character Area Boundaries Map
(http://www.magic.gov.uk/datadoc/metadata.asp?dataset=10)
(http://p1.countryside.gov.uk/LAR/Landscape/CC/jca.asp)

PLANTATT Database
(http://www.brc.ac.uk/resources.htm)